Proceedings

Fifth Webinar

Expert Talk

(Some Aspects of the Development of Cathodes for Microwave Tubes) &

Young Researchers' Talk Series

(Sectoral Waveguide HPM Mode Converters, and

Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillator)

13 March 2021, Saturday

Editors:

Vishal Kesari

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Thinkers in Vacuum Electron Devices Group

India

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From Editorial Desk

We have so far organized five webinar programmes on the forum of our group; recently, we have put together the preceding four 'proceedings' of the webinar series, and posted them on our group forum, for the sake of convenience of the group members. We are happy to bring out now the 'proceedings' of the fifth webinar. One new aspect of the present webinar proceedings is the addition of the post-webinar 'Participant's feedback analyses'. We have added it in the annexure series of the proceedings.

We had two sessions in the fifth webinar. In session 1, which was devoted to the 'cathode', which is said to be the heart of a vacuum electronic device, we had the expert speaker in Dr. RS Raju, who presented his talk on 'Some aspects of the development of cathodes for microwave tubes'. We had in session 2, two brilliant young speakers presenting their talks—Dr. Vikram Kumar on 'Sectoral waveguide HPM converters' and Dr. Ajith Kumar on 'Application of planar helix slow-wave structure in BWOs'. We have presented the abstracts of all these talks as well as the biographies of all the speakers in the proceedings. The pdf versions of all the three presentations of the speakers have been put in the annexure series of the proceedings.

Professor Dr. RS Raju (speaker of session 1, superannuated from CEERI-Pilani, and now with Geethanjali College of Engineering and Technology, Hyderabad, as Professor and Dean (R&D)), who is acclaimed for his seminal contribution in the developmental of the cathodes, has contributed to the area of TWTs as well. We have provided a separate note in the present proceedings that describes in brief his contribution in the area of TWTs.

Dr. Ranjan Barik, who presently spearheads the activities in the area of cathodes and ion thrusters at CEERI, was one of the coordinators of the session 2 of the webinar. He had posted—well in advance, and prior to this webinar—a number of abstracts of the journal papers, on the platform of our group to acquaint the group members with the work on cathodes carried out at CEERI, some of which was led by Professor Raju (speaker of the session 1 of the webinar). Similarly, a website link (https://ieeexplore.ieee.org/author/37413634000) was provided on the group forum to get a glimpse of some of the work carried out by Dr. KS Bhat, superannuated from MTRDC-Bangalore, who was significantly responsible for the activities in the area of cathodes and HPM devices in the country, and, in the present context, who has chaired the session 1 of the present webinar. Also, thanks to the suggestion of Dr. Uttam Goswami, we requested Dr. Alok Gupta of Glowtronics Pvt. Ltd. to highlight his activities in the area of cathodes. Dr. Gupta, in turn, has kindly posted the relevant information on the group forum, which we have included in an annexure of the present proceedings; we sincerely thank him.

Further, in the discussion following the session 1 of the webinar, the group had a consensus on holding a brainstorming session in near future on the different aspects of bottlenecks on manufacturing microwave tubes and their components including 'cathodes'. As a post-webinar follow-up, it was decided that such a session would be chaired by Dr. Lalit Kumar. Further, such a session needs to be supported by the participants from CEERI-Pilani, MTRDC-Bangalore, SAC-Ahmedabad, SAMEER-Bombay, SAMEER-Guwahati, BEL-Bangalore, Pilani Electron Tubes and Devices-Sangrur, and Panacea Medical Pvt. Ltd.-Bangalore, and VEM Technologies Pvt. Ltd.-Hyderabad, and so on. It is strongly hoped that the brainstorming session will be enriched by the advices and inputs from Dr. Surendra Pal, Dr. Chandra Shekhar, Professor KP Maheshwari, Professor Y Choyal, Dr. SN Joshi, Dr. PC Panchariya, Dr. KS Bhat, Professor PK Jain, Dr. SK Datta, Professor Sheel Aditya, Professor MV Kartikeyan, Dr. RK Sharma, Dr. Sanjay Malhotra, Mr. TRK Janardan, Mr. RR Patnaik, Dr. SK Ghosh, Mr. DK Singh, Ms. Shilpi Soni, Mr. Guriqbal Singh, Dr. Alok Gupta, Mr. Raj Singh, Dr. BK Shukla, Dr. LM Joshi, Dr. AK Sinha, Dr. RS Raju, Professor KP Ray, Dr. Anirban

Bera, Dr. Udit Pal, Dr. Shivendra Maurya, Professor BN Basu, and many others.

We express our heartfelt thanks, for sincerely discharging their respective responsibilities in the webinar, to Mr. Raj Singh as the convener; Dr. N Purushothaman as the host; Dr. KS Bhat as the chairperson of the session 1; Dr. Hasina Kahtun as the chairperson of the session 2; Dr. Richards Joe Stanislaus as the coordinator of session 2; and Professor KP Ray as the proposer of vote of thanks. We since thank Dr. Uttam Goswami and Dr. Vishant Gahlaut as web administrators. We profoundly thank the group members to make this webinar a success. It was so nice of them to give their encouraging feedback in 'Participants feedback analyses', which we have presented at the end of the present proceedings. Their feedback inputs will greatly help us to improve further our webinar series.

Vishal Kesari
On behalf of the Editorial Board

Programme of the Webinar

Date: 13 March 2021, Saturday

Time: 04:00 – 06:00 pm

Convener: Mr. Raj Singh

Session 1 - Expert Talk

Chair of the Session: Dr. KS Bhat

Host: Dr. N Purushothaman

Duration	Topic of deliberation	Speaker
04:00 - 04:10 pm	Opening Remark	Dr. KS Bhat
04:10 - 05:00 pm	Some Aspects of the Development of Cathodes for Microwave Tubes	Dr. RS Raju
05:00 - 05:10 pm	Questions and Comments	Audience

Session 2 – Young Researcher's Talk Series

Research contributions of younger researchers in VEDs

Chair of the Session: Dr. Hasina Khatun

Coordinator: Dr. Richards Joe Stanislaus

Duration	Topic of deliberation	Speaker
05:10 - 05:30 pm	Sectoral Waveguide HPM Mode Converters	Dr. Vikram Kumar
05:30 - 05:50 pm	Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillator	Dr. Ajith Kumar MM
05:50 - 06:00 pm	Vote of Thanks	Professor KP Ray

Organizing Committee

Name	Designation	Affiliation	Role
Dr. KS Bhat	DRDO Fellow and Ex-Scientist	Microwave Tube Research and Development Centre, Bangalore	Chair Session 1
Shri Raj Singh	Scientific Officer H	Institute of Plasma Research, Gandhinagar	Convener
Prof. BN Basu	Adjunct Professor	Supreme Knowledge Foundation Group of Institutions, Mankundu Superanuated from Indian Institute of Technology, Banaras Hindu University, Varanasi	Advisor
Prof. KP Ray	Professor	Defence Institute of Advanced Technology, Pune	Vote of Thanks
Dr. Vishal Kesari	Scientist E	Microwave Tube Research and Development Centre, Bangalore	Editor Proceedings
Dr. Hasina Khatun	Pricipal Scientist	Central Electronics Engineering Research Institute, Pilani	Chair Session 2
Dr. Richards Joe Stanislaus	Assistant Professor	Vellore Institute of Technology, Chennai	Session Coordinator
Dr. Vishant Gahlaut	Assistant Professor	Banasthali Vidyapith, Banasthali	Webinar Coordinator
Dr. Uttam Kumar Goswami	Post-Doctoral Fellow	Institute for Plasma Research, Gandhinagar	Webinar Coordinator
Dr. N Purushothaman	Senior Scientist	Central Electronics Engineering Research Institute, Pilani	Host

Dr. Narasimhan Purushothaman

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Host's Words

It was my honour to welcome all the participants to the fifth edition of the webinar series on the Thinkers in VED group. We were having talks and presentations by experts and young researchers in the VED community. The webinar had two sessions. The first session consisted of an expert lecture and the second session was dedicated to presentation by two young researchers.

It was my honour to introduce the chairperson of the first session Dr. K. S. Bhat.

Dr. K Seetharama Bhat received his M.Sc. degree in physics from Mysore University in 1979 and Ph.D. degree from the IIT-Madras in 1984. He has had a long association with Microwave Tube Research and Development Centre (MTRDC), Bangalore, a DRDO Laboratory. He has immensely contributed to the development of dispenser cathodes for vacuum microwave tubes. His research interests include high-density cathodes, pulsed power sources for high-power microwave systems, virtual cathode oscillators, and the effects of HPM on electronic circuits. Dr. Bhat received the DRDO Agni Award for Excellence in Self-Reliance and the NRDC Meritorial Award for M-type dispersion cathodes for microwave tubes, both in 2003. In 2014, he was conferred the DRDO Scientist of the Year award.

Further, I handed over the session to Dr. KS Bhat.

The session 1 was an interesting session on cathode development by Dr. RS Raju. The session took the audience on a journey of cathodes from their origins to their latest versions such as nano-scandate cathodes. It kindled conversations about the latest developments in the area of cathode development and the scope for mass production in the country and export. It is absolutely important to look at the productionization of the cathodes through careful evaluation of the demand and return on investment. Hope the discussion on this important topic continues in the group.

In session 2, we had presentations by two young researchers and the session was chaired by Dr. Hasina Khatun. It was my pleasure to introduce Dr. Hasina Khatun, Principal Scientist, CSIR-CEERI, Pilani.

Dr. Khatun received her M. Sc. degree in Physics from Indian Institute of Technology, Roorkee and Ph. D. degree in Plasma Physics from Birla Institute of Technology, Mesra, India, in 2002 and 2012, respectively. From January 2015 to April 2016, she held a postdoctoral appointment at Korea Electrotechnology Research Institute (KERI), South Korea. She has authored/co-authored 26 research papers in scientific journals and 38 conference proceedings. Her areas of interest are high power millimeter wave devices such as Gyrotron, RF testing and characterization, Gaussian wave optics and photonic crystal based high power millimeter wave oscillator.

I requested Dr. Hasina Khatun to kindly chair the session.

The session 2 had interesting talks by two young researchers, Dr. Vikram Kumar on sectoral waveguide HPM converters and Dr. Ajith Kumar on application of planar helix slow-wave structure (SWS) in BWOs.

The crux of the talk on sectoral waveguide HPM converters by Dr. Vikram Kumar was on interfacing the high power VEDs to other devices which require different mode pattern (for example, $TM_{0,1}$ to $TE_{1,1}$ mode conversion). This was an important talk in terms of understanding the system-level requirement and making suitable changes in the design of VED.

The talk by Dr. Ajith Kumar was focused on the design of helix based BWOs for higher frequency. It is a highly relevant talk considering the push for high frequency VEDs. The planar helix SWS has the advantage of ease of fabrication thus allowing for high power output at high frequencies such as W-band and above. More research on advanced fabrication techniques will help propel this promising research topic further.

Lastly, I requested Dr. K. P. Ray to deliver the vote of thanks.

Session 1

Expert Talk

Topic of Deliberation

Some Aspects of the Development of Cathodes for Microwave Tubes

Speaker

Dr. RS Raju

Cathodes: An Overview

(Part of the book: BN Basu, *Electromagnetic Theory and Applications in Beam-wave Electronics*, World Scientific, 1996.)

Cathode — the emitter of electrons — is described as the heart of a microwave tube. The type of the microwave tube in which the beam-wave interaction has been demonstrated in this treatise (chapter 8) uses a cathode in which the mechanism of electron emission is thermionic. It may be mentioned that there are some crossed-field tubes like magnetrons in which the secondary emission also adds to the mechanism of electron emission. In such tubes secondary electrons are emitted from the cathode when the latter is bombarded by primary electrons.

The thermionic cathodes may be of two types — directly heated and indirectly heated. A directly heated cathode is made in the form of a filament of an emitting material like tungsten and tantalum. The filament is heated to a high temperature by passing electric current through it. The material therefore should be chosen to have a high melting point. Tungsten has a melting point of 3370ºC. Tantalum has a lower melting point — 2850ºC. The work function, which is the energy required to liberate an electron from the surface of the material, is lower, namely, 4.1eV for tantalum than for tungsten, namely, 4.6eV. Thus more emission is expected from the surface of tantalum, say, ~10A/cm^2, than from that of tungsten, say, ~ 0.5A/cm^2, at around 2200ºC, though the former is more prone to being poisoned by the residual gases present in the device which is essentially a vacuum tube. Tantalum is used as an electron emitter in X-ray tubes and high voltage transmitting and diode rectifier tubes. In some devices like magnetrons for a microwave oven, thorium is mixed with tungsten to obtain a composite material — thoriated tungsten which has a relatively low value of work function, namely, 2.6eV — lower than those of both tungsten (4.6eV) and thorium

(3.5eV). The reduction in work function may be attributed to the formation of a dipole layer reducing the electrostatic forces on the tungsten surface. In order to reduce the evaporation of thorium and hence increase the cathode life, thoriated tungsten is subject to carbonization (heat-treated in a hydrocarbon) to form tungsten carbide to which thorium adheres more than it does to pure tungsten. One can obtain an emission density ~3A/cm^2 at around 2200^{o}C from a thoriated tungsten cathode.

Majority of today's microwave tubes, however, use indirectly-heated cathodes. In such version of cathodes, the emitting surface is formed on a thin metal cylinder which is indirectly heated by an insulated heater in the form of a filament. This allows all the parts of the cathode surface to attain the same potential. The design of the heater-cathode assembly of the device should also provide for expansion and contraction without over-stressing the heater wire or the insulator between the heater and the cathode. The heater material should be so chosen that its recrystalisation temperature is well above its operating temperature. Typically, tungsten/tungsten-rhenium has been used as a heater material. The heater is often potted with alumina into a cavity on the bottom of the cathode to ensure high temperature cycling stability, stability with time, high rigidity to withstand rigors of environment, less warm-up time, etc. In an extensively used type of indirectly heated cathode known as oxide-coated cathode, a mixture of barium, strontium and calcium carbonates (typically in the percentage proportion by weight of 57.3:42.2:0.5) is coated on the emitting portion of the metal cylinder usually of nickel which is doped with a small fraction of zinc, tungsten/zirconium or magnesium which acts as an activator. The carbonates are reduced to oxides by the process of activation which involves heating the cathode by passing large current through the heater filament and drawing current to the anode (the electrode at a positive potential in the vicinity of the cathode). The combination of barium oxide and free barium (work function ~1.8eV), which is obtained by partial reduction, lowers the work function of the cathode to provide space-charge limited electron emission around quite a low temperature ~600 ^{o}C. The increased emission could also be attributed to the available free electrons in the oxide semiconductors. The emission density in an oxide-coated cathode at 650 – 700^{o}C could be hundreds of mA/cm^2 under dc or cw operation and tens of A/cm^2 under pulsed operation. Thus by the choice of a suitable duty cycle, that is, given a time to recover, such a cathode can yield high emission at a relatively low temperature. However, such a cathode is likely to be easily poisoned by residual gases in the device, more so if operated at a low temperature. On the other hand the operation at a high temperature may cause the evaporation of the active cathode material, namely, barium from the cathode surface.

The search for cathodes providing a higher emission current density, a higher pulse-length operation, a longer life, a lower heater power requirement, a reduced susceptibility to damage by residual gases in the tube, a potential for reactivation if exposed to leakage, etc. led to the development of a class of cathodes known as dispenser cathodes — so named because such a cathode takes care in continually replenishing/dispensing the active barium from the interior of the cathode which eventually evaporates from the emitting surface.

In its simplest form, known as the L-cathode, the dispenser cathode consists of barium-strontium carbonates in a cavity behind a porous tungsten plug. There are many variations from this simple form of cathode, namely, pressed cathode, A-, B-, M-, MM (mixed-metal)- types, CPC (coated particle cathode), etc.

The pressed cathode is made by blending and mixing base powder, namely, tungsten or tungsten-iridium, emissive mix, namely, the mixture of barium, calcium and strontium, either oxides or carbonates, and an activator, typically, zirconium hydride. The mixture is pressed (140 -

1400x10^6 N/cm^2) into a molybdenum sleeve, or alternatively, into pellets and then crimped into a molybdenum cylinder; sintered in hydrogen and then lathe-finished.

The A-type cathode is first formed from a porous tungsten and then impregnated with barium aluminate. The B-type cathode is a modified version of the A-type in which calcium oxide is added to the impregnants to reduce the barium sublimation rate as well as to enhance emission properties of the cathode. The proportions of the mix impregnated into porous tungsten are, typically, 5 BaO:3 CaO:2 Al_2O_3 (5:3:2), 4:1:1, 3:1:1, etc. It may be mentioned that the aluminate stabilizes calcium oxide which is otherwise hygyroscopic. The chemical reaction showing barium as a product may be put as:

$$W + 3\,Ba_3Al_2O_6 + 6\,CaO = 3\,Ba_2CaAl_2O_6 + Ca_3WO_6 + 3\,Ba.$$

A typical flow-chart for making such a cathode consists in (i) taking a base powder of typically 2-14μm size high-purity tungsten/ tungsten-iridium, (ii) pressing it isostatically in a sealed rubber mould (~140x10^6 N/cm^2) so as to increase the density of particles; (iii) sintering it (~2500°C for 30 minutes) to increase the density further; plastic-or copper-infiltering it, in order to make it easily machinable; (iv) shaping it in a machine as desired; (v) removing the infiltered plastic/copper; (vi) melting the impregnants or emissive mix into the porous tungsten; finally, (vii) cleaning it, say, by grit-blasting with alumina. Some of the control areas are emitter temperature, pore size, pore per unit area, uniformity of pores, etc. One may obtain several A/cm^2 at 1100^{o}C or higher with a B-type cathode.

The M-type cathode came into being while aiming at reducing the cathode operating temperature and obtaining an emission current density comparable with or greater than that of the B-type cathode, and a longer life. In an M-type cathode, which is essentially a B-type cathode with a thin metal film coated on its emitting surface, the porous tungsten impregnated with barium-calcium aluminate is coated (~2000 - 10,000 AU) with a thin layer of osmium-iridium or osmium-ruthenium, by the process of sputtering or vapor depositing or ion-plating, and then hydrogen-fired for several minutes to sinter the coating onto the tungsten substrate. Surprisingly, although the film material has a higher work function than tungsten, yet its effect is to reduce the overall work function and yield the same current density as that of the B-type but with a cathode operating temperature reduced by ~90^{o}C. The coating thickness should be optimum so that neither it should be so thin as to degrade by diffusion into the tungsten matrix, thereby converting the cathode into a B-type, nor it should be so thick as to impede the supply of barium to the emitting surface. The emission delay ~4 minute has been reported as a disadvantage of the M-type if used as a fast warm-up cathode.

In an attempt to remove the demerit of the M-type cathode in respect of cathode degradation, another cathode, namely, the mixed metal matrix (MM) cathode has come into existence. In such a cathode, the enhancing metal is put into the tungsten matrix itself. The other innovations in cathode technology include the coated particle cathode (CPC) which is made of specially coated particles bounded to a nickel surface. Recently, the deposition of tungsten-osmium alloy on the surface of porous tungsten matrix has been tried out. In another version of dispenser cathodes, pores have been provided on a thin foil of tungsten by laser drilling or ion-etching. Thus the present-day cathode technology has been making continuous progress aiming at high emission density, low operating temperature, less susceptibility to damage and surface degradation due to residual gases and diffusion of film coating; ruggedness; reduction of the electrical breakdown, RF losses, grid emission caused by sublimed materials; less warm-up time, etc.

Biography of Speaker in Session 1

Professor Dr. RS Raju

Dr. RS Raju received his B.Tech. degree in Electronics and Communication Engineering (ECE) from JNTU College of Engineering, Kakinada in 1976, M. E. degree in Microwave and Radar Engineering from University of Roorkee (presently Indian Institute of Technology, Roorkee) in 1978, and Ph. D. in Physical Electronics from University of Cambridge, U. K. in 1987.

He joined CSIR-Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani, India in 1978 and worked in the area of Microwave Engineering till 2014. Subsequently, he worked for one year as an Emeritus Scientist at CSIR-CEERI. During this period, he worked on various projects for design and developed various microwave tubes for space and defence applications. Since Nov 2016 he is working as a Professor in ECE Departement and Dean, R&D at Geethanjali College of Engineering and Technology (GCET), Hyderabad. His present areas of interest includes design and development of microwave devices, and nanotechnology for high emission density electron emitters.

He recived various awards and honors, including Commonwealth Scholarship award in 1982 for pursuing Ph. D. in U. K., and JC Bose Memorial Award for Best Engineering paper in 1992 by IETE. He has been member of International Steering Committee, International Vacuum Electron Sources Committee (IVeSC).

He has 18 publications in national and international journals and 6 national patents in his credit.

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Contribution of Dr. RS Raju in the Analysis of Helical Slow-wave Structures for Wideband TWTs

Dr. RS Raju is internationally acclaimed for his work on cathodes first at Cambridge University (for his doctoral thesis entitled "Impregnated Cathodes for Use in High Power Microwave Tubes") and then at CSIR-CEERI, Pilani. However, that he significantly contributed to the electromagnetic field analysis of helical slow-wave structures of wideband travelling-wave tubes may not be known to many youngsters.

He gave me the privilege of working with him at CEERI in the area of field analysis of helical slow-wave structures while I was then teaching at Banaras Hindu University and working for CSIR as Distinguished Visiting Scientist at CEERI. However, long before, when I was teaching at Regional Institute of Technology (RIT), Jamshedpur, Dr. Raju used to help us from CEERI by verifying the hand calculations of Dr. AK Sinha who was then working at RIT in the same area for his doctoral degree of Ranchi University (and who became later well known for his R&D in the area of gyrotrons and who became largely responsible for establishing the gyrotron lab at CEERI).

Dr. Raju has evidenced his work in the area of of field analysis of helical slow-wave structures of TWTs through his publications that I could collect from my archive as follows:

- R. S. Raju, S. N. Joshi, P. K. Jain, and B. N. Basu, "Modeling of practical multi-octave band helical slow-wave structures of a traveling-wave tube for interaction impedance," IEEE Trans. Electron Devices, vol.39, pp. 996-1002 (1992).
- S. Kapoor, R. S. Raju, R. K.Gupta, S. N. Joshi, and B. N. Basu, "Analysis of an inhomogeneously-loaded helical slow-wave structure for broadband TWT's," IEEE Trans. Electron Devices, vol.36, pp. 2000-2004 (1989).
- L. Kumar, R. S. Raju, S. N. Joshi, and B. N. Basu, "Modeling of a vane-loaded helical slow-wave structure for broadband traveling-wave tubes," IEEE Trans. Electron Devices, vol.36, pp. 1991-1999 (1989).

I wish Dr. RS Raju all the best.

Dr. KS Bhat

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Chairman's Desk in Session 1

It gives me a great pleasure to chair this session on a topic which is very close to my heart. We have none other than a stalwart in this field, Dr. RS Raju, who has dedicated his career to the development of various types of cathodes in the country. It will be a privilege to hear him. Way back in the 1980s, M/s Bharat Electronics, Bangalore got into a Tranfer of Technology (ToT) agreement with the Varian USA, now the CPI, for the production of certain broadband tubes required for some of the EW programs of the country. However, the cathode technology was not included in the transfer agreement, and M/s Varian agreed to continue to supply the cathodes for the tubes under ToT for the next ten years or so. Thus even though many of the tubes under ToT were in production in BEL, the import dependence on cathodes remained.

By then there were lots of efforts in the development of cathodes by (i) Centre of Research in Microwave Tubes, Electronics Engineering Department, BHU, Varanasi (Dr. DS Venkateswaralu, Dr. Anima Chatterjee, and others); (ii) CSIR-CEERI, Pilani (Dr. SN Joshi, Dr. AK Chopra, Dr. RS Raju, Dr Ranjan Barik, and others;) and (iii) M/s BEL, Bangalore (Mr. Ramana Reddy, Mr. R Natarajan, Mr. Deendayalan and others) to indigenise these cathodes (type B, M and MM, etc). Later in 1986, Dr. MD Rajnarayan initiated the work on cathodes at MTRDC, too. Thus, started the saga of indigenization of cathodes of type B, M, MM, and so on, in the country.

I would like to acknowledge the help that was received from late Dr. Arvind Shroff of Thales and Dr. Alok Gupta of Glowtronics, Mysore in our endeavour to develop indigenous cathodes. Many youngsters then joined the stream, both at CEERI (Dr. R Barik, Asish Shukla, and others) and MTRDC (Dr. M Ravi, Santosh Kumar K, Deepa, and others), and today we can together proudly say that we have the technology of dispenser cathodes within the country. Many of the cathodes developed have been used in tube prototypes, and their performances have been found as good as imported cathodes.

However, the fact that we are still importing these cathodes is a matter of concern. I hope at the end of this talk we will have some time to deliberate on how we should go on to the production of the cathodes in the country. The question arises: Have we not proven the technology to the satisfaction of the users? Is there anything still lagging which we should do to fill in the gaps? In my opinion, the demand for the number of cathodes being very small is the reason that we are not able to rope in any private entrepreneurs. Hence, I feel those who are the manufacturers of tubes should also take up the production of cathodes required by them. Initially the Return on Investment (ROI) may be negative. However, in the long run when the microwave tubes made in India start getting the export market, it will turn out to be profitable. I am also of the opinion that every indigenous effort of developing a tube by R&D should include at least one deliverable with an indigenously developed cathode incorporated in it. That would bring in the required seriousness on the part of both the tube and cathode developers.

I wish this webinar a great success in sharing the valuable knowledge and experience of the honourable members of the 'VED Thinkers' group.

Professor Dr. RS Raju

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Some Aspects of the Development of Cathodes for Microwave Tubes

Abstract of Talk in Session 1

Microwave sources/generators rely on electron beam, which is generated from an electron gun in which a cathode is incorporated to act as an electron emitter. It is highly essential for a very high current as the frequency of operation increases. This demands a cathode capable of delivering current levels of upto 100 A/cm^2. This requirement can be met from a special class of cathodes called "dispenser cathode".

The term "dispenser cathode" can be used to describe any cathode on which a thin film of emitting material is produced at the surface and is continuously replenished at the operating temperature. Conventional dispenser cathodes deliver emission of upto 5 A/cm^2 at typically 1100^{o}C. The cathode is made out of porous tungsten (W) pellet into which a composition of 5BaO:3CaO:2Al2O3 is melted through a process called impregnation. This type of cathode is called basic impregnated dispenser cathode or "B-type" cathode. A potted-heater assembly is fitted to provide thermal energy and that the pellet is supported by a molybdenum sleeve.

During operation, Ba/BaO reaches the surface and smears a "near" atomic monolayer due to the reaction of Ba-Ca-aluminates with W. The name "dispenser" is derived due to the fact that as the active material (Ba/BaO) evaporates a fresh material is dispensed (replenished) from the bulk of matrix through pores. The end of life is the end of supply of active material to the surface. The merit of a cathode is decided on two basic factors: (i) uniformity of emission all across the surface and (ii) work function (φ), which is a potential barrier at the surface for the electrons to come out of surface. When Ba/BaO rests on tungsten surface (of φ 4.6eV) a positive dipole is formed, as Ba transfers two of its valence electrons to the tungsten which is electronegative due to which the φ reduces to 2.0eV. This tremendous change enables high emission which otherwise is not possible from a pure tungsten surface.

The developmental research, to improve emission, is carried out in three different directions by: (a) using a combination two or more matrix materials which is called "mixed matrix" (MM) cathode, (b) coating metal/ alloy of high work function than the base material which is called "coated-cathode" and (c) introducing scandium into the impregnant which is called "Scandate" cathode. The merits and demerits of these types of cathode are compared. The reason for emission enhancement in scandate cathodes is explained using a semiconductor model. These cathodes were subjected to accelerated life tests; and, the results show life of beyond 10 yaers is possible at normal operating temperatures. These impregnated scandate cathodes, though excellent emission, have non-uniform emission which is not desirable for use in MW tubes. Therefore, a new methodology of making cathodes is evolved using nanotechnology in which the pellet material together with impregnant material are prepared using solgel technique to mix in atomic scale. The nanopowder is pressed to form a pellet. This technology enabled emission of 100 A/cm^2 as tested at CSIR-CEERI, Pilani and MTRDC-DRDO, Bangaluru.

The work carried out and the achievements at CSIR-CEERI, MTRDC-DRDO and Glowtronics, Mysore on various types of cathode are highlighted. An emphasis is given on productionization of cathodes in India as these are critical components for microwave tube programme.

Session 2

Young Researcher's Talk Series

Research contributions of younger researchers in VEDs

Topic of Deliberation 1

Sectoral Waveguide HPM Mode Converters

Speaker 1

Dr. Vikram Kumar

Topic of Deliberation 2

Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillator

Speaker 2

Dr. Ajith Kumar MM

Dr. Hasina Khatun

Senior Scientist
Microwave Devices Division
CSIR - Central Electronics Engineering Research Institute
Pilani - 333 031 (Rajasthan), INDIA

Chair's Words in Session 2

The webinar series organized by the Group are very much informative and relevant to our ongoing research as well as for futuristic research in VEDs.

I welcome the eminent seniors and junior scientists/ professors and research scholars to the second session of the fifth webinar, which is devoted to the dissemination of research contribution of younger researchers in VEDs. We are all privileged learning from the work done by the young minds and their work based on the present and futuristic need of VEDs.

The first speaker Dr. Vikram nicely presented the work on sectorial waveguide for HPM. The presentation described the modelling and analyses of the sectorial waveguide with horn antenna for 125GW power predicted by CST simulation. The second speaker Dr. Ajith also scholarly presented his work on the application of the planar helix slow-wave structure in BWO.

The work done by both the young researchers can be benefited from by the R&D Institutes/Universities/Industries who are working in their areas of research, and vice-versa.

Thus, in my opinion, the second session of the webinar has served the motto of the VED Thinkers Group. I am fortunate being given by the Group the responsibility of Charing this session and I sincerely thank the organizers of the webinar.

Dr. Richards Joe Stanislaus

Assistant Professor (Sr)
Vellore Institute of Technology, Chennai
Tamilnadu, INDIA

Webpage: https://linktr.ee/RichardsJoeStanislaus

Email: richardsjoes@gmail.com

Coordinator's Words in Session 2

As a coordinator, Dr. Richards Joe Stanislausto gave an introduction of Dr. Vikram Kumar to deliver his research presentation on "Sectoral Waveguide HPM Mode Converters".

In his research presentation, Dr. Vikram discussed the state-of-the-art work in mode converters, HPM TM_{01} to TE_{11} SWG mode conversion, mode matching analysis of SWG mode converters and its scope in the future work. Dr. KP Ray congratulated Dr Vikram's presentation. He also further commented that the mode converters were limited to conical horn antennas and requested to work on TE_{10} to TE_{11} mode conversion. Dr. KS Bhat suggested trying to incorporate the conversion from a mixture of modes generated by most of the HPMW sources. Dr. Hasina Khatun requested for the dimensions of the sectoral waveguide. The dimensions for 3GHz, the length was 400 for complete structure and diameter was 110mm. Dr Hasina asked if the thermal analysis was performed as the proposed power levels were 1.5GW power for the SWG, foe which Dr Vikram promish to incorporate such studies in the future work.

Dr. Richards then invited Dr. Ajith Kumar to deliver his research presentation on "Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators".

In his research presentation, Dr. Ajith Kumar gave an introduction about the modes in helix slow wave structures, tape helix analysis of planar helix with straight edge connections, Interaction impedance of Non-fundamental space harmonics and on W-band backward wave oscillators. Dr Richards asked if PIC simulations were performed and if the interaction impedance calculated in CST studio suite was specific to the region of electron beam or was it with the inbuilt macro? Dr. Ajith stated that PIC simulations were indeed carried out and the interaction impedance was calculated in the region specific to the electron beam in the slow wave structure by taking the longitudinal electric field and the power flow in the SWS.

Biographies of Speakers in Session 2

Speaker 1

Dr. Vikram Kumar received his B. Sc. Engineering degree in electronics and communication engineering from Magadh University, Bodh Gaya, in 2008, and M. E. degree from Birla Institute of Technology Mesra, Ranchi, India, in 2011. He completed his Ph. D. in 2019, from Indian Institute of Technology, Banaras Hindu Ubniversity, Varanasi. He is currently working as Assistant Professor at National Institute of Technology Patna. His research interests include HPM mode converter and antennas.

Speaker 2

Dr Ajith Kumar M. M received his B.Tech. degree in electronics and communication engineering from the Cochin University of Science and Technology, Kochi, in 2010, and M.Tech. degree in RF and microwave engineering from Indian Institute of Technology, Roorkee, in 2013. He completed his Ph.D. degree from Nanyang Technological University, Singapore in 2020 on the topic "Application of planar helix slow-wave structure in backward-wave oscillators".

Dr. Vikram Kumar

Assistant Professor (Contractual)
Department of Electronics and Communication Engineering
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Sectoral Waveguide HPM Mode Converters

Abstract of First Talk in Session 2

The evolution of high power microwave (HPM) sources using vacuum tubes was primarily for defence application, but from the past few decades researches are going on for the non-defence applications also. These non-defence applications enhance the requirement of compact and lightweight HPM systems. Although for the microwave generation devices like high power electronic devices, it is difficult to produce gigawatt power level. However, most of the HPM sources radiate radio frequency (RF) power in the azimuthally symmetrical modes TM01 or TEM modes, and the radiation pattern of such modes contain null at the axis of propagation. Thus, there is an essential requirement of the mode converters for the HPM systems to convert TM_{01} mode to TE_{11} mode, where the TE_{11} mode radiation pattern has its boresight along the axis of propagation. During the past few decades, substantial research interest has been provoked in the development of a mode converter compatible with HPM sources and to convert TM_{01} mode to TE_{11} mode. The SWG mode converter is well recognized as they designed by separating coaxial waveguide with using axial radial metallic plates. By using SWG mode converter the applications on HPM systems require maximum RF

power in the direction of propagation. Among the variety of mode converter available, the SWG mode converter still finds its dominance for delivering high convergence efficiency, high power capability, along with easier design and development procedure and this is an area where the mode converters based on gradual discontinuities are not able to compete. There exists a power handling capability gap in between the all metal and dielectric loaded SWG mode converter therefore all metal SWG mode converter is more beneficial.

This lecture will demonstrate the overview of the HPM system, including its key sub-system. The need of mode converter in the HPM system will have to be discussed, along with its working mechanism. The operating principle of the SWG mode converter has swotted and its analogy will be discussing to support its operation. Using electric field expressions, a relation between phase delay, the length of the sectoral region and axial propagation constants will be established. Three classes of mode converter will have to be discussed in this lecture. The literature review will be presented to discuss the problems arising from the state of the art for SWG mode converter. Also, the objective of the HPM mode converter will be illustrated in which the characteristics of beam stability, power handling capability, conversion efficiency and compactness will be included and demonstrated in this lecture.

Dr. Ajith Kumar MM
Lecturer in Electronics
MVGM Government Polytechnic College, Vennikulam
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Thiruvalla, Kerala, INDIA

Email: 4ajithkumar@gmail.com

Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillator

Abstract of Second Talk in Session 2

Travelling-wave tubes (TWTs) are one of the most popular device among vacuum electron devices. TWTs can be used as amplifiers, constituting travelling-wave tube amplifiers (TWTAs), or as oscillators, constituting backward-wave oscillators (BWOs). A BWO is one of the most reliable and spectrally pure voltage-tuneable high frequency oscillator. A slow-wave structure (SWS) is a very important component in TWTs. It becomes challenging to build and operate TWTs at millimetre-wave frequencies (30 - 300 GHz) since the dimensions of the SWSs and the beam tunnel that accommodates the electron beam reduce as the frequency of operation increases.

Microfabrication techniques are a possible solution to achieve the required small sizes. Hence research on microfabrication-compatible SWSs is very important. Planar helix slow-wave structure with straight-edge connections (PH-SEC) is a planar counterpart of circular helix SWS which is one of the most popular SWS for TWTs. The PH-SEC is readily amenable to microfabrication. The PH-SEC has been studied for

TWTA applications in the past few years. In this thesis we investigate its potential for application in BWOs.

First, the Fourier decomposition method is used to evaluate, more accurately than before, the interaction impedance for the fundamental and non-fundamental space harmonics of the SWSs such as the circular helix. Accurate evaluation of the interaction impedance for different space harmonics in a SWS is an important step for the design of TWTs. Results are presented for the variation of interaction impedance inside the SWS with frequency and position.

Field-theory based analysis is the fastest method to determine the dispersion characteristics of SWSs. The results from such an analysis can be used for the initial selection of dimensions of the PH-SEC for a TWT with given target specifications. In the second investigation, the dispersion characteristics as well as the interaction impedance of the PH-SEC are obtained using the tape-helix approximation. The analysis is simplified by combining the tape-helix analysis and the effective dielectric constant (EDC) method. Moreover, a PH-SEC immersed in a homogeneous dielectric medium has been fabricated and tested. The measured phase velocity compares very well with that obtained from the analytical results.

The third investigation presents simulation results for the design and performance of a BWO that operates at W-band and uses a microfabrication-compatible PH-SEC as the SWS. The oscillator is designed to operate with a beam voltage varying from 7 kV to 11 kV and a beam current of 20 mA. The particle-in-cell (PIC) simulation results show that the oscillator frequency tunes from 86.9 GHz to 100 GHz with a tuneable bandwidth of 14%. Further, a scaled version of the PH-SEC operating at X-band is also fabricated and measured. The measured S-parameters and the phase velocity match very well with the simulation results.

Finally, a new technique is proposed to improve the efficiency of the conventional BWOs. The technique uses an additional electron beam inside the conventional BWO; the additional beam is synchronized with the fundamental forward-wave space harmonic and provides amplification like a TWTA. The technique is illustrated using a circular helix SWS at Ku-band. It is shown that the proposed technique improves the DC-to-RF conversion efficiency of the conventional BWO by a factor ranging from three to six depending on the beam configuration. The same technique for efficiency improvement is also illustrated using the PH-SEC.

The studies reported in this thesis show that the microfabrication-compatible PH-SEC SWS has an excellent potential to realize BWOs which can operate at millimetre wave frequencies.

Topic of Deliberation

Vote of Thanks

Proposed by

Professor KP Ray

Professor KP Ray

Professor, Dean (SR) and Head
Electronics Engineering and CSE Department
Defence Institute of Advanced Technology
Pune, India

Email: kpray@diat.ac.in, kpray@rediffmail.com

Vote of Thanks

At the outset we express our gratitude to senior and experienced colleagues for being instrumental in providing such a platform 'Thinkers in VED'. It is a very effective form interaction and learning.

We wish to thank Prof. RS Raju for very lucid and informative talk on '*Cathode Development'.* He made the lecture very simple and always addresses to youngsters so that they are able to grasp the concept. We are also thankful to other younger speakers; Dr. Vikram Kumar, who spoke in much organised manner on '*Sectoral Waveguide HPM Mode Converters'* and Dr. Ajith Kumar M. M., who gave informative lecture on '*Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillator'*.

Thanks are also due to Dr N Purushottam for hosting the event and Dr. Vishant Gahlaut and Dr Uttam K Goswami and their whole team for web management.

Both the Chairpersons of the two sessions; Dr. KS Bhatt and Dr. Hasina Khatoon conducted the sessions very efficiently. We thank them for introducing the speakers and maintaining the timings of the session.

We also thank all the coordinator Dr. Richards Joe Stanislaus for conducting the events.

The back bone of the event was the Convener Mr. Raj Singh, we thank him for overseeing the coordination of this event.

Finally these events are envisaged by Stalwards in the field; Professor BN Basu, who details the event up to last point for successful completion, Professor KP Maheswari, Dr. SN Joshi, Dr. LM Joshi, Professor Y Choyal, Dr. Alok Gupta, Dr. Lalit Kumar and many other senior colleagues, who always grace the event and participate whole heartedly to encourage youngsters. We will remain ever grateful to them.

At the end I thank all the Participants to make this webinar successful.

Annexure I:
Expert Talk Slides

GCET

Some Aspects of Development of Cathodes for Microwave Tubes

CSIR-CEERI

Presentation **by**

Dr RS Raju, Ex-Chief Scientist, CSIR-CEERI, Pilani, Rajasthan

Presently **at**

Geethanjali College of Engineering and Technology, Hyderabad as Prof ECE and Dean, R & D

Mobile: 9413723303, e-mail <raju.ceeri@gmail.com>

Presentation **in**

VEDA Society on March 13, 2021 (Online: <https://meet.google.com/evz-jwow-xda>)

Contents

- **Introduction to Dispenser cathode:** Importance ,Classification and Electrostatic model
- **Dispenser cathode at CSIR-CEERI**:
  - ⇒ Development work: Actively started due to the Sponsorship from DoE
  - ⇒ Facilities at CSIR-CEERI: Fabrication and Testing
  - ⇒ Nano-Scandate cathodes, Cathodes for Ion Thrusters
- **Dispenser cathode at MTRDC-DRDO**:
  - ⇒ FE cathodes, Fast warmup cathodes, Large size cathodes, MBC and their usage in actual cathodes
- **MTRDC-CEERI joint work:** Development of Multi-beam Cathode and Sputter Coating System

Theme of presentation

- **Covering: (a) Dispenser cathode development at CEERI and MTRDC and (b) Comparison of different types**
- **Discussions on: (a) Future scope and (b) Productionization**

- Introduction
- Oxide coated cathode
- Different Types of Dispenser cathode
- Emission mechanism and Fabrication

Definition, History & Applications of Dispenser Cathode

✧ Definition

The term "dispenser cathode" can be used to describe any cathode on which a thin-film of emitting material is produced at the surface and continuously replenished at the operating temperature.

✧ Invention

☛ **Lemmens, 1950 ⇒ L-cathode**

Comprised of porous tungsten disc, moly sleeve & tungsten reservoir containing a solid solution of Barium & Strontium carbonates

☛ **Levi in,1955 ⇒ Impregnated cathode**

(Basic Impregnated Dispenser Cathode: B-Type)

Impregnated with BaO+Al_2O_3.
Subsequent addition of CaO improved work function (ϕ) & evaporation rate

☛ **P Zalm & van Stratum, 1966 ⇒ M-Type**

(Metal-coated Impregnated Dispenser Cathode: M-Type

✧ Applications:

MW tubes, Gyratrons, FEL's & TV tubes

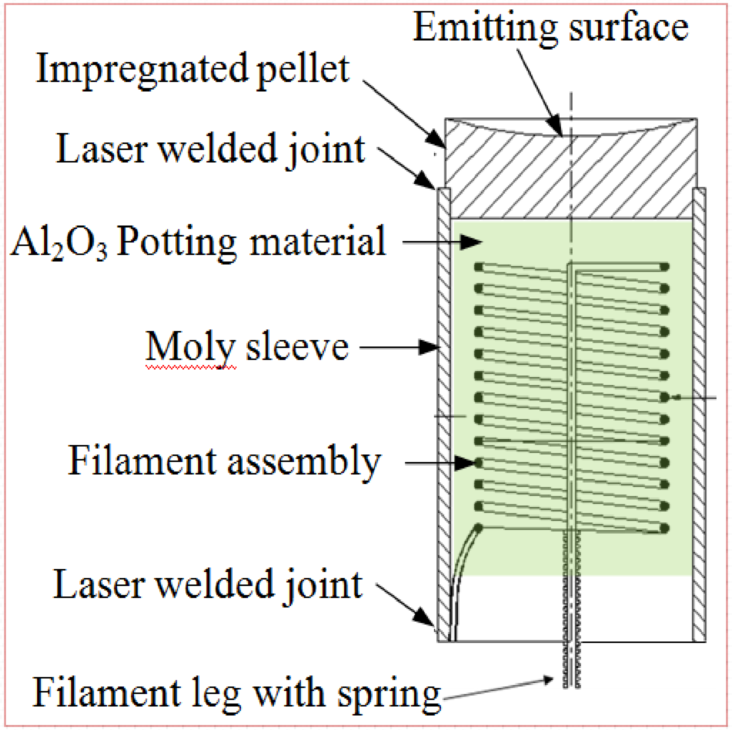


Fig. 1 Cross sectional view of dispenser cathode

Type	BaO: CaO: Al_2O_3	Use
S-Type	5:3:2	Semicon
B-Type	4:1:1	Phillips
B-Type	6:2:1	Cambridge

Development of Oxide Coated Cathode

✧ What is work function

Since the electrons are attracted to the positive nuclei of the metal atoms, they normally stay inside the metal and require energy to leave it; this is called the work function of the metal.

Oxide coated cathode inside Magnetron

✧ History

Arthur Wehnelts discovered Oxide cathode in 1904.

Oxide coated cathode consists of sprayed coating of alkaline earth oxides on Nickel base. Mg, Mn, Si, Al, Ti, and C are added to the nickel base as impurities to reduce inter-face resistance and supply free barium through reduction process.

Modern formulations utilize a mixture of barium oxide, strontium oxide and calcium oxide.

✧ Major advantages

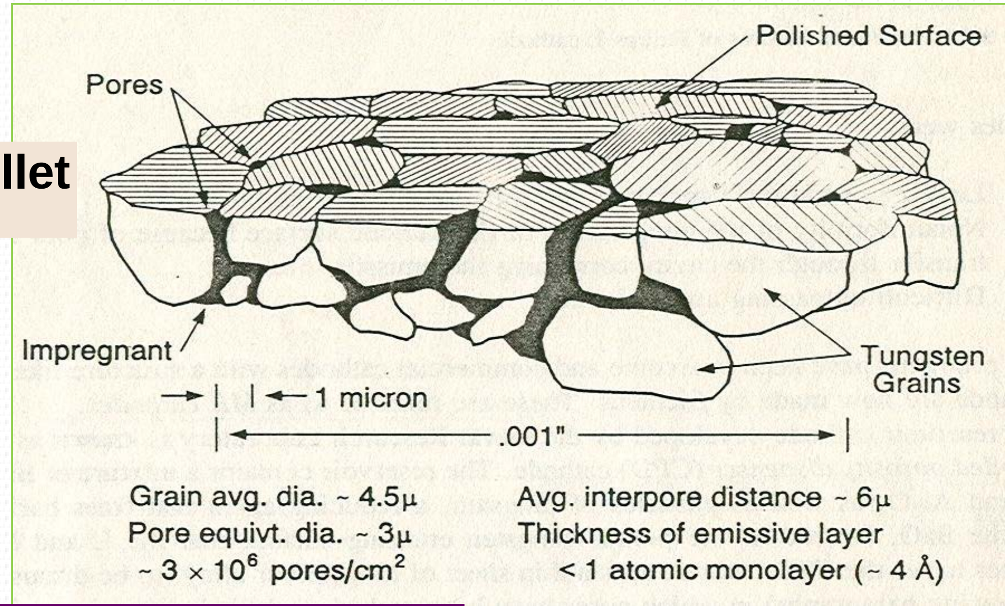
- *Excellent pulse emitter (acts like an impurity semiconductor): φ =1.35 eV (J 1000 times B-Type)*
- *Easy to fabricate; still used in magnetrons.*

✧ Limitations

- *Current density not more than 1 A/cm^2 under CW due to joule heating and consequent damage to the coating.*
- *It is poisoned in poor vacuum conditions and cannot withstand ion bombardment*
- *The coating is brittle and easily damaged by mechanical shocks.*
- *Under long pulse conditions, the current decay is high.*

Emission Mechanism Impregnated Dispenser Cathode

Features of an Impregnated pellet
(MC Green, Tech Rep, July 1981)

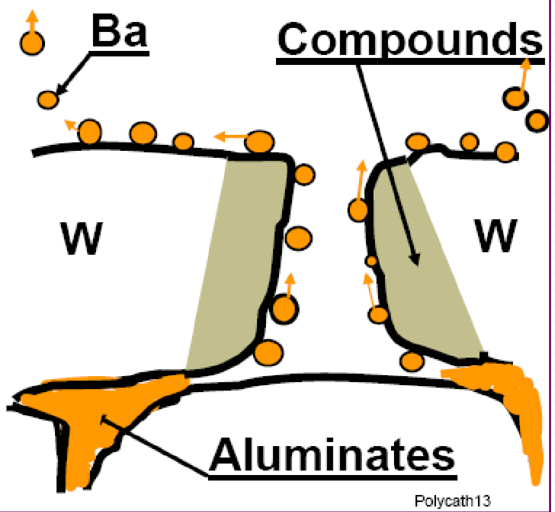


The activation is done up to1200°C.

Aluminates + W ⟶ Ba +(Ba,Ca,W,O) compounds

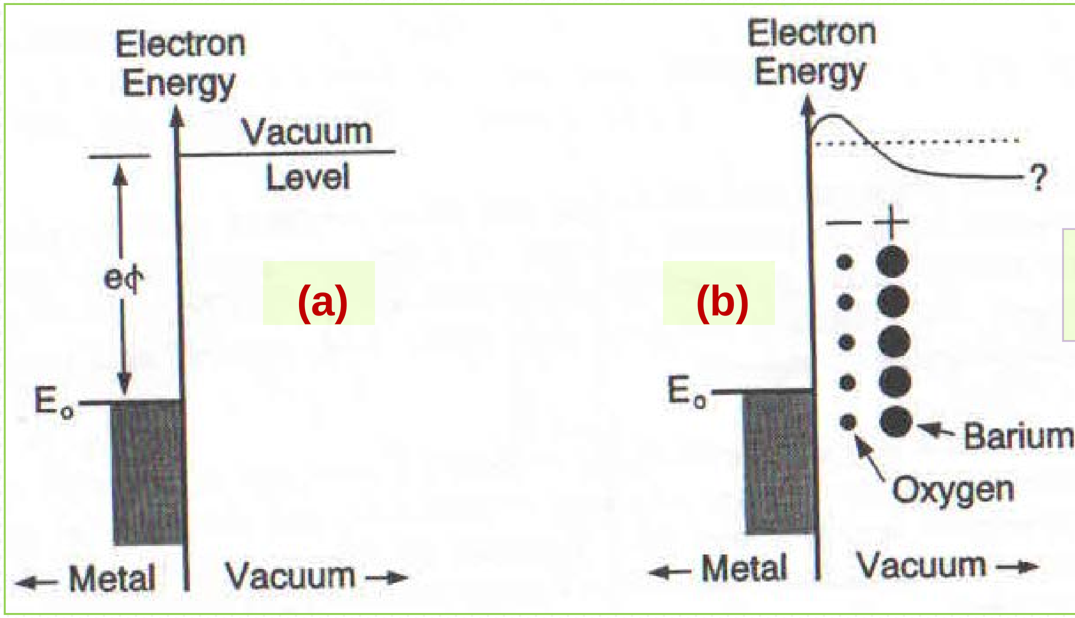
The free Ba moves to W surface through the pores lowering the work function of the surface from 4,5 eV down to 1.9 eV.

The baryum slowly evaporates at the working temperature 950-1100 °C.

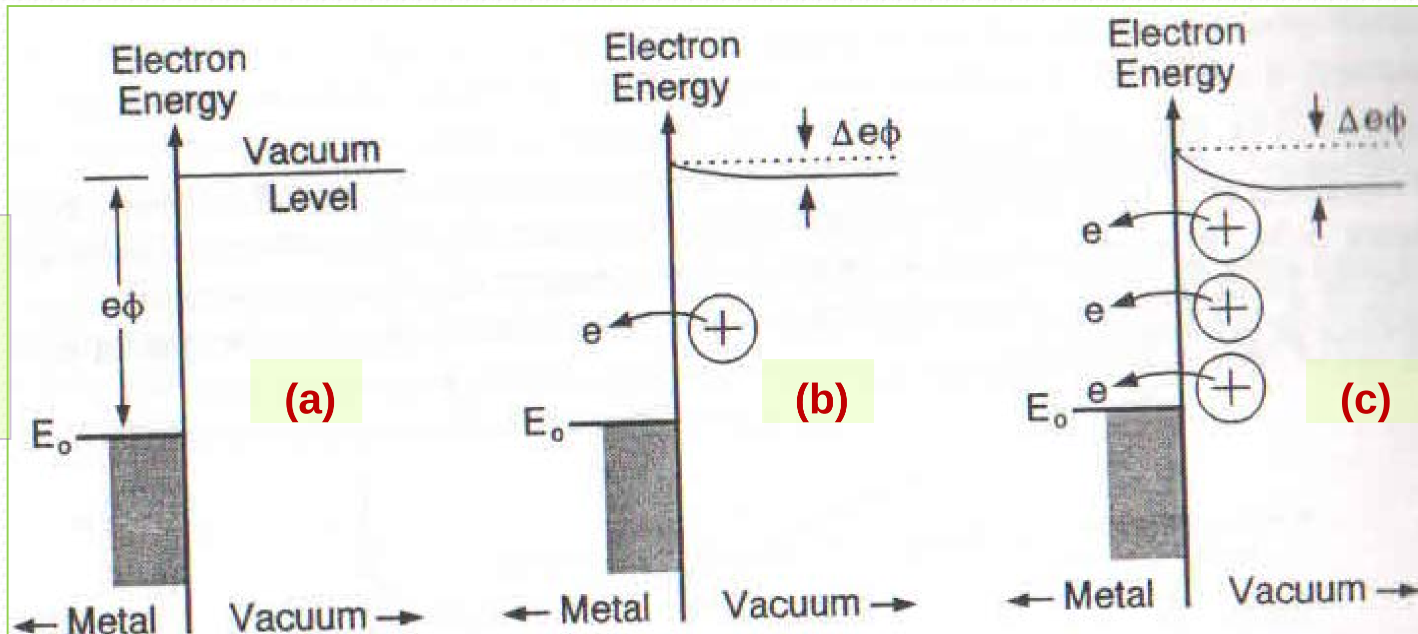


Transport of Ba/BaO from bulk

Dispenser cathode surface physics



Effect of Oxygen and Barium on Energy level diagram



Energy level diagram for metal without (a) and with (b) and (c) ions near surface

Electrostatic model and Branching of Development

Ba on W (of φ 4.6 eV) ⇒ 2.05 eV

Ba on Os (of φ 5.4 eV) ⇒ 1.85 eV

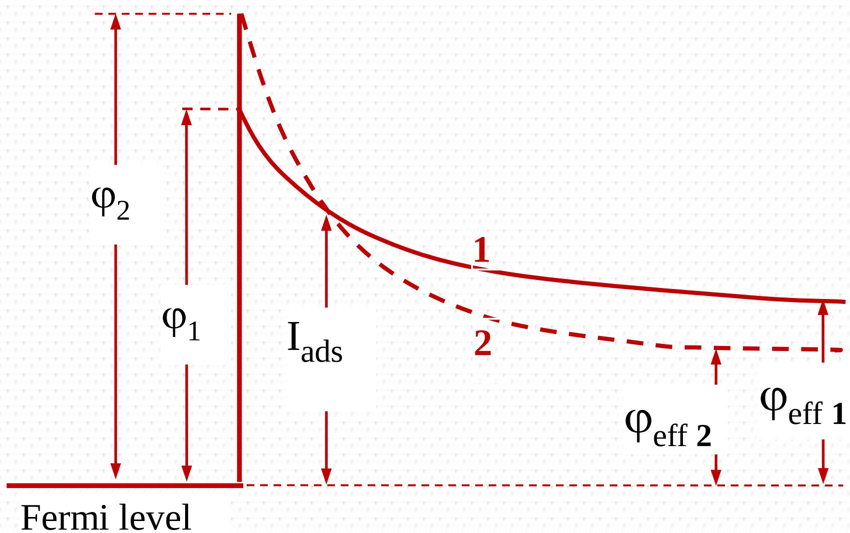


Fig. 3 Potential curves showing how the effective work function (φ_{eff}) decreases with the increase in base work function. I_{ads} is energy of energy of adsorption as Ba/BaO rests on surface

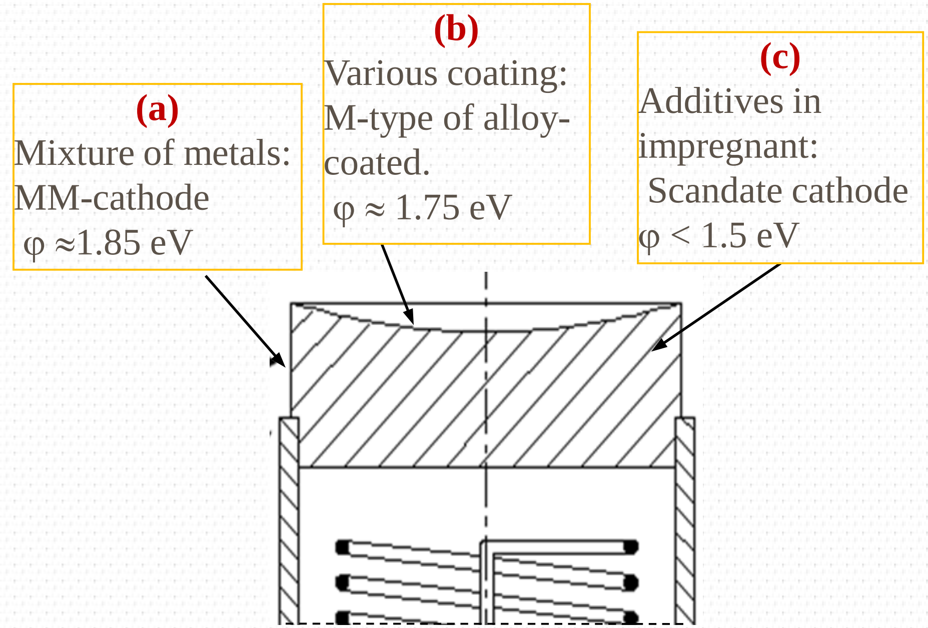


Fig. 2 Branching of cathode development: (a) mixed metals as base material, (b) coating of various metals/ alloys on the surface and (c) various impregnant compositions.

- **B-Type** (Basic-Type) ⇒ 2.05 eV -
- **M-Type (Os of 0.1 μm)** ⇒ 1.90 eV Phillips Lab, Endoven
  Alloy-Type (2Os:2Re:1W) ⇒ 1.75 eV Cambridge, U.K.
- **MM-Type (Os:W)** ⇒ 1.80 eV EMI Varian, U.K.
- **Scandate** ⇒ 1.70 eV Phillips Lab, Endoven
  (3% by weight of Sc_2O_3)
- **Nano-Scandate** ⇒ 1.50 eV Chinese

Impregnated cathode under Space charge and Temperature limited regions

Childs' law

Current (I) α Voltage $(V)^{3/2}$

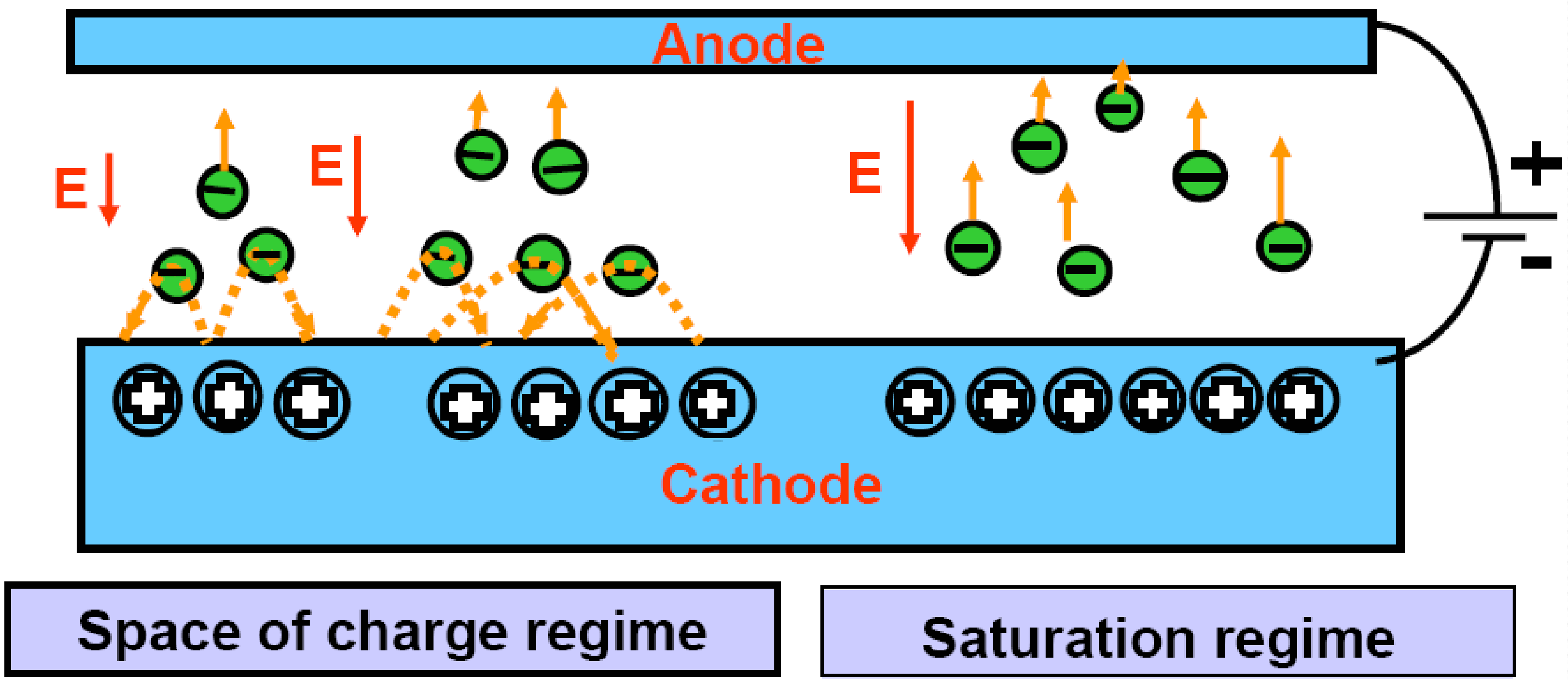
$I = \rho V^{3/2}$

Richardson-Dushman Eqn.

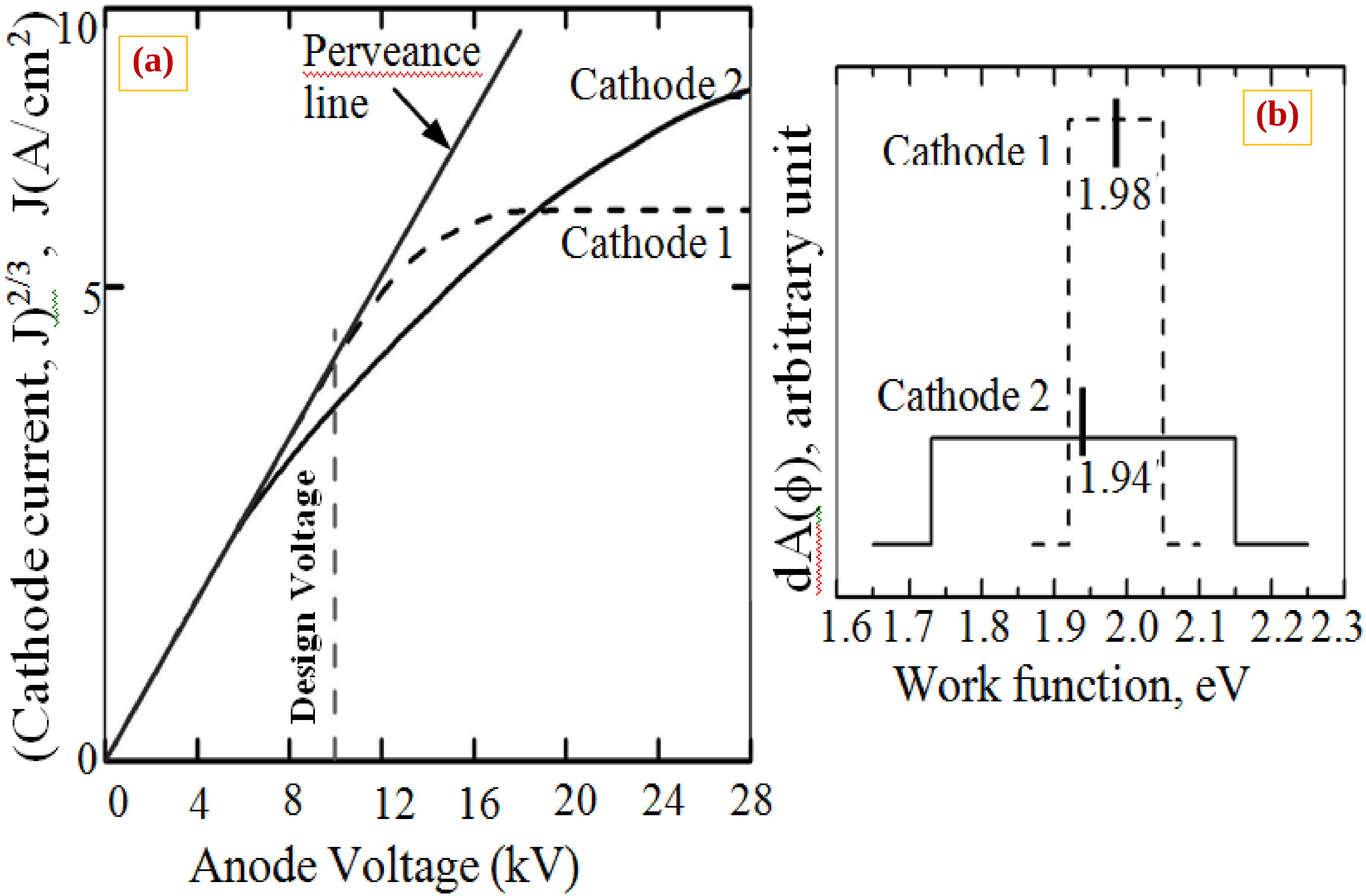
$I = S A_0 T^2 e^{-e\Phi/kT} . e^{\sqrt{E}}$

Useful to estimate work function

Electron emission by thermal energy +electrical field.

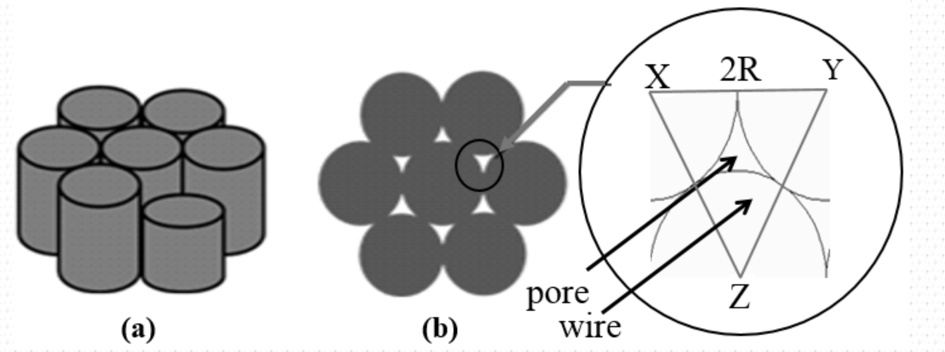


Influence of Emission uniformity on the available current

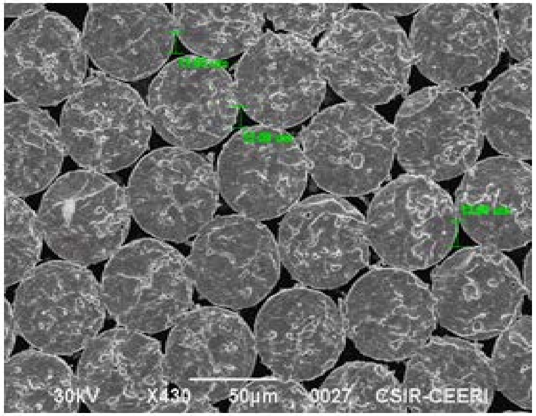


(a) Comparison of I-V characteristics of a gun with cathodes of (b) different work function distribution at an operating temperature of 1320 K.

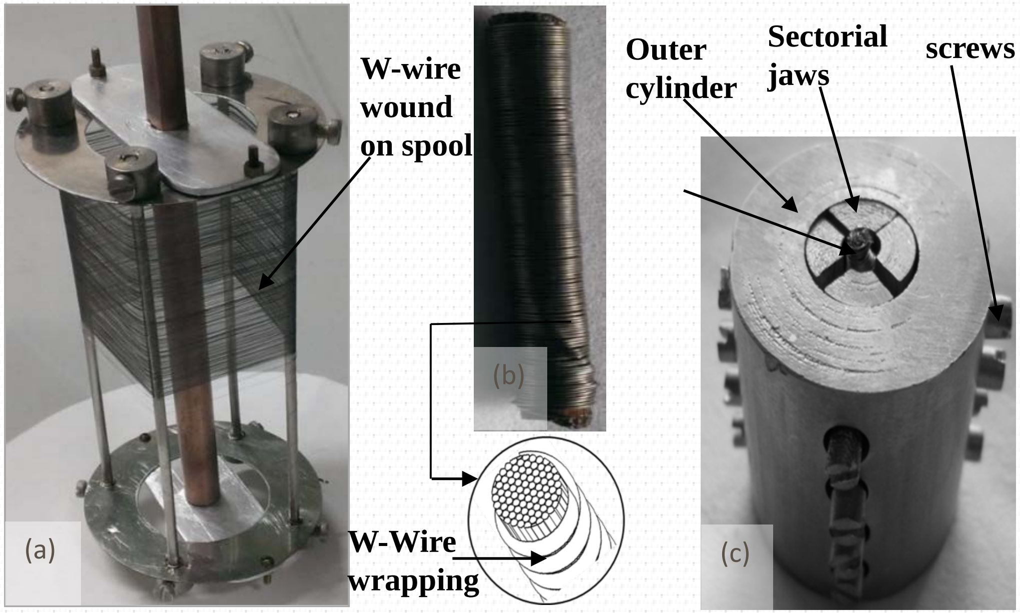
Development of Active Sintered Controlled Porosity Dispenser (CPD) Cathode



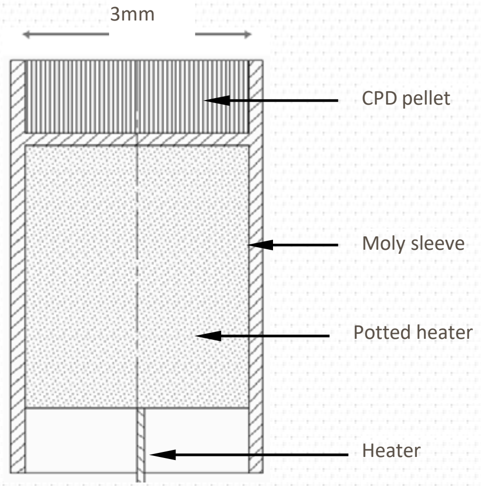
(a) Closely packed W-wires, and (b) Hexagonal wire geometry generated in a CPD pellet after sintering. The triangle XYZ represents the unit cell of the geometry



SEM picture of sintered W-wire pellet



Photographs of: (a) spool on to which W-wire is wound for Ni-plating, **(b) W-wire bundle, and (c) compression fixture with sectorial jaws.**



Drawing of CPD cathode pellet integrated with potted heater.

19-Aug-2015

Dear Mr. SINGH:

Your Manuscript TED-2015-07-1008-R entitled "**Study and Development of Active Sintered Controlled Porosity Dispenser (CPD) Cathode", has been given careful consideration by our reviewers. It has been decided that it would merit publication**, provided that MANDATORY REVISIONS were made in accordance with the enclosed comments. The revised manuscript must be submitted by 10-Sep-2015.

Dr. Manfred Thumm, Editor, IEEE Transactions on Electron Devices

manfred.thumm@kit.edu

Reviewer(s)' Comments to Author:

Reviewer: 1

This is an excellent paper with very interesting results. I congratulate the authors on their research.

There is a error in the references on page one in column two. The reference "4-8" refers to work on laser drilling, chemical etching and lithography; however, reference [8] refers to work by Ives et al, who have not performed research in this area. This reference should probably be "4-7". The following reference "9" should be verified to insure it properly refers to the work of Sing et al.

The reference "9" in the following sentence, referring to the work of Falce and Ives, should be changed "8.“ Figure 3b should be increased in size for clarity. I could not make out the details of the winding configuration. It would also be helpful if Figure 3a could also be increased in size, as it’s difficult to see the wires on the form.

On page 3, line 8, column 1: There appears to be missing text. “…respectively, at The variation....”

Again, I congratulate the authors on a most interesting manuscript.

Reviewer: 2

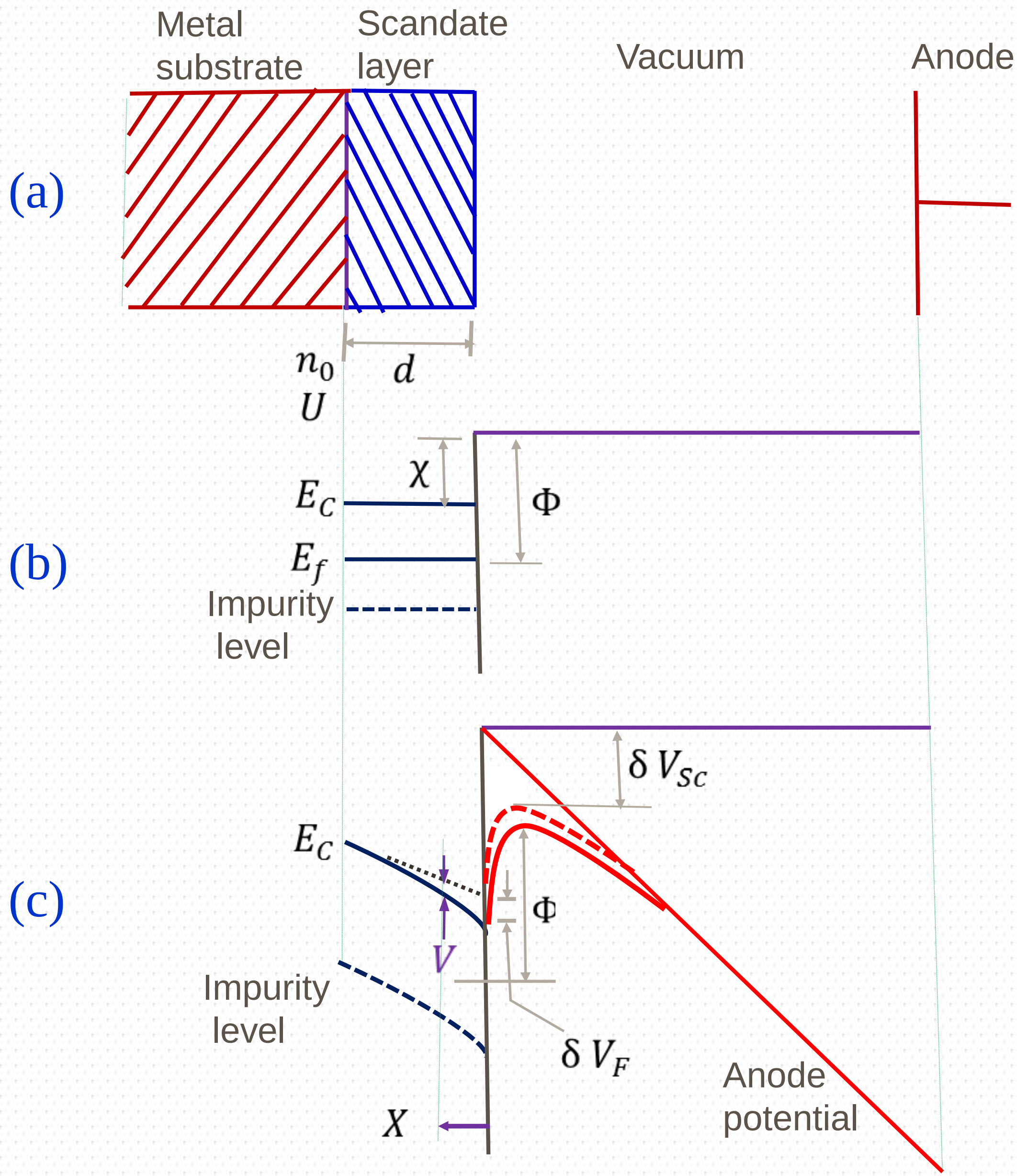
Comments to the Author

The fabrication steps of a CPD cathode by adopting active sintering are analytically described and the operation of a cathode produced by this procedure was experimentally checked. In addition, a theoretical analysis was presented in order to identify the optimal range of the wires thickness and to explore the behaviour of the cathode when subjected to ion bombardment.

In general, it is a well written manuscript. However, there are several points which should be corrected such as a mistake in the text in page 3/ column 1/line 8, a deformation of the text of the figures 1,6, and 7 and definition of EDM in page 2/column1/line 55 is missing.

- Semiconductor Model
- Use of Nano-technology

Energy level diagram used to analyze semiconducting behavior



(a) Scandate cathode in plane parallel diode

(b) Energy levels in the absence of field

(c) Energy levels as modified by the positive filed at the surface

Terms used:

Φ work function

V potential at distance x from surface

U anode field at metal surface

n_0 concentration of electrons in scandate layer

χ electron affinity of scandate layer

with the applied F, there is reduction in internal work function by δV_F and external work function by δV_{Sc}

Finite thickness model: Raju & Maloney, IEEE Trans ED Vol. 41, Dec 1994, 2460-2467

This model was derived by modifying Wright's model [11] treated for oxide coated cathodes.
In the case of a semiconductor, because of limited concentration of free electrons in the conduction band, the external electric field is not screened at the very surface; rather it penetrates into the surface. This effect brings the work function down by δV_F in addition to the reduction in external work function due to the Schottky effect. Therefore the net reduction in work function is [$\boldsymbol{\delta V_F + \delta V_{Sc}}$].

In the space charge region, the number of free electrons/m^3 (n_-) and ionized donor centers/m^3 (n_+) at a distance "x" from surface can be written as

$$n_- = n_0 \exp(eV/kT) \quad , \quad \text{and} \qquad \text{A1.1}$$

$$n_+ = n_0 \exp(-eV/kT) \qquad \text{A1.2}$$

where n_0 is free electron concentration in the body of scandate layer at temp. T, e the electron charge, **k** the Boltzmann's constant and V the potential at a distance x from surface.
The net charge density n is given by

$$n = -2n_0 \sinh(eV/kT) \qquad \text{A1.3}$$

[11] DA Wirght & J Woods, Proc Phys Soc, Vol 65B,1952, pp 134-145

For this charge distribution, Poisson's eqn. becomes

$$\frac{d^2V}{dx^2} = \frac{2e\,n_0}{\varepsilon_r\varepsilon_0}\sinh\frac{eV}{kT} \qquad \text{A1.4}$$

An integration on both sides yields

$$\left(\frac{dV}{dx}\right)^2 = \frac{4kTn_0}{\varepsilon_r\varepsilon_0}\cosh\frac{eV}{kT} + U_1 \qquad \text{A1.5}$$

where U_1 is a constant of integration
The eqn. is solved for a thick layer and a thin layer.

Thick layer:
In the case of a thick layer, the field & potential should vanish at a distance far from surface, i.e.

$$\left(\frac{dV}{dx}\right) = 0, \quad \text{and} \quad V = 0 \quad \text{as } x \to \infty \qquad \text{A1.6}$$

Using this condition, (A1.5) can be written as

$$\frac{dV}{dx} = \pm\sqrt{\frac{8kTn_0}{\varepsilon_r\varepsilon_0}}\sinh\frac{eV}{kT} \qquad \text{A1.7}$$

lowering of WF due to space charge can be found by applying continuity eqn. at oxide-vacuum interface, i.e.

$$\epsilon_r\left(\frac{dV}{dx}\right) = F, \quad \text{and} \quad V = V_W \quad \text{at } x = 0 \qquad \text{A1.8}$$

where F is external field at the surface and V_W the corresponding potential in space charge region.

Semiconductor model, continue . . .

With the previous condition, (A1.7) can be written as

$$\frac{e}{4kT}F = \frac{\epsilon_r}{2L}\sinh\frac{eV_w}{2kT} \qquad \text{A1.9}$$

where L is the Debye length which is given by

$$L = \left(\frac{2\, n_0\, e^2}{\epsilon_r \epsilon_0 kT}\right)^{-1/2} \qquad \text{A1.10}$$

Eqn. (A1.9) is similar to that of Wright [11] when coating resistance in his model is neglected.

Finite layer:

Considering the original model for an infinite oxide layer and altering the form of (A1.7), the following equation is obtained.

$$\frac{dV}{2\sinh(eV/2kT)\cosh(eV/4kT)} = \pm\sqrt{\frac{8kTn_0}{\epsilon_r\epsilon_0}}\,dx \qquad \text{A1.12}$$

An integration on both sides yields

$$\tanh\frac{eV}{4kT} = C\exp(\pm x/L) \qquad \text{A1.13}$$

where C is the integration constant.

If the potential at the surface is assumed to be V_F, i.e., $V=V_F$ at x=0, (A1.13) can be written as (after eliminating the constant)

$$\tanh\frac{eV}{4kT} = \tanh\frac{eVF}{4kT}\,\frac{\sinh[(d-x)/L]}{\sinh(d/L)} \qquad \text{A1.14}$$

By using the following continuity equation at the vacuum oxide interface, i.e.

$$\epsilon_r\left(\frac{dV}{dx}\right) = F, \quad \text{and} \quad V=V_F \text{ at } x=0 \qquad \text{A1.15}$$

(A1.14) reduces to

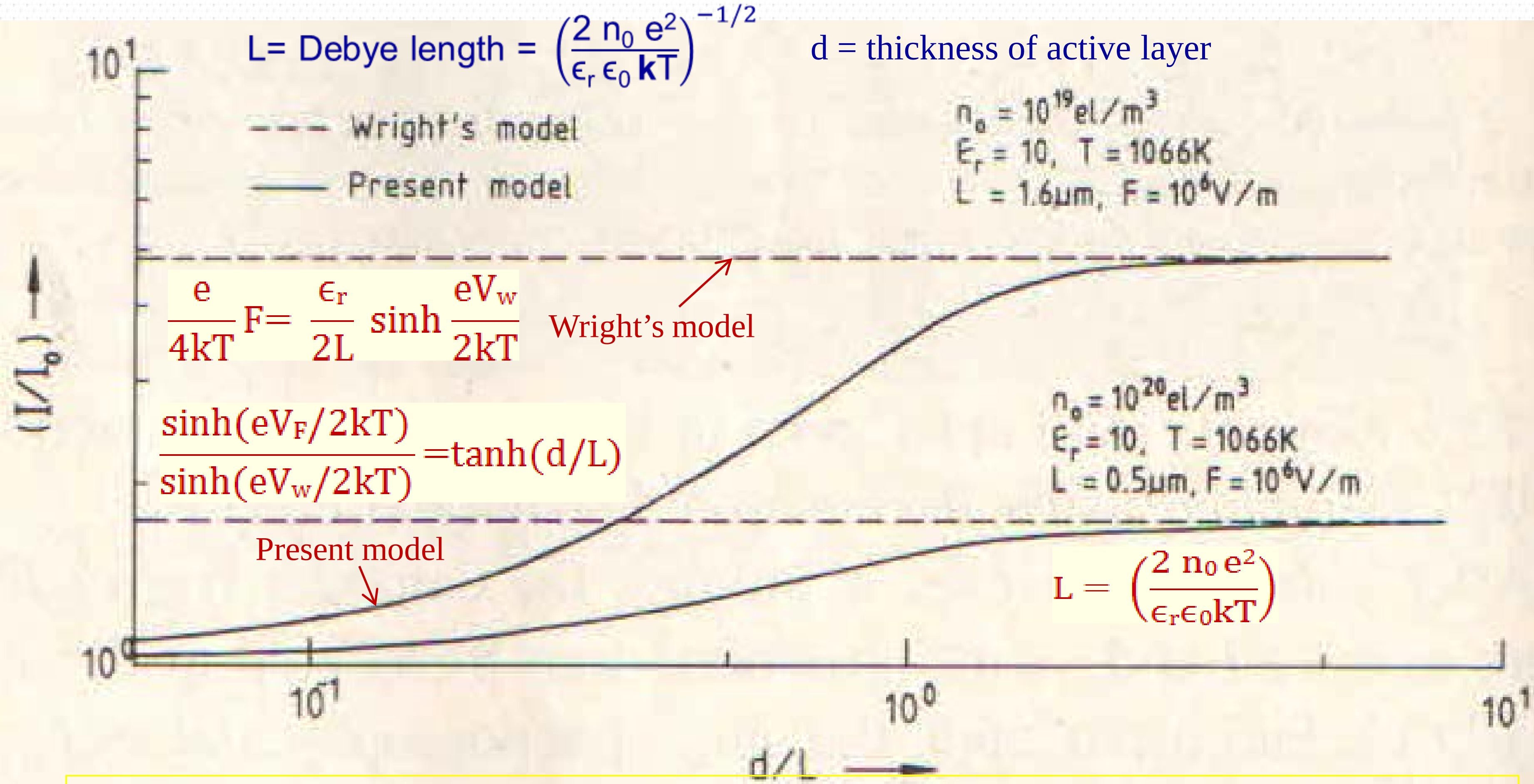
$$\frac{eV}{4kT}F = \frac{(\epsilon_r/2L)\sinh(eV_F/2kT)}{\tanh(d/L)} \qquad \text{A1.16}$$

From (A1.16) and (A1.9), the following relation is obtained

$$\frac{\sinh(eV_F/2kT)}{\sinh(eV_w/2kT)} = \tanh(d/L) \qquad \text{A1.17}$$

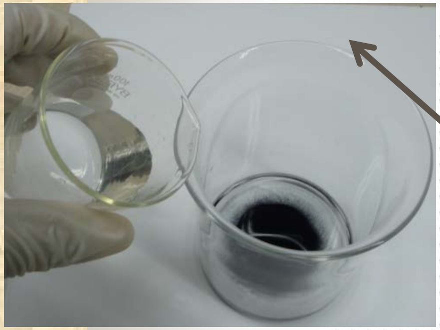
The terms V_F and V_W represent the potential lowering in the present model & Wright's model, respectively. When the thickness of oxide layer Is a few Debye lengths, the potential lowering predicted from both the models is similar.

Semiconductor model, continue . . .



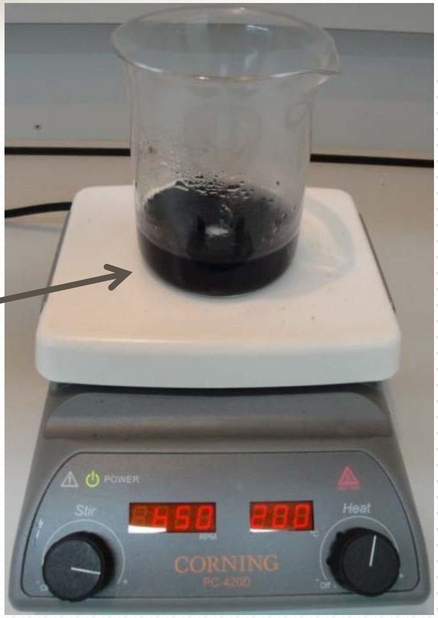
Logarithmic plot of normalized diode current versus depth normalized to Debye length for a given field, temperature, and dielectric constant.
$\mathbf{I_0}$ is the value of zero-field current and **I** is that including field enhancement.

Sequence of Sol-gel synthesis process



3% aqueous solution of (Sc(NO3)3) & HNO3.

⇓



Reaction occur at 200 0C temperature

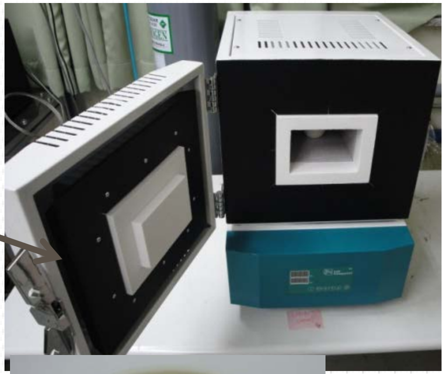
⇓

Dissolve tungsten oxide into this solution

⇓

Dry the gel and grind in agate mortar

⇓

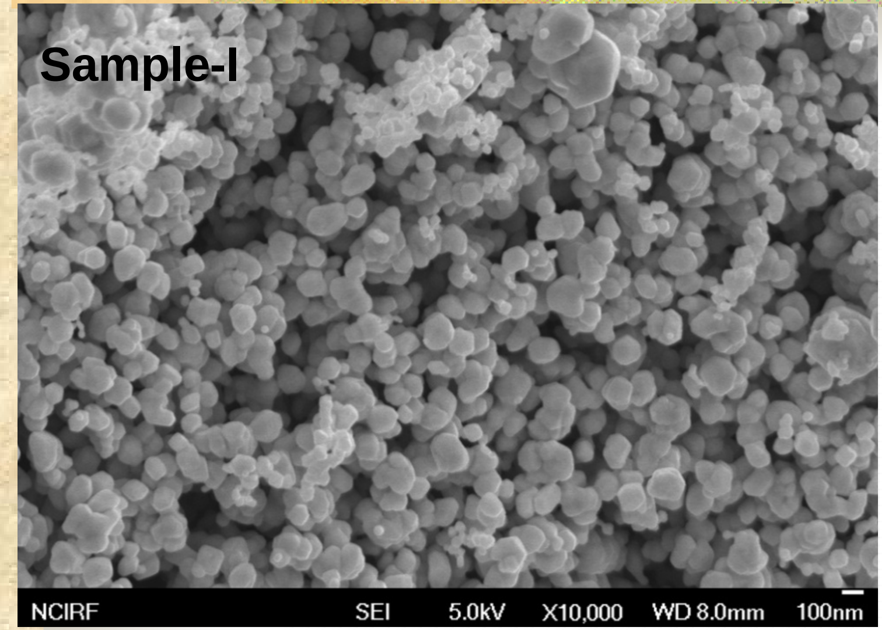


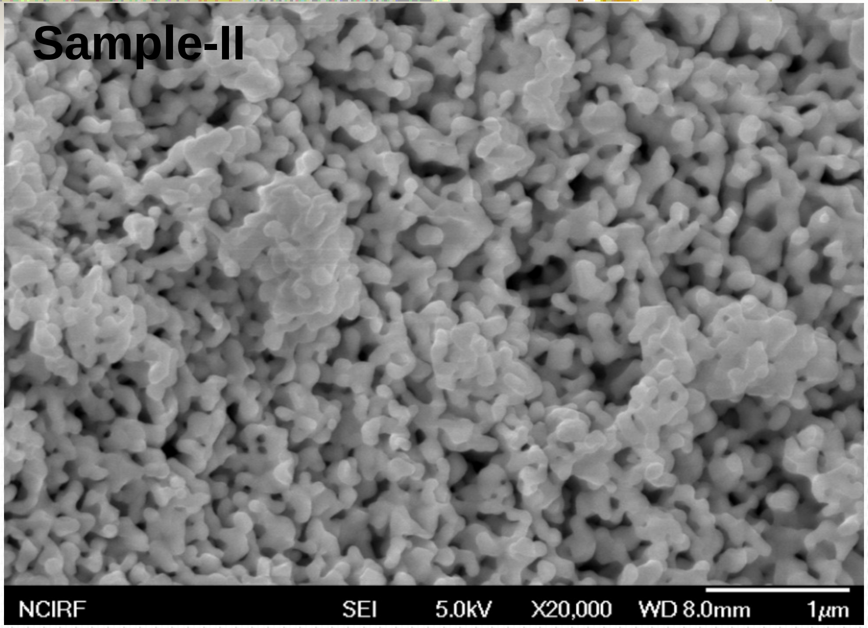
Calcine at 500 0C temperature

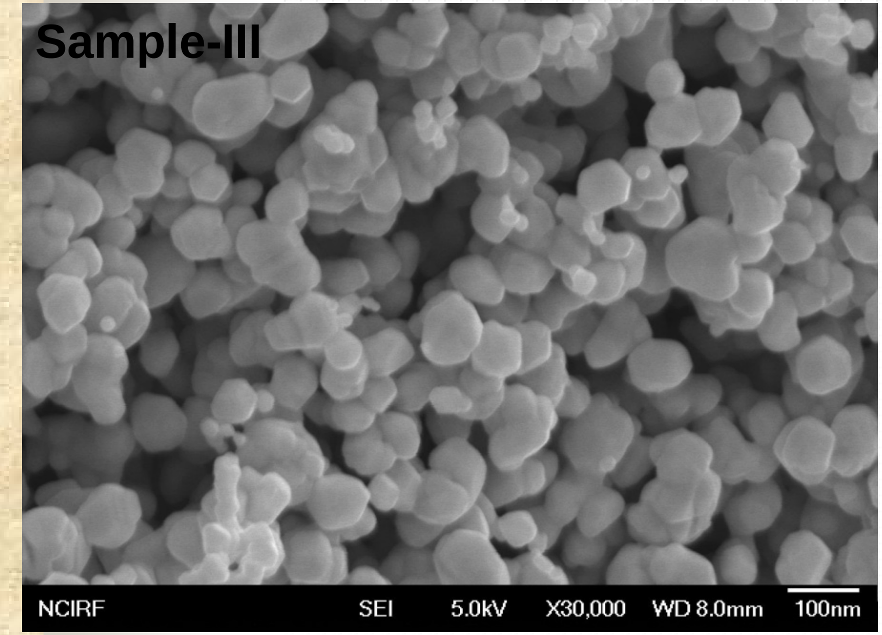
⇓

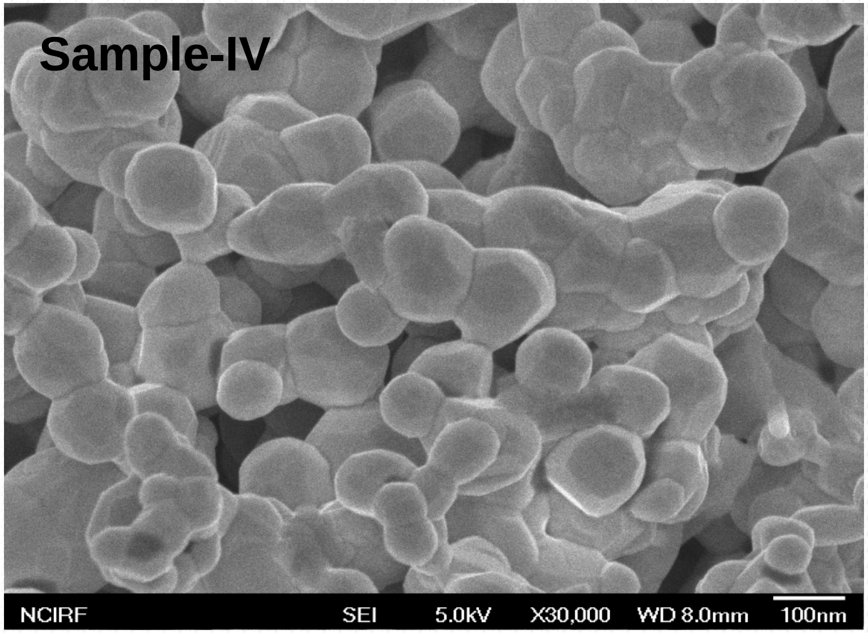
Fire in Dry hydrogen in 700 0C temperature

SEM image shows spherical shaped particle









- Work on Ion Thrusters
- Supply of cathodes to ISSC

Development of Thermionic Emitter for Electric Propulsion System

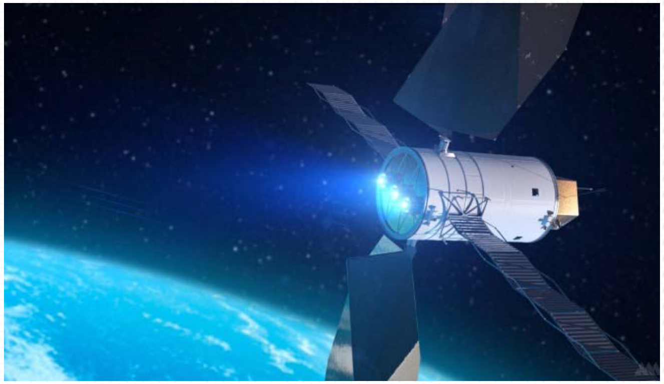
User Specifications:

- Dimension: Φ 5 mm, Length-15 mm
- Current Density > 12 A/cm^2 @1200 ^{0}C

Application Potential:

- Electric propulsion system for satellite

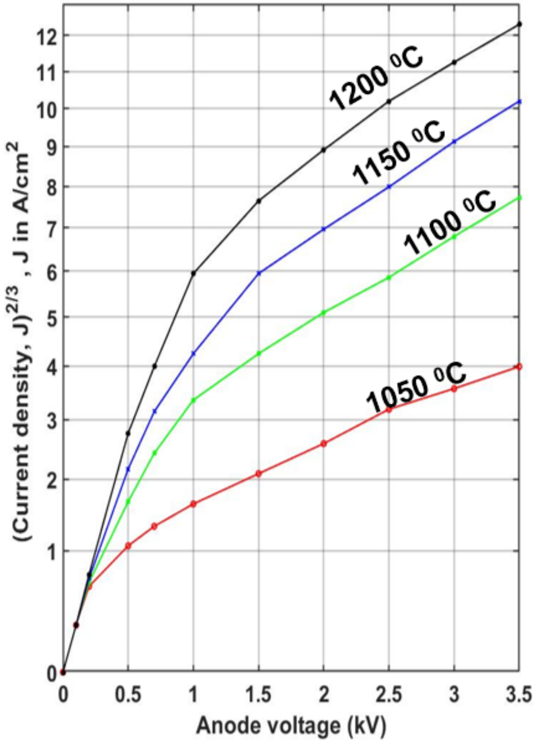
Optical image of emitter



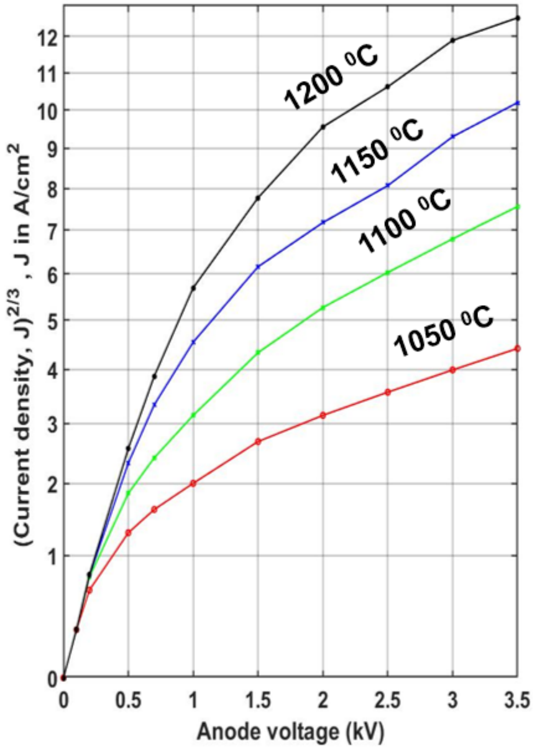
Electric propulsion system for satellite

Sponsoring Agency: VSSC, ISRO

20 nos of prototype and 50 nos of flight proven emitters delivered within stipulated time



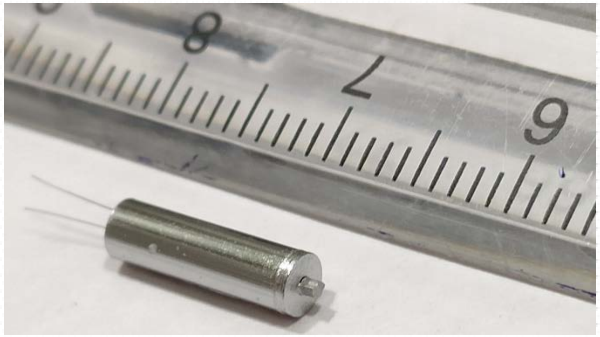
I-V Characteristic of emitter developed at CEERI



I-V Characteristic of imported emitter supplied by VSSC

Development of High Current Density Cathode for THz devices

User Specifications:
- Device Dimension: Φ 0.8 mm
- Current Density @1150 C > 100 A/cm^2

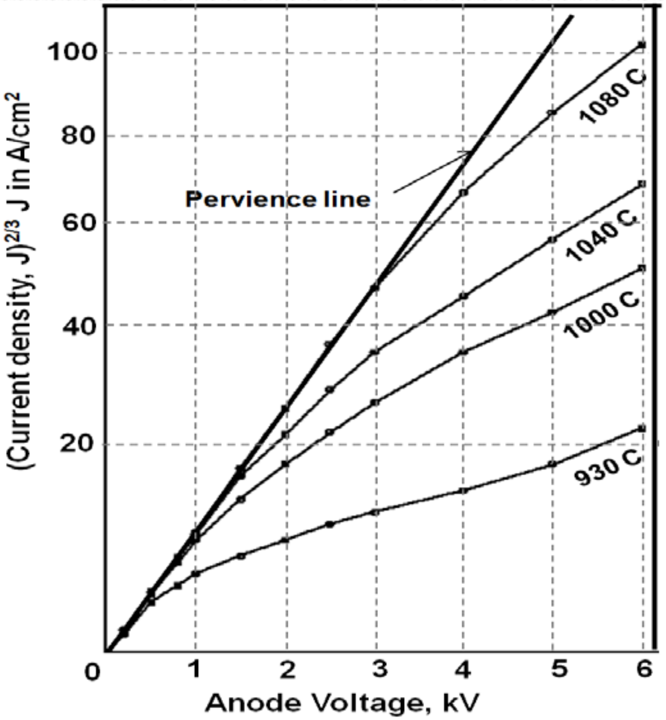


Optical photograph of Cathode

Application Potential:
- THz Vacuum Electron Devices

Sponsoring Agency:
ER & IPR, DRDO, New Delhi

User: MTRDC, DRDO
10 nos. of cathodes delivered to user



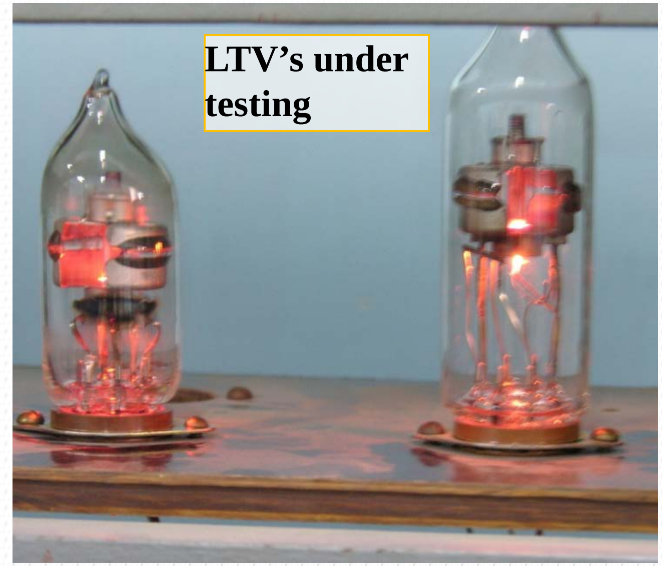
I-V characterization in diode mode

Product Delivered to VSSC-ISRO

Published in VSSC internal journal “Countdown”-August 2019

Characterization

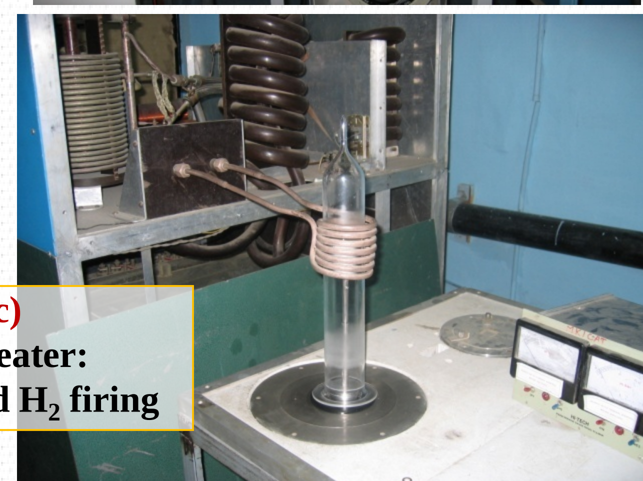
Photographs: Pinch off of Life Test Vehicle (LTV) and Life Testing of Diodes



Parts & Facilities

(a)
Sputter coating system

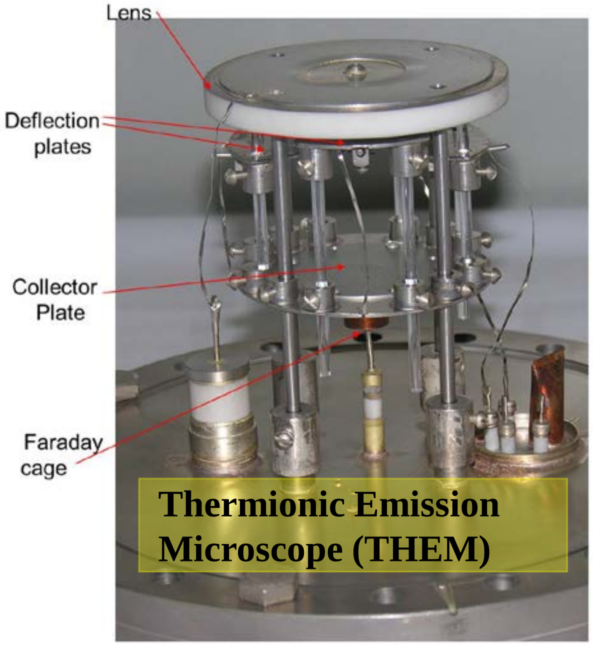
(b)
Mini-Table top furnace



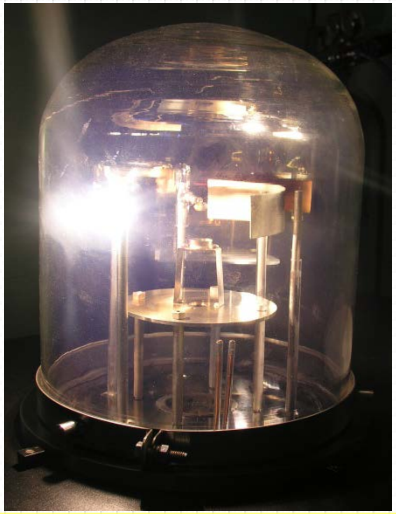
(c)
Induction heater:
Vacuum and H_2 firing

- ✧ **De-coppering : 1100^{o}C in vac**
- ✧ **Pellet-sleeve brazing: Mo-Ru 1900^{o}C wet H_2**
- ✧ **Heater sintering : 1850^{o}C in wet H_2**
- ✧ **Potting : 1700^{o}C wet H_2**
- ✧ **Impregnatioon : 1550^{o}C in Dry H_2**

Photographs of R&D facilities for cathode development at CSIR-CEERI



Thermionic Emission Microscope (THEM)



DC Triode Sputtering System

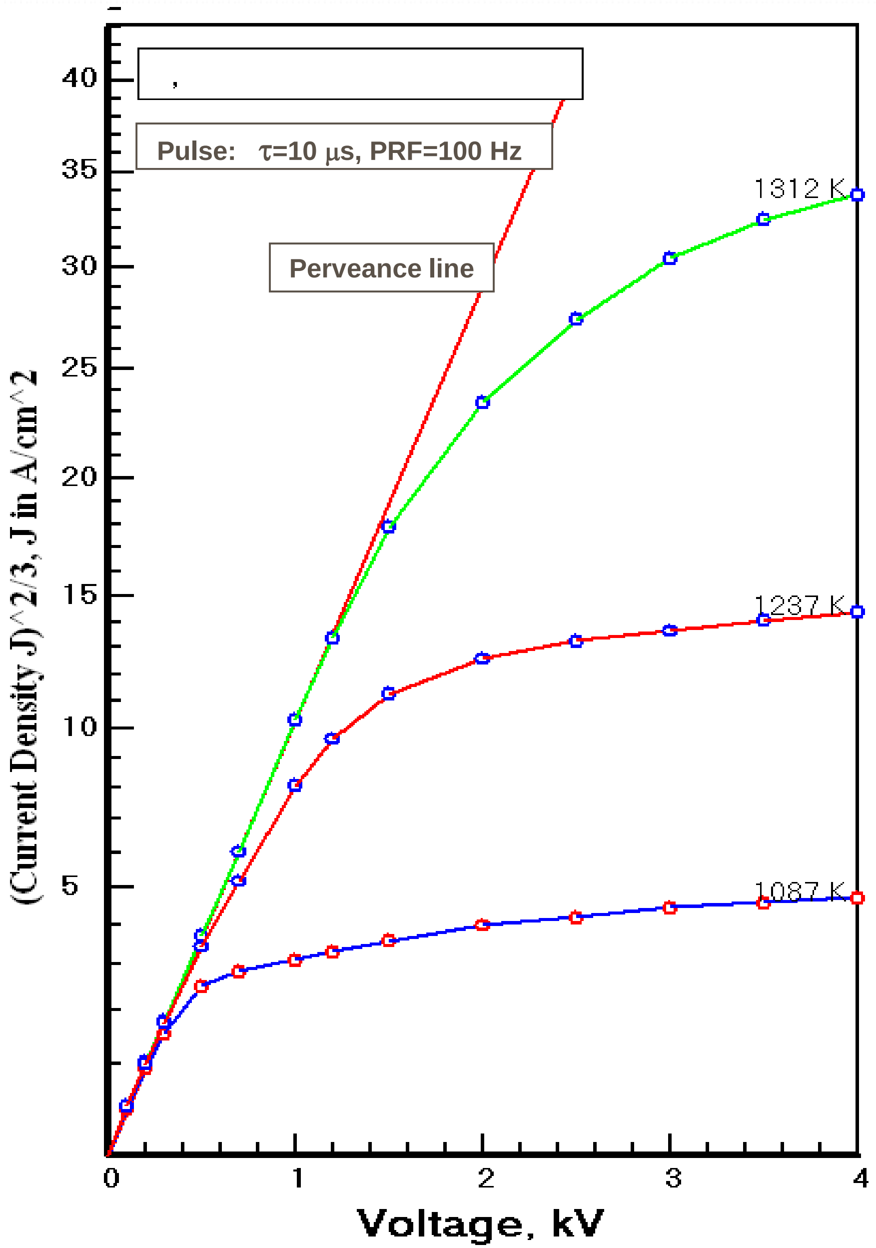
Photograph of HT Furnace

LTV

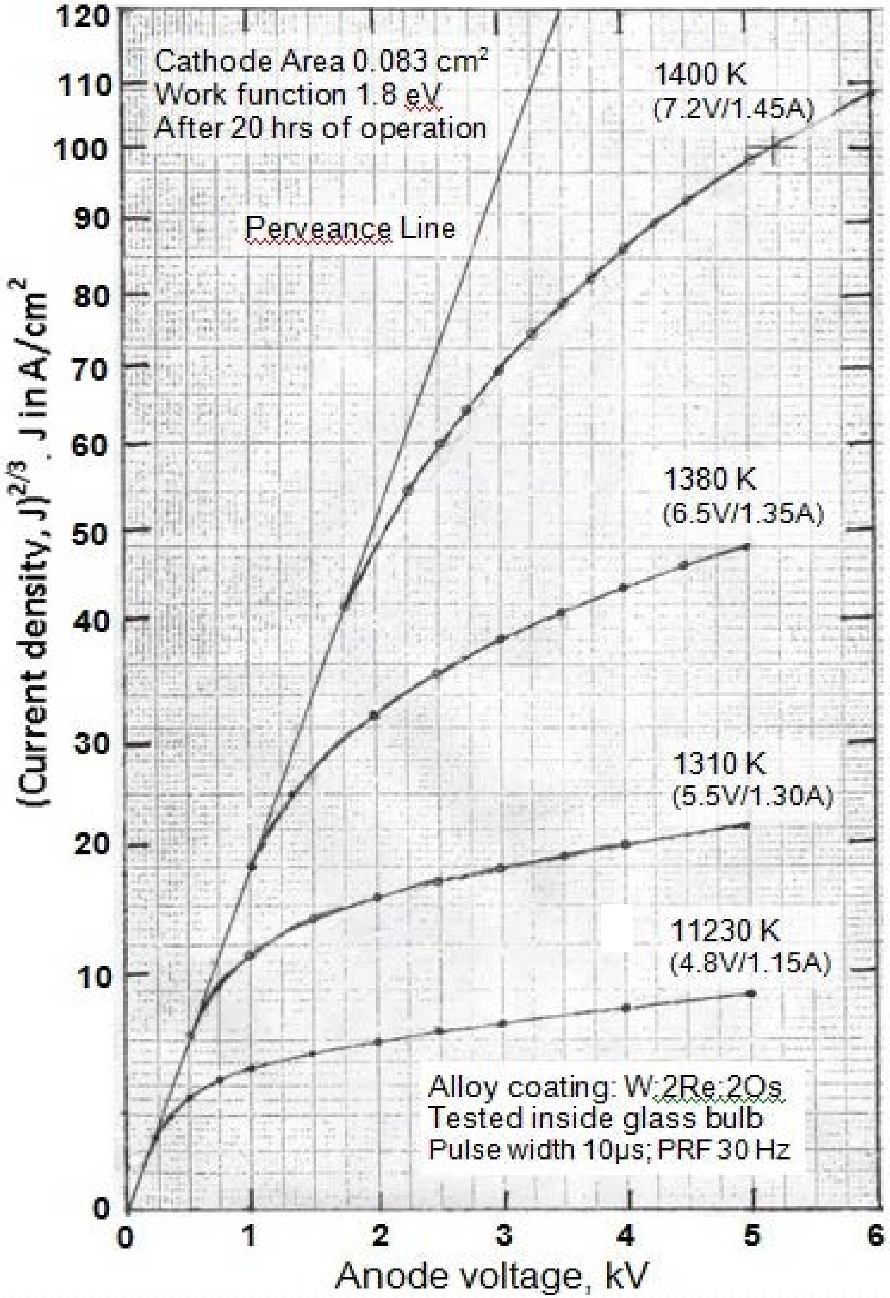
AES system

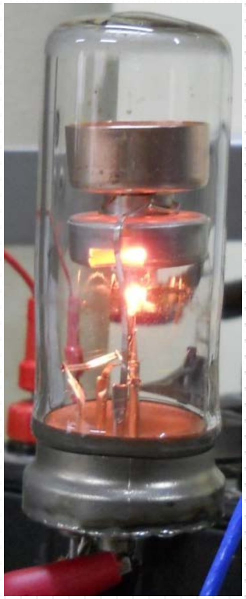
RF Induction Heater

Pulse emission characteristics of Alloy-film cathode in LTV



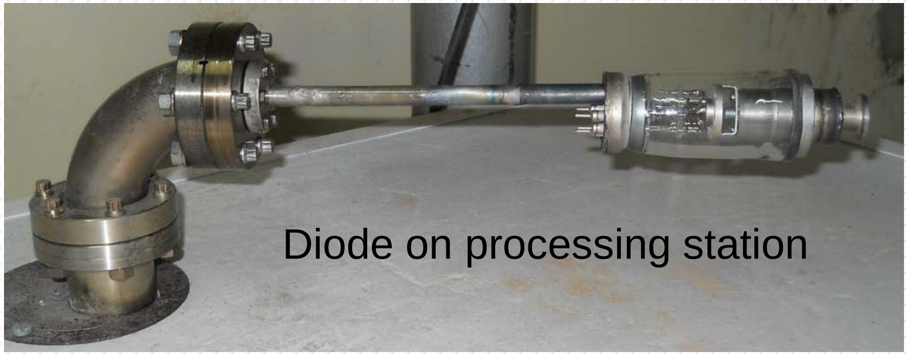
Diodes incorporated with Alloy-film cathodes



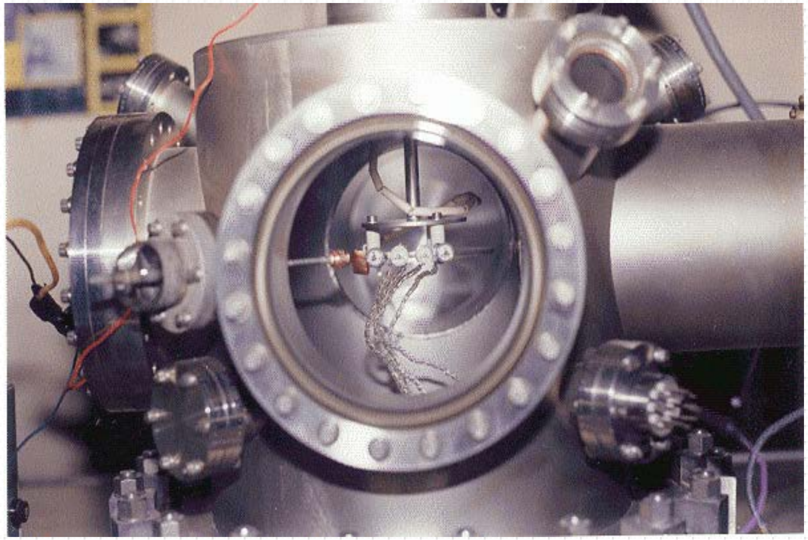

Radiation-cooled diode under operation

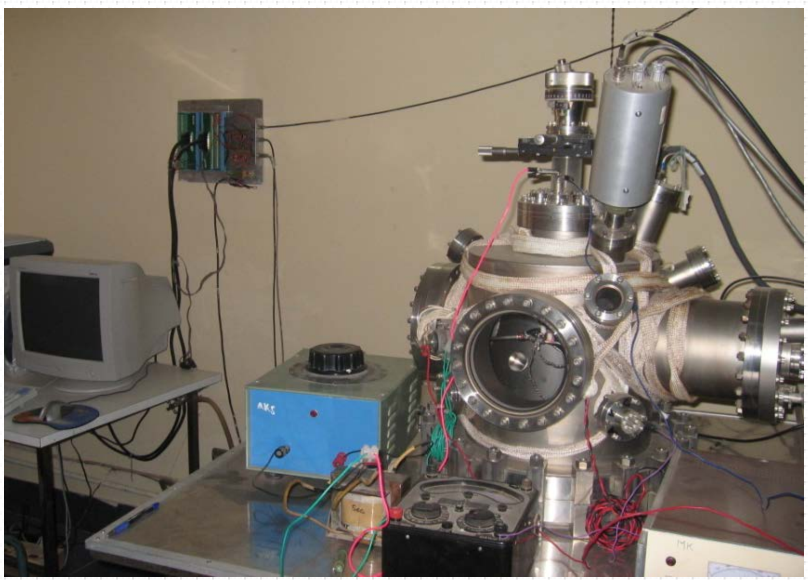

Water-cooled diode during glass blowing

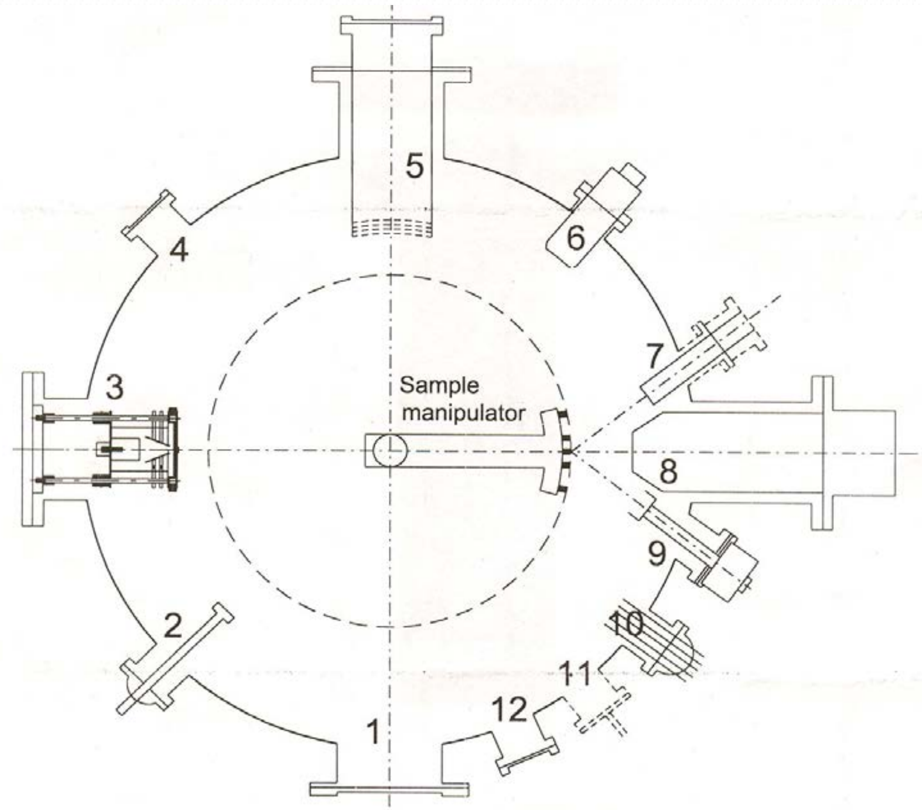

Processing station


Diode on processing station

Auger Electron Spectroscopy (AES) System for surface characterization





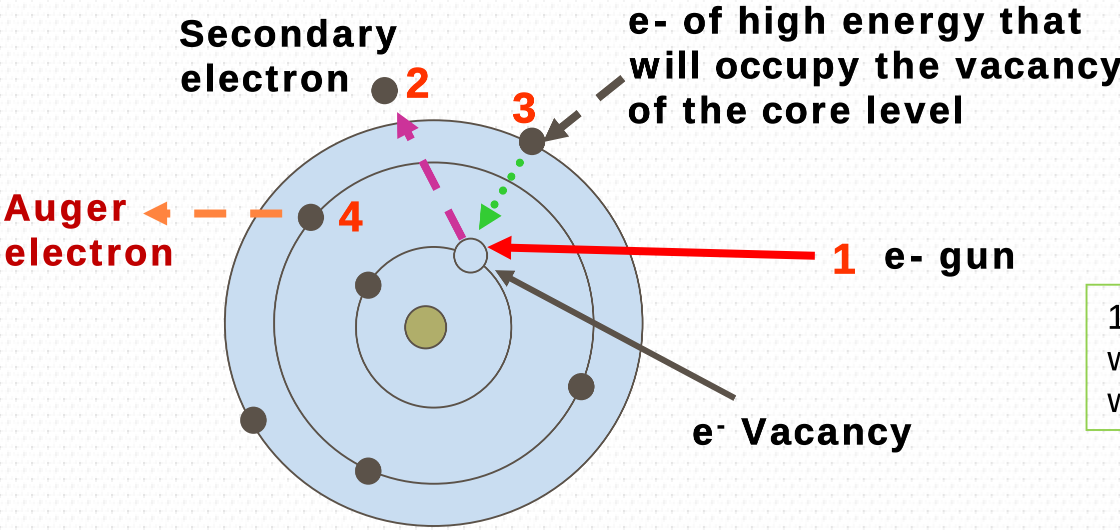


Chamber of Analytical System

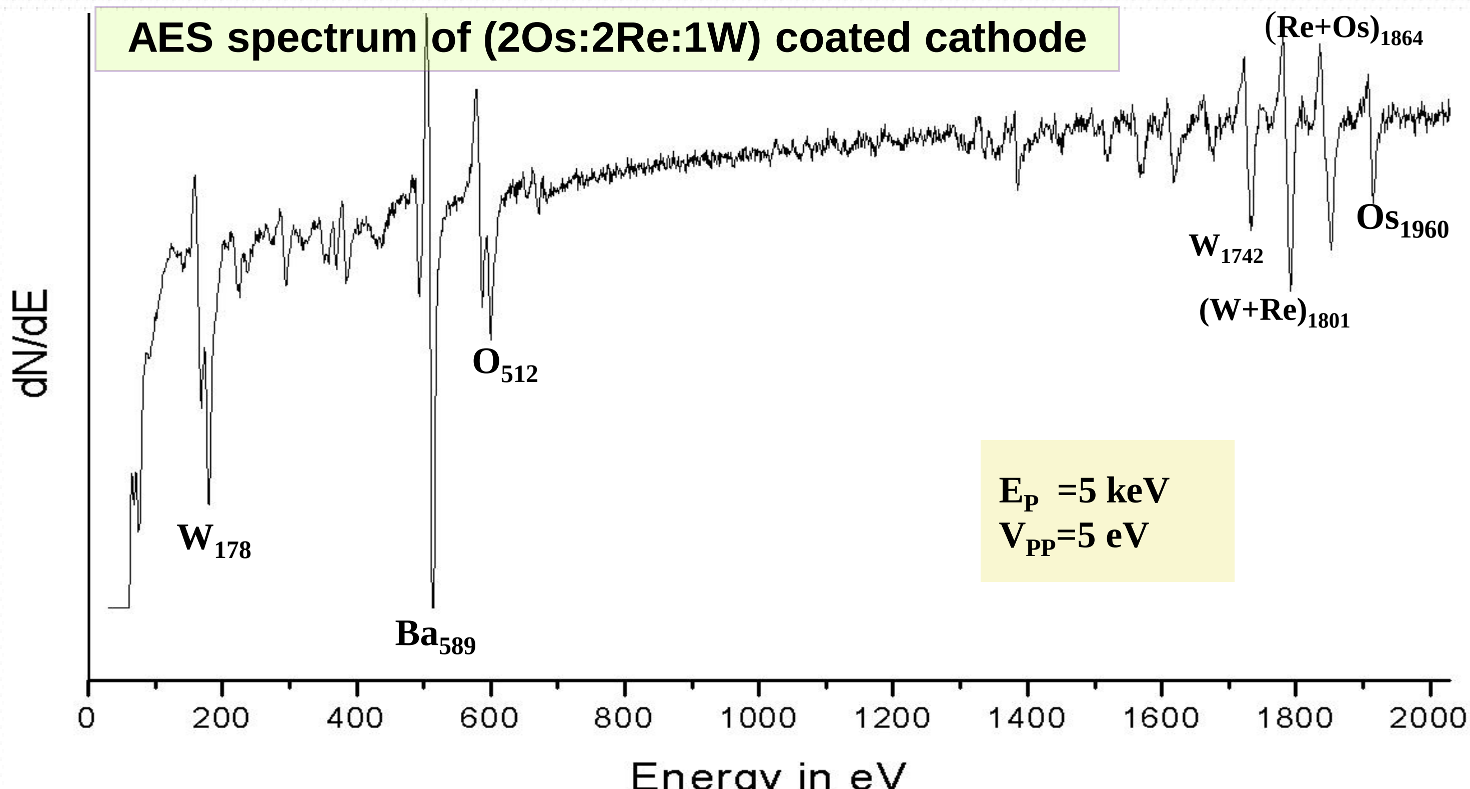
1. Viewing window
2. Anode
3. Access flange
4. Viewing window
5. ErLeed
6. Mass spectrameter
7. Ion Gun
8. CMA
9. Sec. El detector
10. El. feed through
11. Leak valve
12. Viewing window

Auger Electron Spectroscopy (AES)

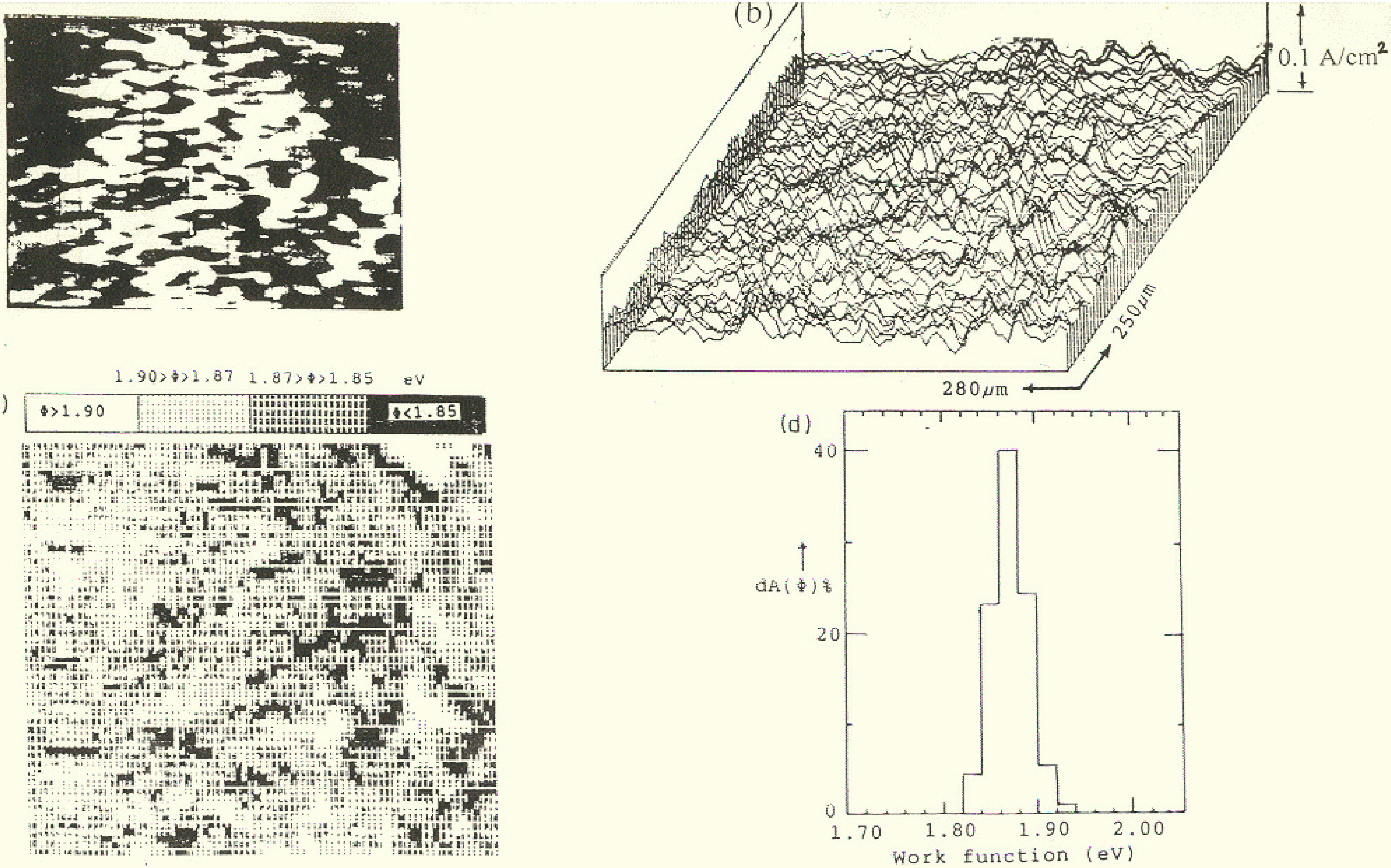
(*Transitions explained with reference to free atom*)



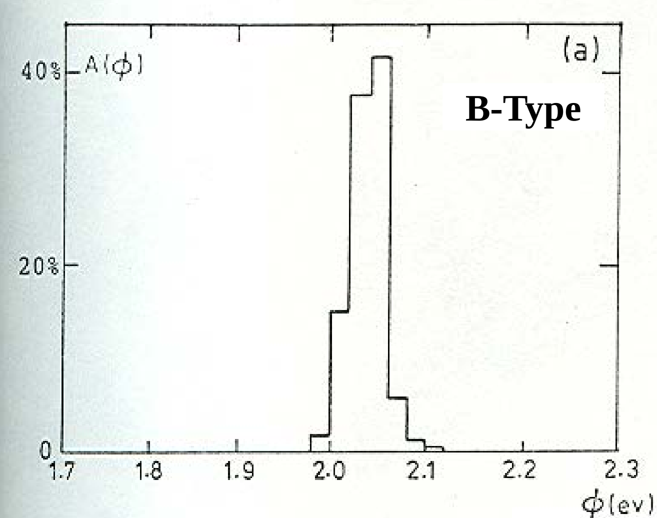
1, 2, 3 and 4 are the order of steps in which the e-s will move in the atom when hit by the e- gun.

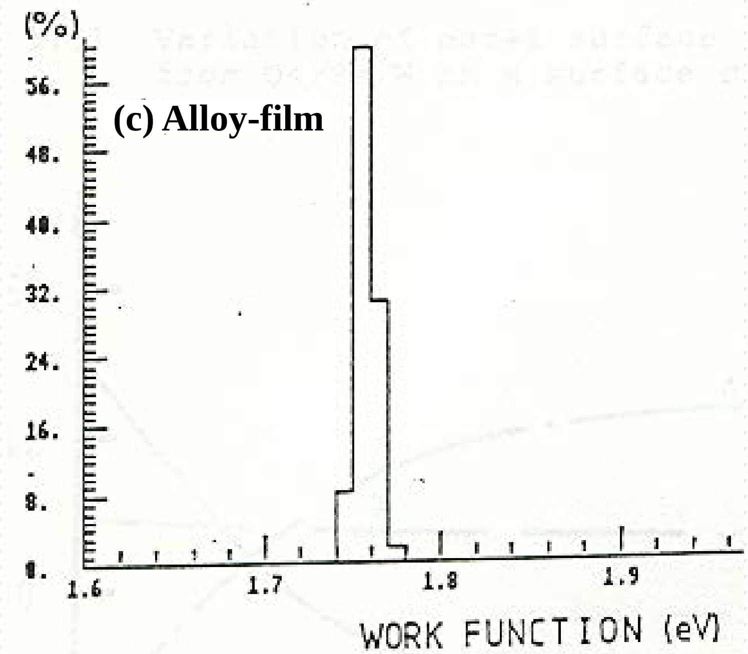


Thermionic Emission Microscope (THEM): Emission map, WF map & WF histogram

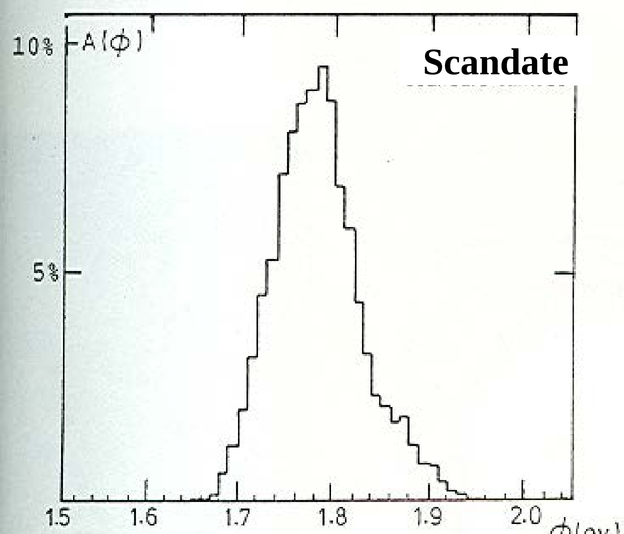


Work function histograms of different types of cathode

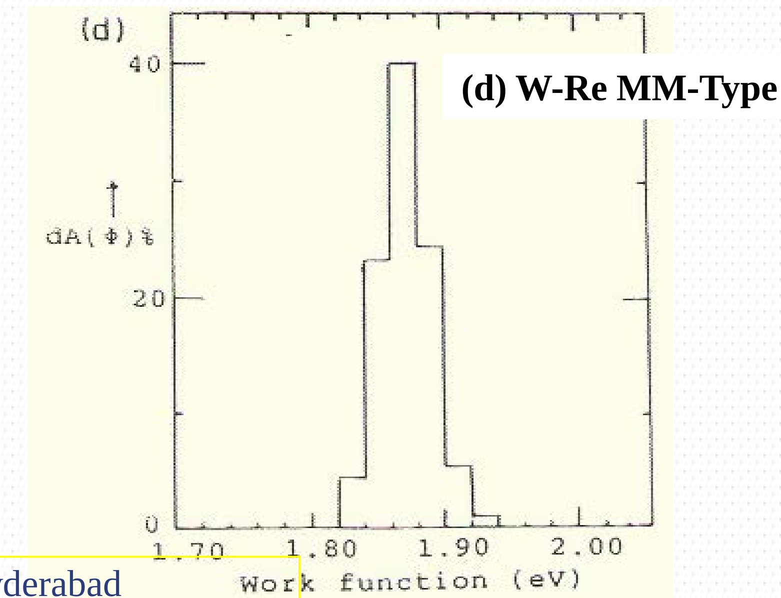




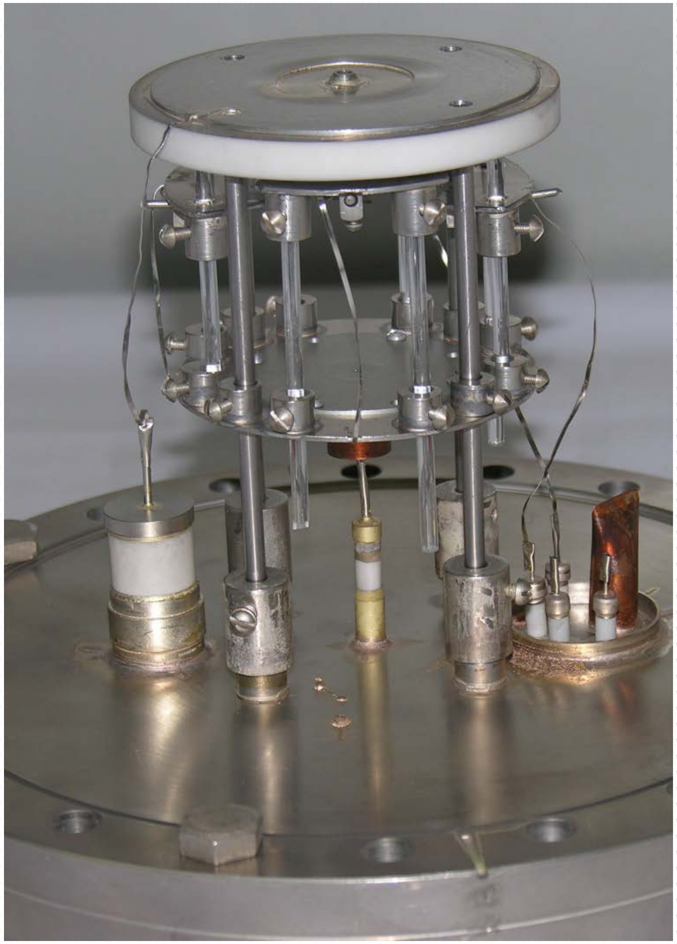
$$J = A_0 e^{-e\varphi/kT}$$



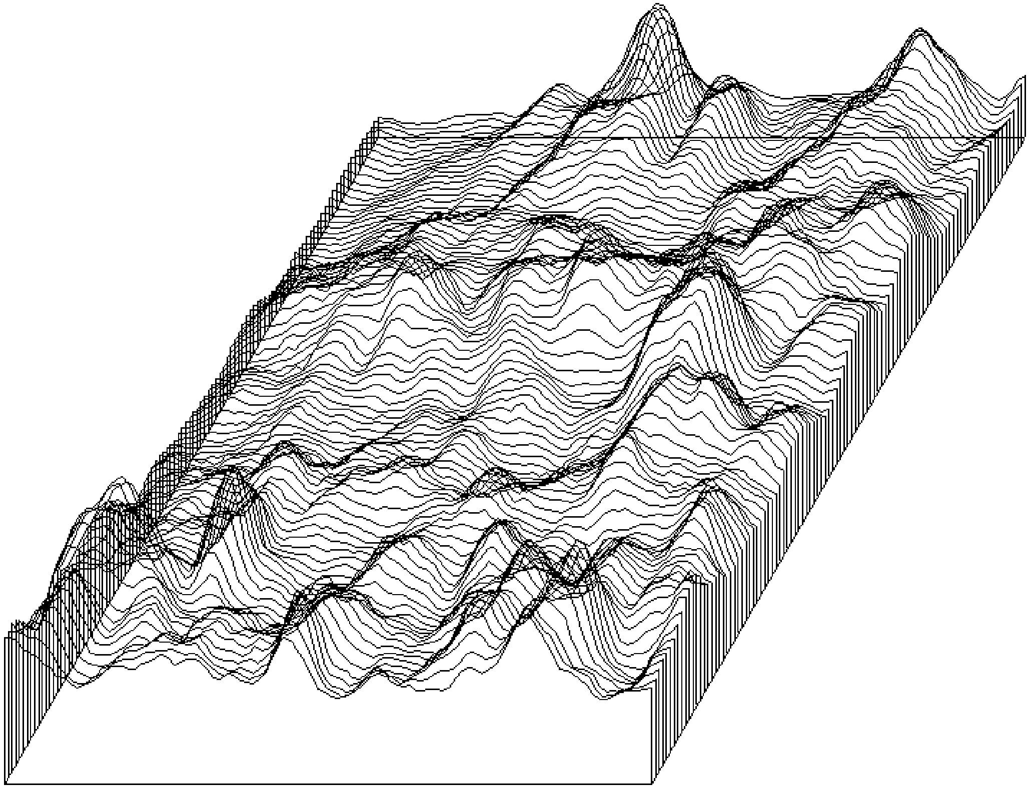
.8 Work function histograms of (a) B-type cathode, and (b) scandate cathode plotted from the data obtained from THEM -Maloney and Zhang [20]



1st Prototype of Thermionic Emission Microscope developed at CEERI



1st Prototype of THEM
Components mounted on flange:
(a) Electrostatic Immersion Lens,
(b) Deflection system &
(c) Faraday cage

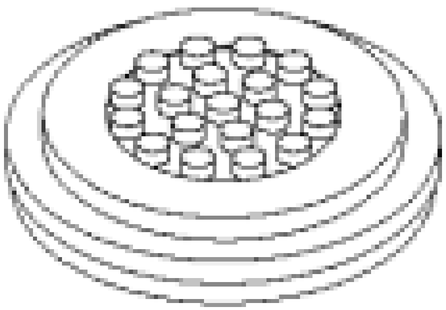


Emission plot of Dispenser cathode.

Fabrication of Multi-beam cathodes

Multi-beam Cathode and Dev. of Custom-built DC Triode Sputtering System

Drawings and photographs of MBC



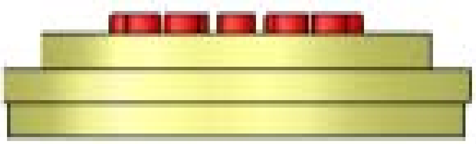
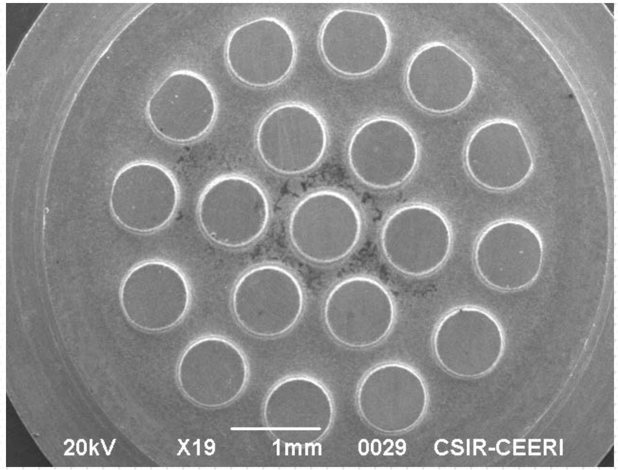
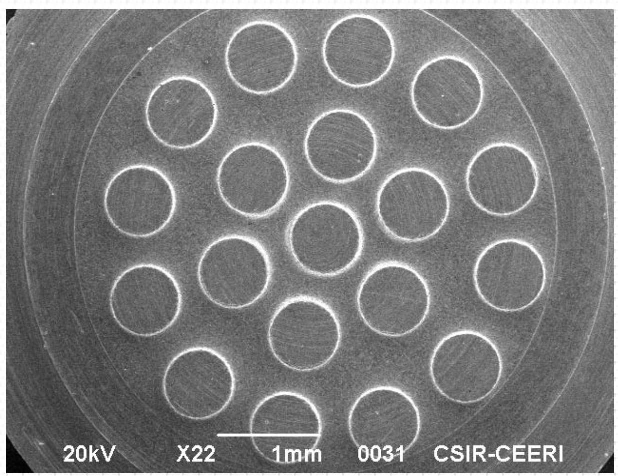


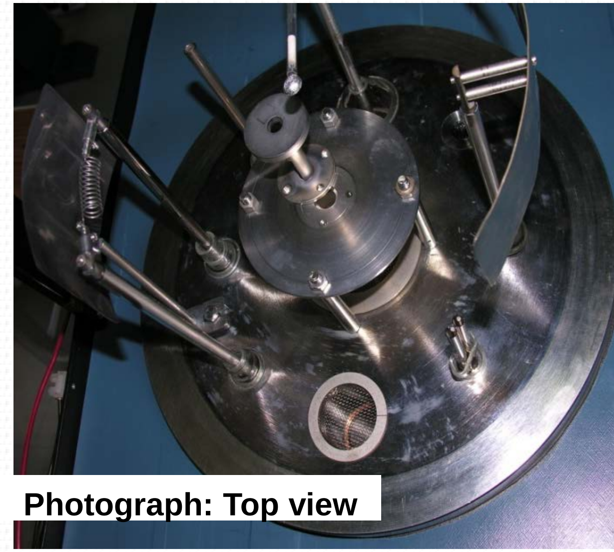
Diagram of MBC



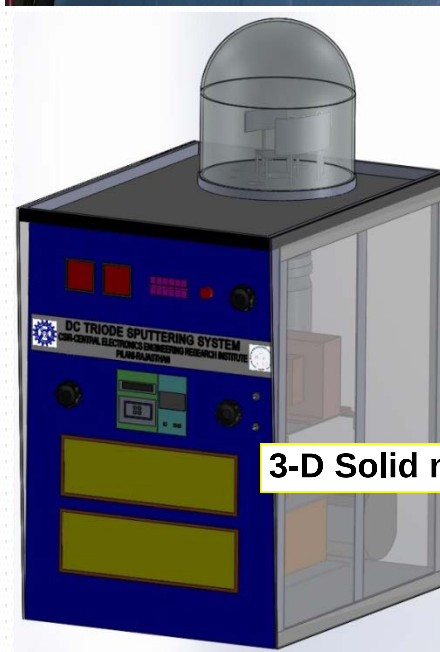


SEM image of MBC made out of EDM

Photograph and Solid Model of DC Triode Sputtering System

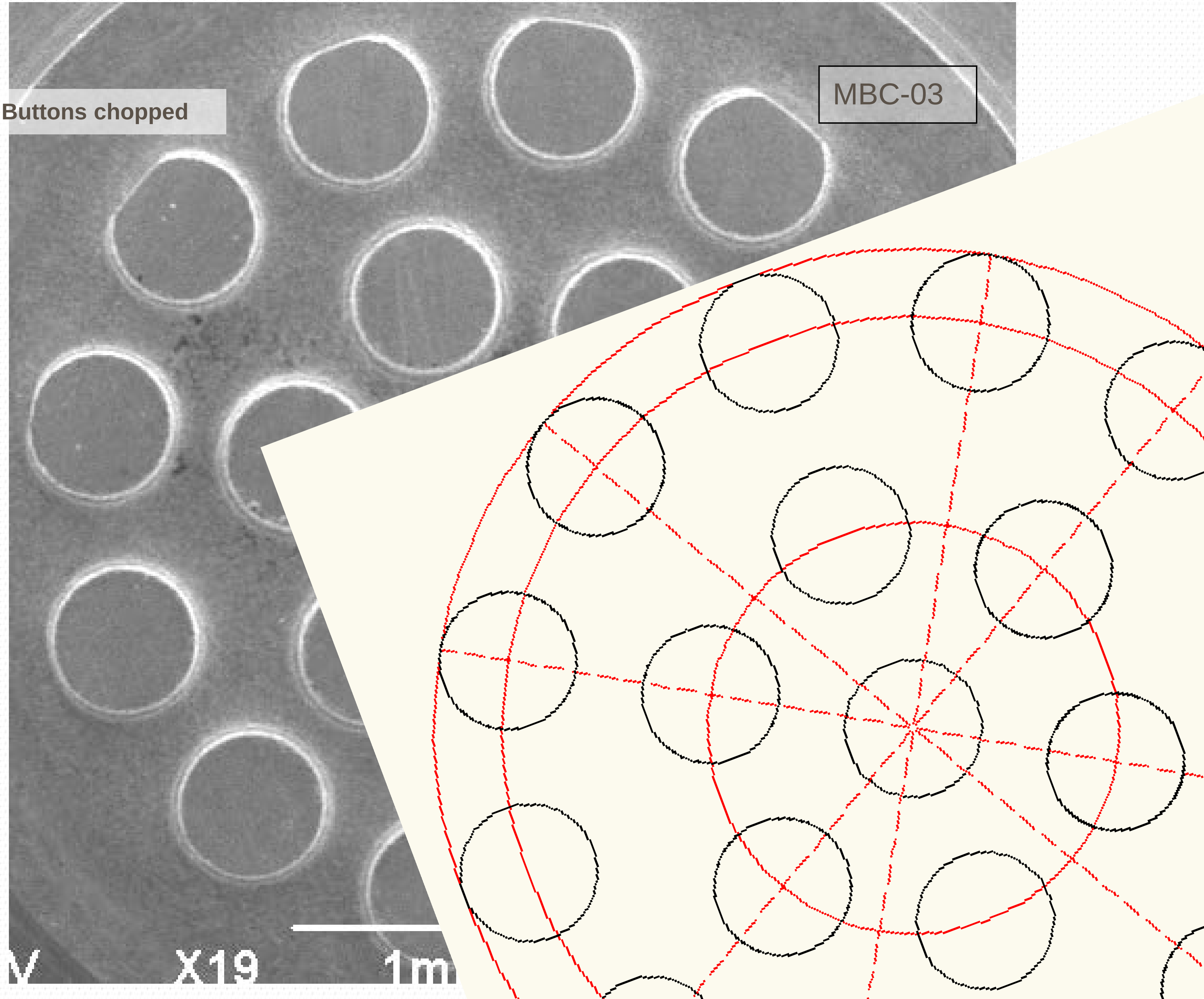


Photograph: Top view



3-D Solid model view

Edges of five Buttons chopped



Conclusions

- **Mixed matrix (MM)-cathode (out of W-Re nano-powder):**
  - Current density (J) > 10 A/cm^2 possible for several years
- **Alloy-film cathode (1W:2Re:2Os):**
  - **Life Tests indicate**: J > 50 A/cm^2 possible for several years of operation.
  - **Pulse emission Tests**: J about 12 times as compared to Type-B
  - **THEM studies indicate**: Narrow work function distribution (i.e. excellent uniformity having <0.05 eV against 0.14 eV of Type-B).
  - **Auger studies**:
    - Ba/W low and Ba/O more as compared to B-Type
    - W/Re/Os compositions stabilize to equal proportions after activation
  - **Application**:
    - Good candidates for MW tubes needing high beam currents
    - Highly suitable for Gyrotrons but demands good vacuum conditions
- **Nano-Scandate** (cathode made out of nano-technology):
  - Emission beyond 100 A/cm^2 possible (≈ 100 times B-Type)
  - Suitable for THz devices.

Future scope and Productionization of Cathodes

Future scope

- The demand for lower frequency range devices is expected to come down and the demands for higher frequency devices in THz region are expected to go higher . As the dimensions shrink at THz regions, the need for high current density cathodes shoots up.

- The candidates meeting the above needs are:
  (a) Alloy-film cathodes (φ = 1.75 eV): possessing high uniformity throughout the life which can deliver upto 50 A/cm^2 for more than 5 years.

  (b) Nano-scandate cathode (φ = 1.5 eV): possessing high uniformity throughout the life which can deliver beyon 100 A/cm^2 . Life test data under practical conditions are not available.

  There is great deal of work for the youngsters to work in this area.

Production of cathodes in India

- **A lot of developmental work was done in cathode area; however, we are still importing cathodes.**
- **Industries are to be contacted and to be funded as cathodes have strategic importance.**

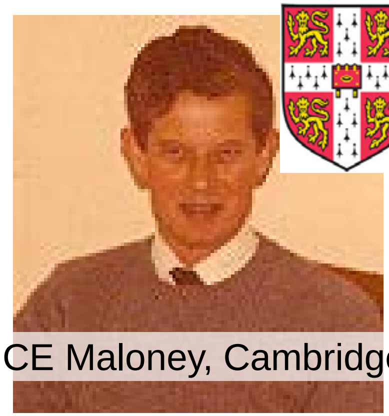
Thanks to all the participants for patient listening

I thank the following eminent personalities due to whom I could reach to this stage

Technologist & Visionary

Technologist & Big brother

Microwave Guru & Eminent personality of International repute

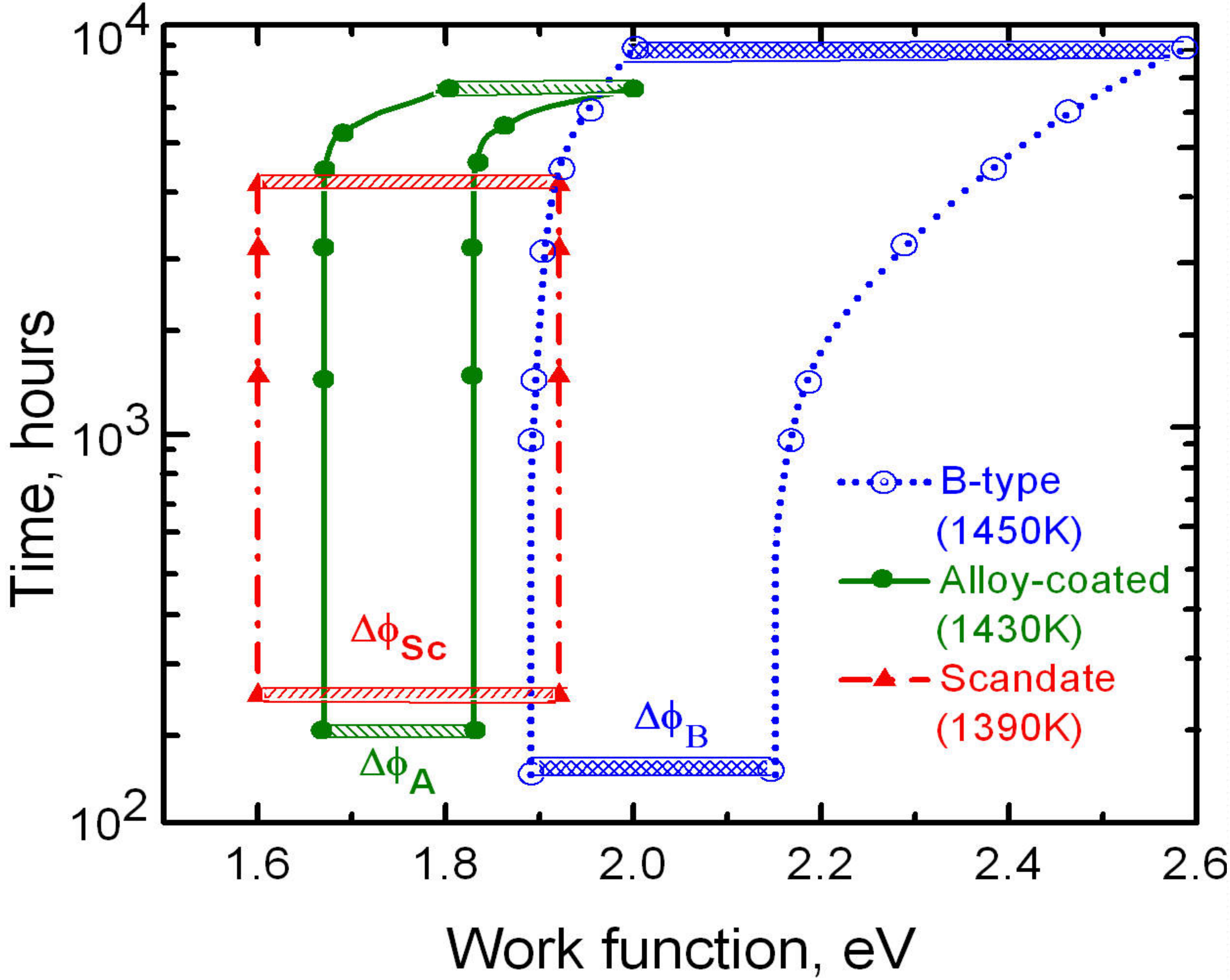


Dr CE Maloney, Cambridge

Scholar & Ph.D. Guide

Spare Slides

Change in emission, expressed in work function, with time of LTV's



Methods for preparation of Nano-scandate powder

Route-I (Nitrides Route) [Wang's approach]**:**
Nitrates of Ba, Ca, Al, Sc & Ammonium Metatungstate

Take:
Nitrates of Ba, Ca, Al & Sc
Ammonium Metatungstate
→ Make aqueous solution (De-ionized water and Citric acid)
→ Dry and Calcine
→ Reduce & make powder

Route-II (use of special solvents/ chelating agents) [CEERI's plans]:
Nitrates / carbonates of Ba, Ca, Al, Sc and W powder & special solvents

Take:
Nitrates / carbonates
Tungsten powder
→ Make aqueous solution (dissolve in special soln. and add Citric acid/ Oxalic acid
→ Dry and Calcine
→ Reduce & make powder

Route-III (carbonyl route) [CEERI's plans]:
Carbonyls/carbonates of Ba, Ca, Al, Sc & W and special solvents

Take:
Carbonyl compounds/ carbonates
→ Make aqueous solution (De-ionized water / organic solvent)
→ Centrifugation
→ Reduce & make powder

Various modules of THEM

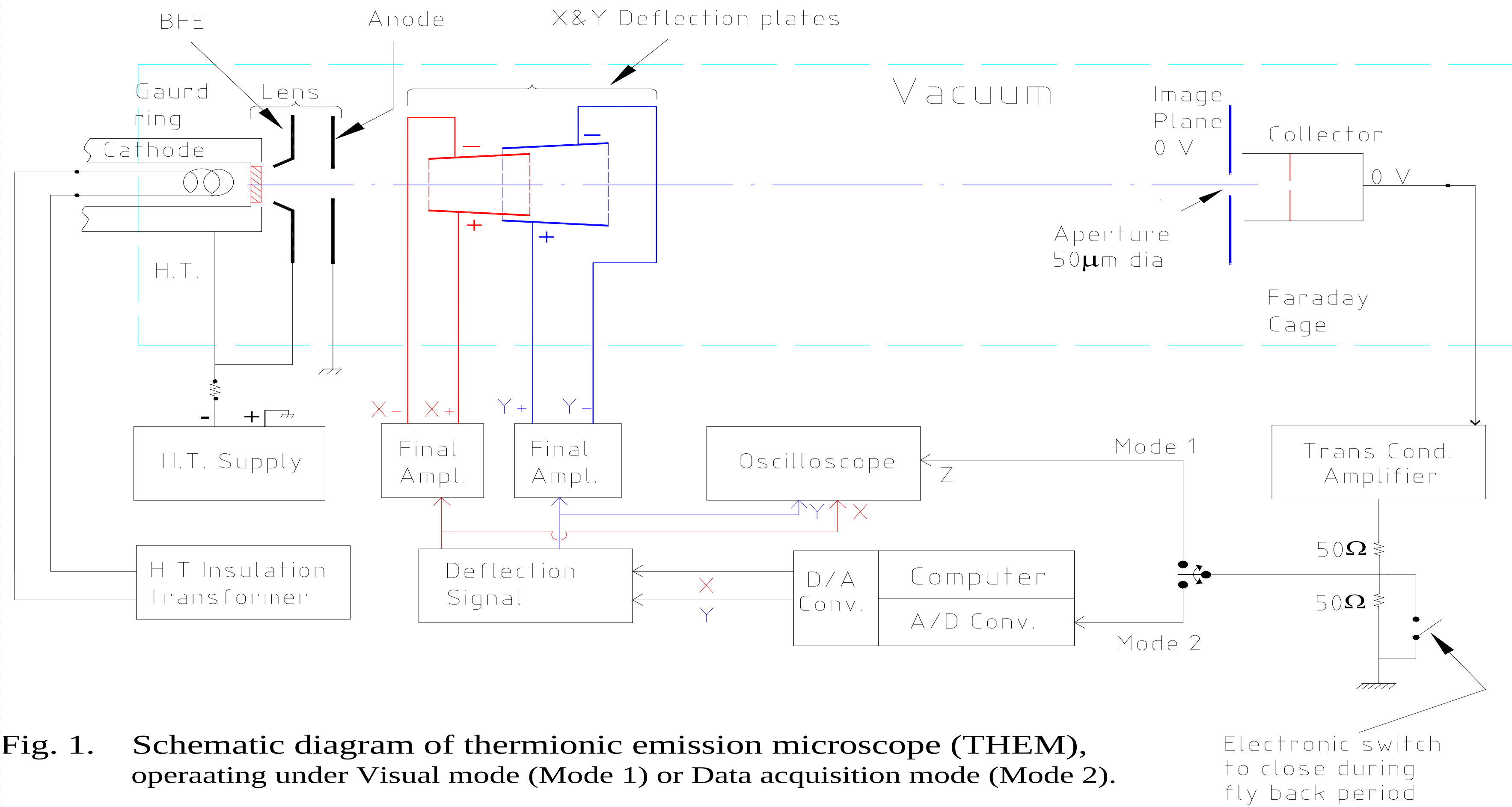
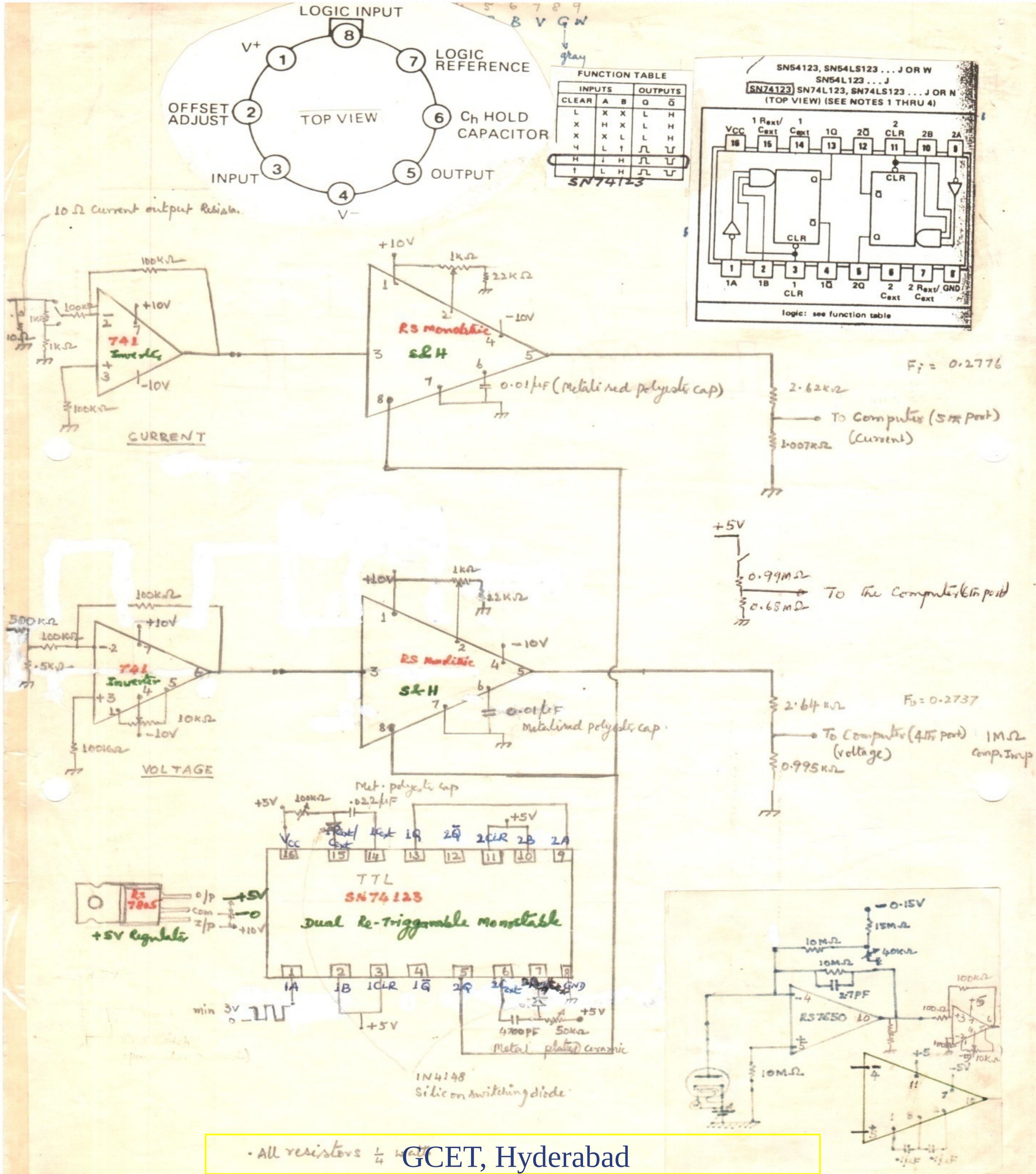


Fig. 1. Schematic diagram of thermionic emission microscope (THEM), operaating under Visual mode (Mode 1) or Data acquisition mode (Mode 2).

I-V data acquisition system



Annexure II:
Young Researcher's Talk-1 Slides

Sectoral Waveguide HPM Mode Converters

Presented By

Dr Vikram Kumar

Temporary Faculty
Department of Electronics & Communication Engineering
National Institute of Technology Patna

For VED Society
Date: 13 March 2021
https://meet.google.com/evz-jwow-xda

Outline

- **Introduction**
- **State of Art**
- **HPM TM_{01} to TE_{11} SWG Mode Converter**
- **Mode Matching Analysis SWG Mode Converter**
- **Conclusion & Scope of Future Work**

High Power Microwave System

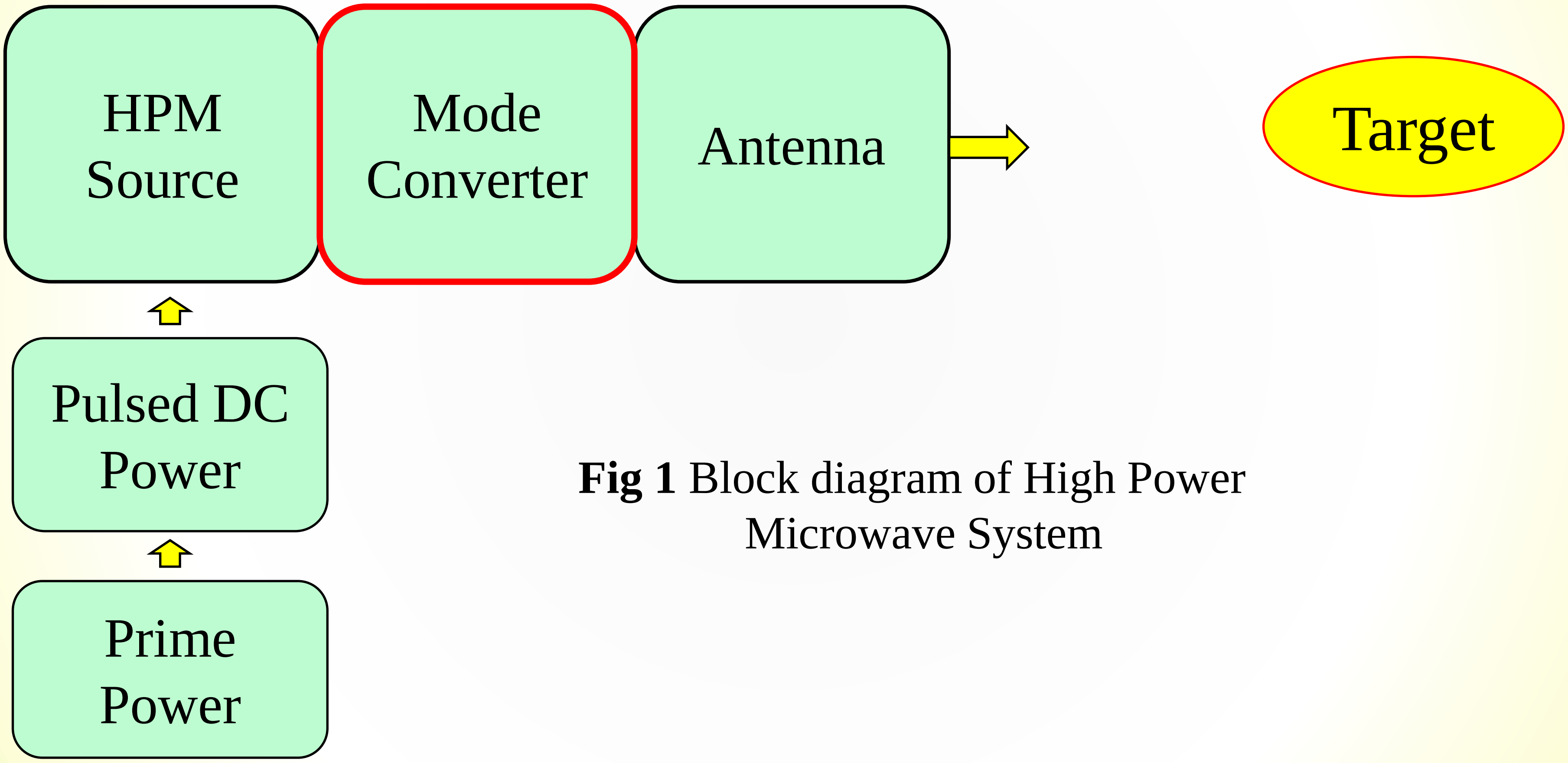


Fig 1 Block diagram of High Power Microwave System

Applications of the HPM system

- **HPM Weapons**: These weapons are known as E-bomb, used for disabling, jamming or upsetting electronic devices.
- **Space Beam Driven Rocket**: In place of solid or liquid fuel propulsion, researches are going on to achieve thrust from microwave radiation.
- **Solar Power Transmission through Space**: Using photovoltaic cells driven HPM system, microwave power will be beamed on the earth surface. Then by receiving this beamed power through space can be use as an alternative of power supply.
- **Radar capability enhancement** by using high power microwave.
- **Rebuilding the Ozone Layer** by HPM.

Modes Through The HPM Sources

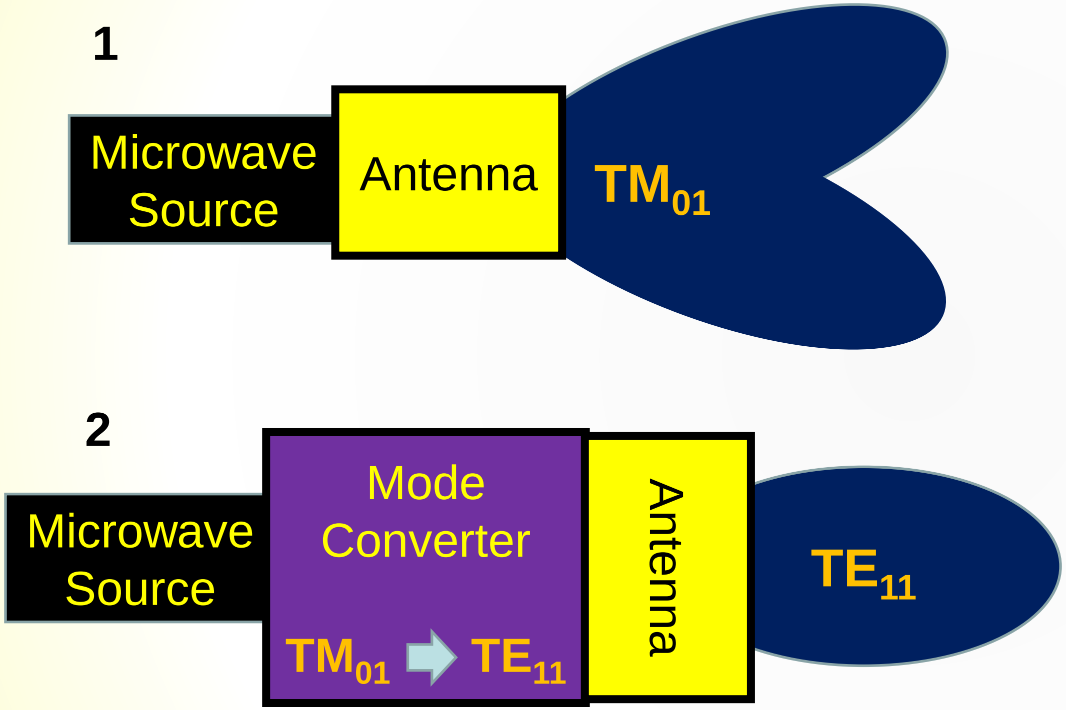
HPM Sources	Significant Modes Generated	Remarks
Magnetically Insulated Line Oscillator (MILO)	TEM or TM_{01}	Over the Beam Dump mode is TEM
Relativistic Backward wave Oscillator (RBWO)	TM_{01} and TM_{02}	To increase the BWO power, it is to designed for higher order modes TM_{0n} modes
Vircator	TM_{0n}	
Relativistic Klystron Amplifier (RKA)	TEM or TM_{01}	Due to coaxial extraction mode is TEM
Relativistic Magnetron	TM_{01} or TE_{11}	Depend upon extraction but efficiency is higher in TM_{01} generation

- ✓ Barker R.J. and Schamiloglu E., High Power Microwave Sources and Technologies, IEEE Press Series on RF and Microwave Technology, New York, 2001.
- ✓ Benford J., Swegle J.A. and Schamiloglu E., High Power Microwaves, Second Edition, CRC Press, Taylor & Francis Group, California, USA, 2007.
- ✓ Qin F., Xu S., Lei L.R., Ju B.Q., Wang D., A Compact Relativistic Magnetron With Lower Output Mode, *IEEE Transactions on Electron Devices;* 2019, v. 66(4), pp.1960 - 1964.

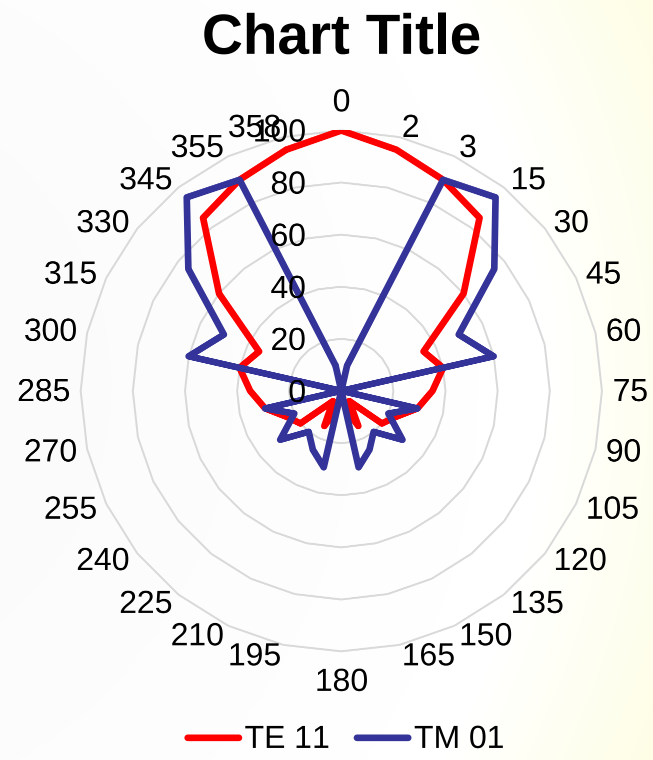
Mode Converter

- By using specific deformation in a waveguide, if the propagating mode is transformed to the required mode, then this deformed waveguide is known as Mode Converter.
- In early days of microwaves, it is called as Mode Transducer (Montgomery *et al.*1948).

Need of Mode Converter…



(a)



(b)

Fig 2 (a) Comparison of Microwave system and **(b)** Radiation pattern of TE_{11} and TM_{01}

Classification of Mode Converter

- In general there are three types of mode converter

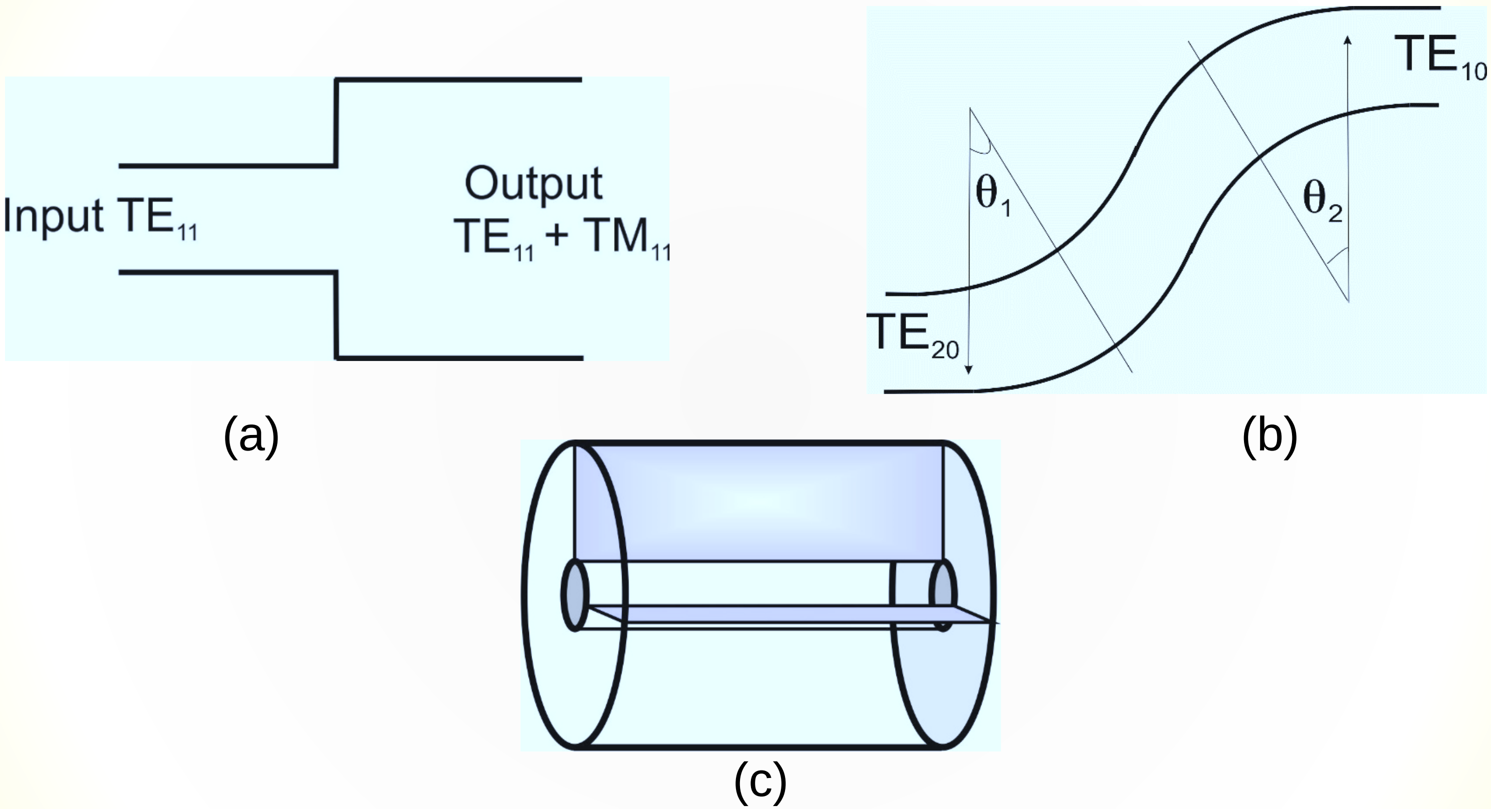


Fig 3 (a) Abrupt Discontinuity **(b)** Gradual Discontinuity
(c) Axial Discontinuity

(a) Abrupt Discontinuity

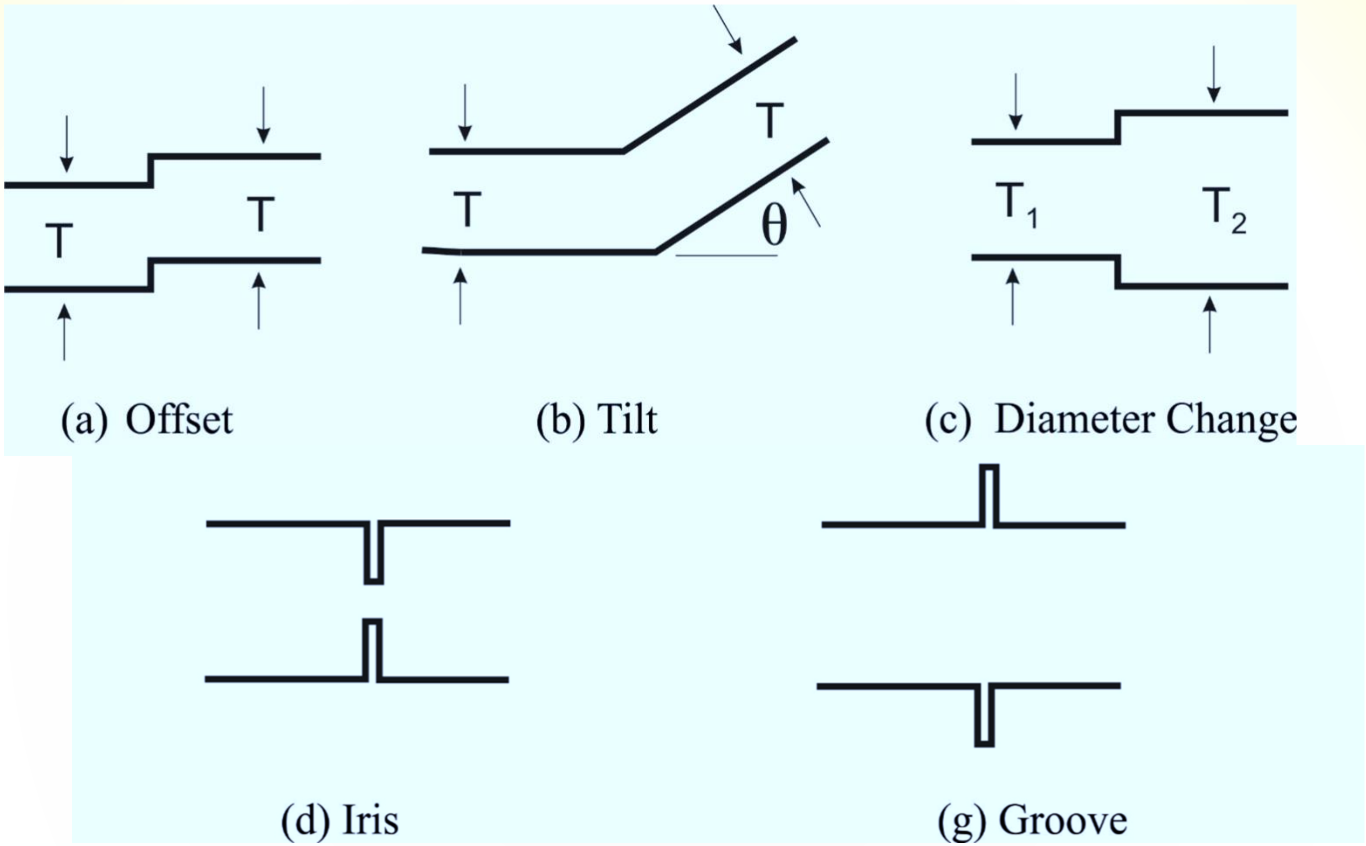


Fig 4 Abrupt Discontinuity (Okress 1968).

Change in cross sectional area like abrupt offset, tilt, diameter change, iris, and grove results in spurious signal. Waveguide interruption are known to induce coupling between modes.

(b) Gradual Discontinuity

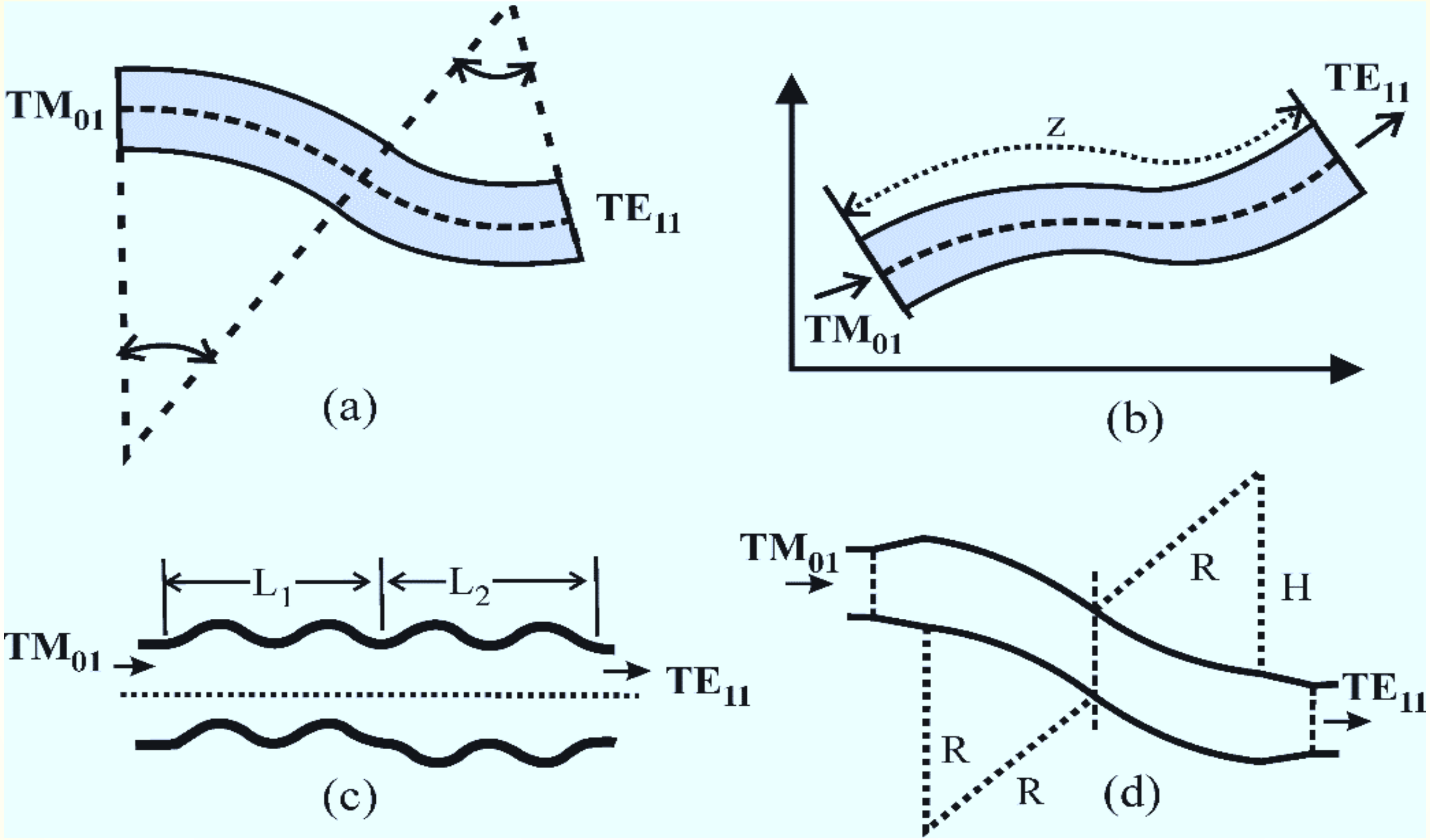


Fig 5 Gradual discontinuity; schematic mode converters of (a) Yang *et al.* (1995), (b) Ling and Zhou (2001), (c) Yang *et al.* (1997), (d) Lee *et al.* (2004).

(c) Axial Discontinuity

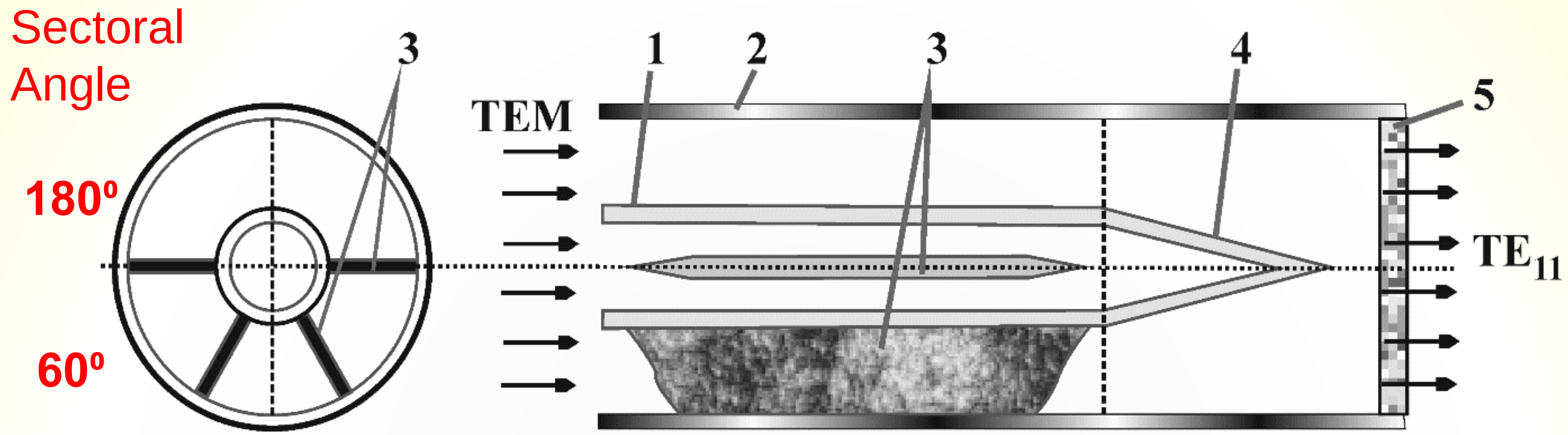


Fig 6 Schematic SWG mode converters by Somov *et al.* (1998)

1 - Inner conductor of the coaxial waveguide;
2 - The outer conductor of the coaxial waveguide;
3 - Longitudinal and radial diaphragm separating the waveguide into sectors;
4 - Conical aligner section of the radiator
5 - Dielectric window for the emission output.

- **Mode converter is divided in one 180⁰ sector and three 60º sectors.**
- **First sectoral waveguide mode converter reported scientific journal.**
- **With Magnetically insulated line oscillator (MILO) as a source device.**

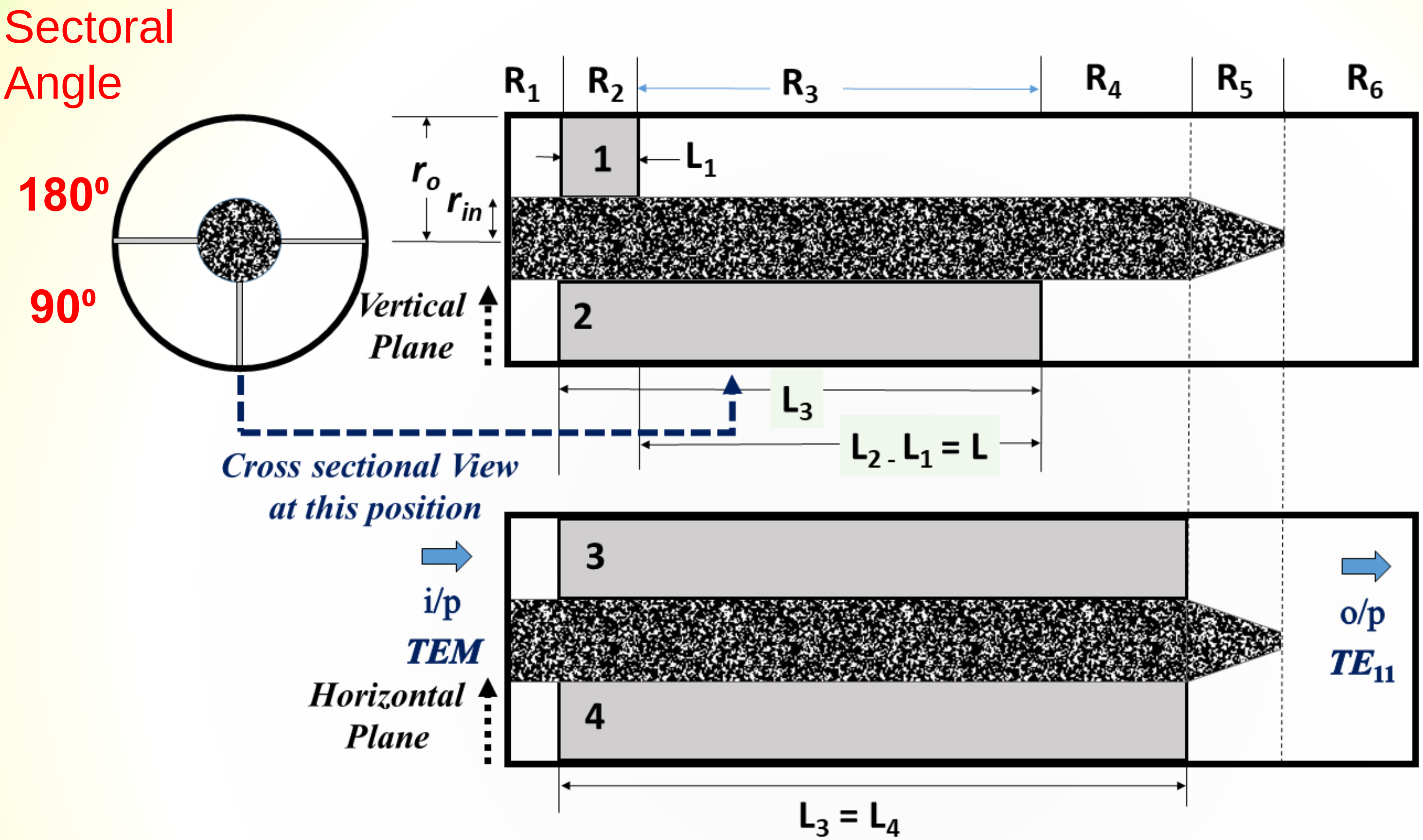


Fig 7 Structure of the novel mode converter reported by Yuan *et al.* (2005). Left: Axial view of SWG mode converter in vertical plane and horizontal plane, Right: front view displaying four SWGs.

So what is Sectoral Waveguide (SWG)?

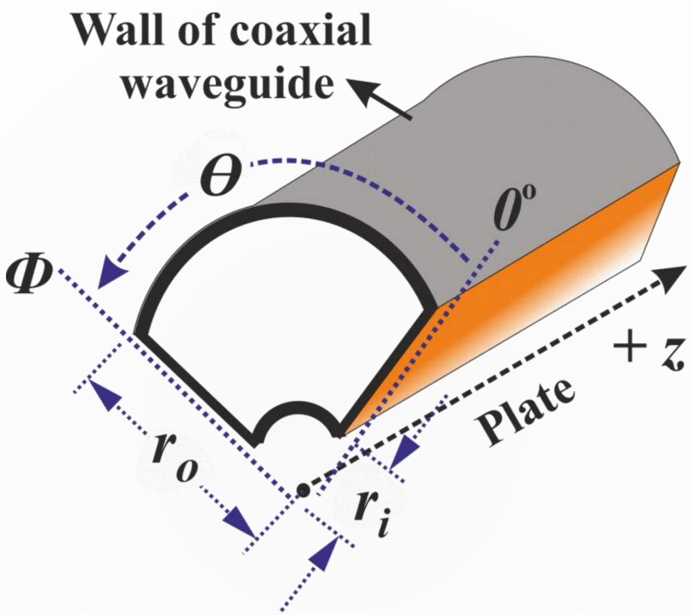


Fig 8 Sectoral waveguide

- An SWG consists of a sector formed by partitioning a coaxial waveguide with conducting metallic plates.

SWG Mode converter

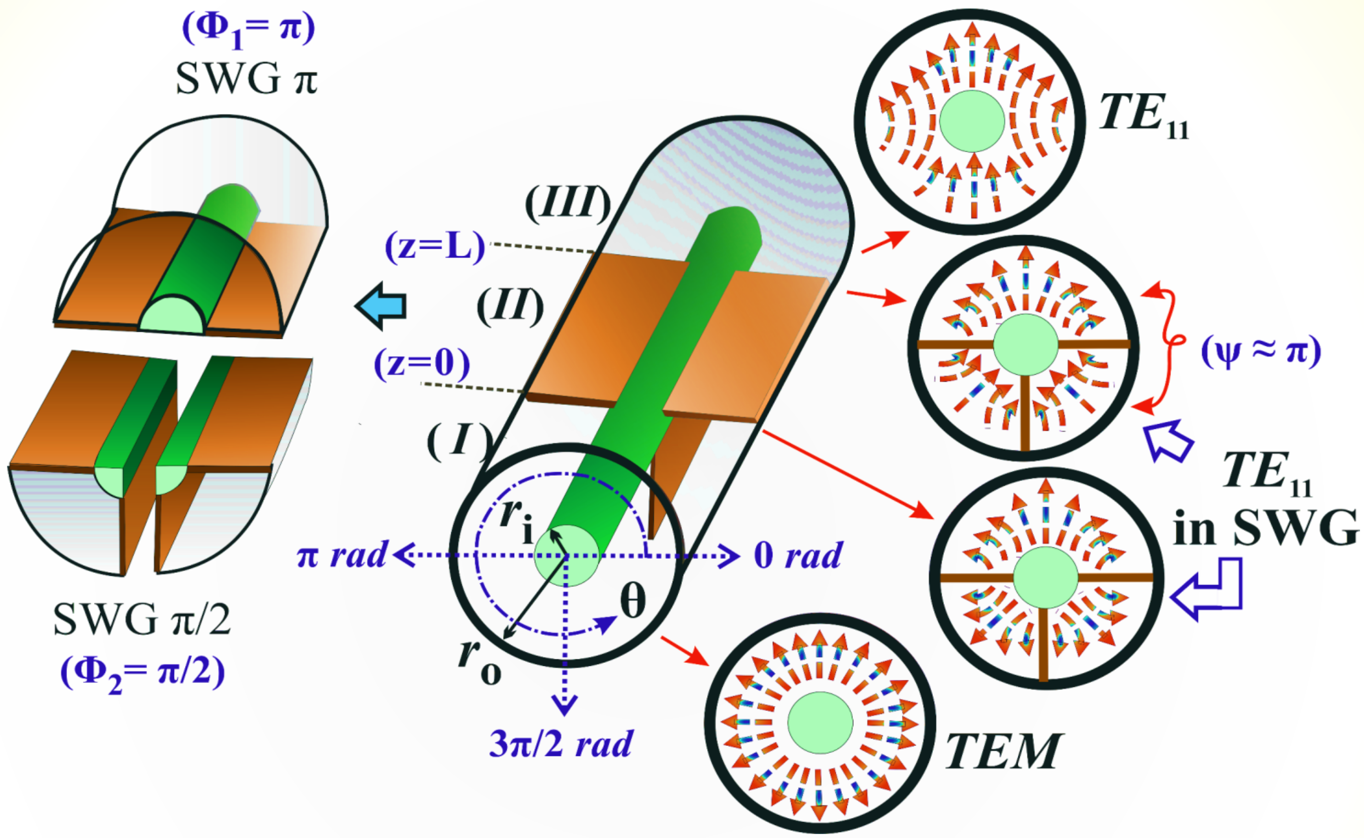


Fig 9 The typical model of SWG Mode Converter (*TEM* to TE_{11}) has been shown in the centre. In the right-hand side, the mode pattern has been shown, according to the axial positions in the mode converter, keeping upper half semi-circle field vector maximum outward. The left-hand side of the figure shows the separation of the coaxial waveguide to SWGs.

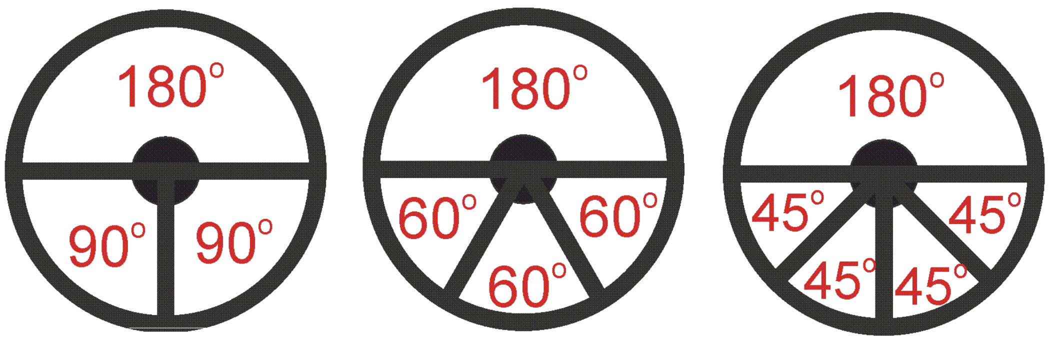


Fig 10 Cross sectional view of different combination of SWGs to form mode converter.

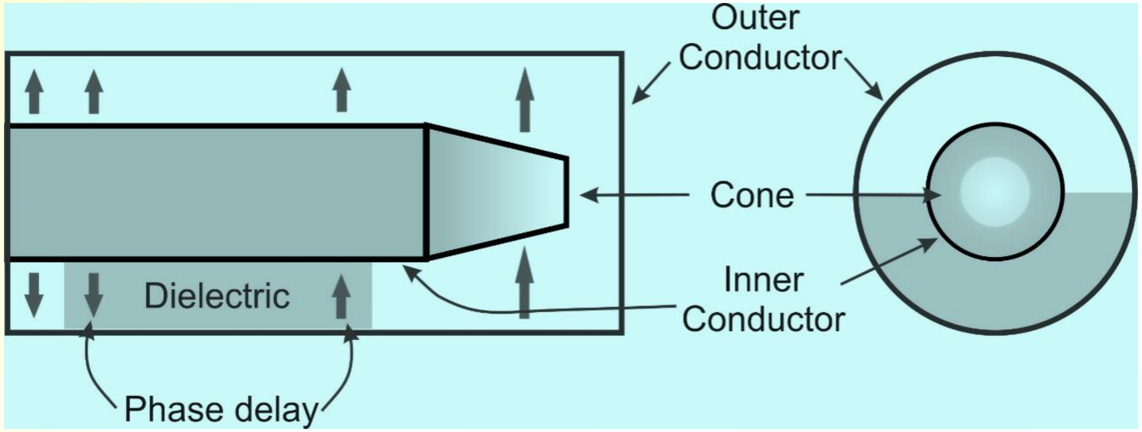
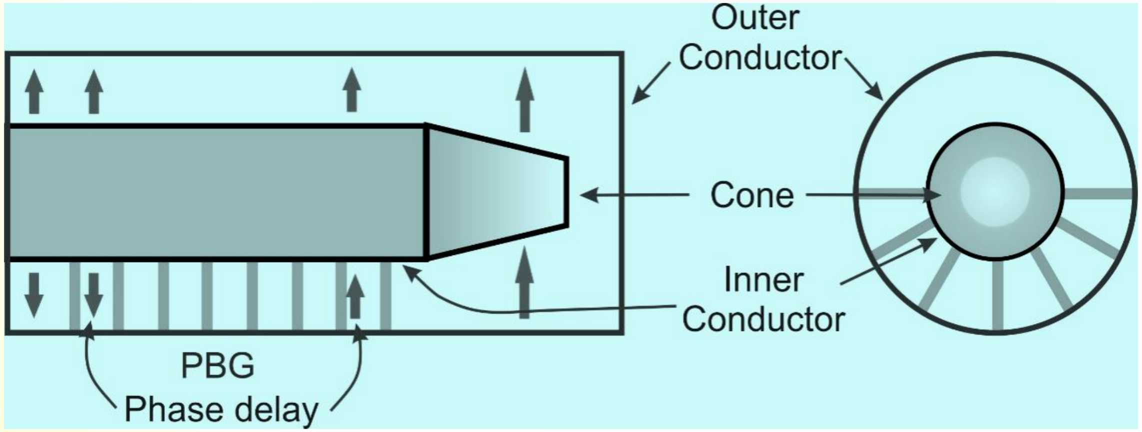


Fig 11 (a) Dielectric loaded SWG mode converters design, by Chittora *et al.* (2015).



(b) Metallic photonic loaded SWG mode converters design, by Wang *et al.* (2015).

Folded SWG Mode Converter

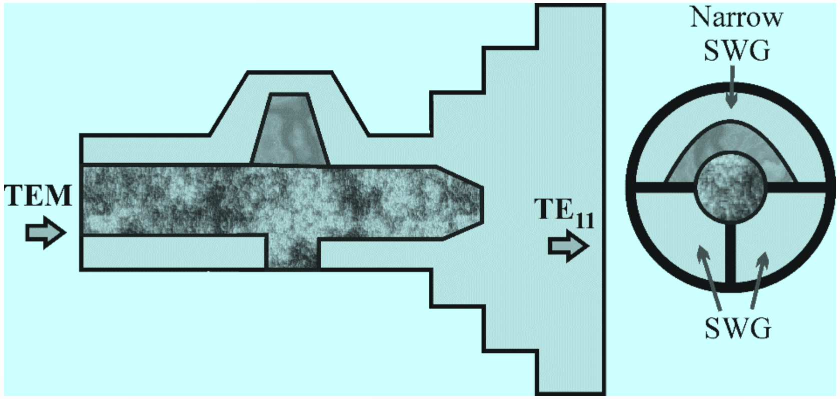


Fig 12 Schematic of tapered delay SWG mode converters by Wang *et al*. (2013)

By changing the radius of upper two SWG $_{\pi/2}$, while keeping two lower SWG as it is, the π phase delay is achieved. This results in the mode conversion of *TEM* to TE_{11} mode.

HPM TM_{01} to TE_{11} SWG Mode Converter

*Part of this work has been published as:

- ✓ Kumar V., Dwivedi S. and Jain P.K., "Experimental Investigation and Design of Sectoral Waveguide TM01 to TE11 Mode Converter," Journal of Microwave Power and Electromagnetic Energy, Vol. 53, Page 276-295, 2019.
- ✓ V. Kumar, S. Dwivedi, P. K. Jain, "Mode Matching Analysis for Characterisation of the SWG Mode Converters", Microwave and Optical Technology Letters, Vol. 61, Page 2619-2627, 2019.

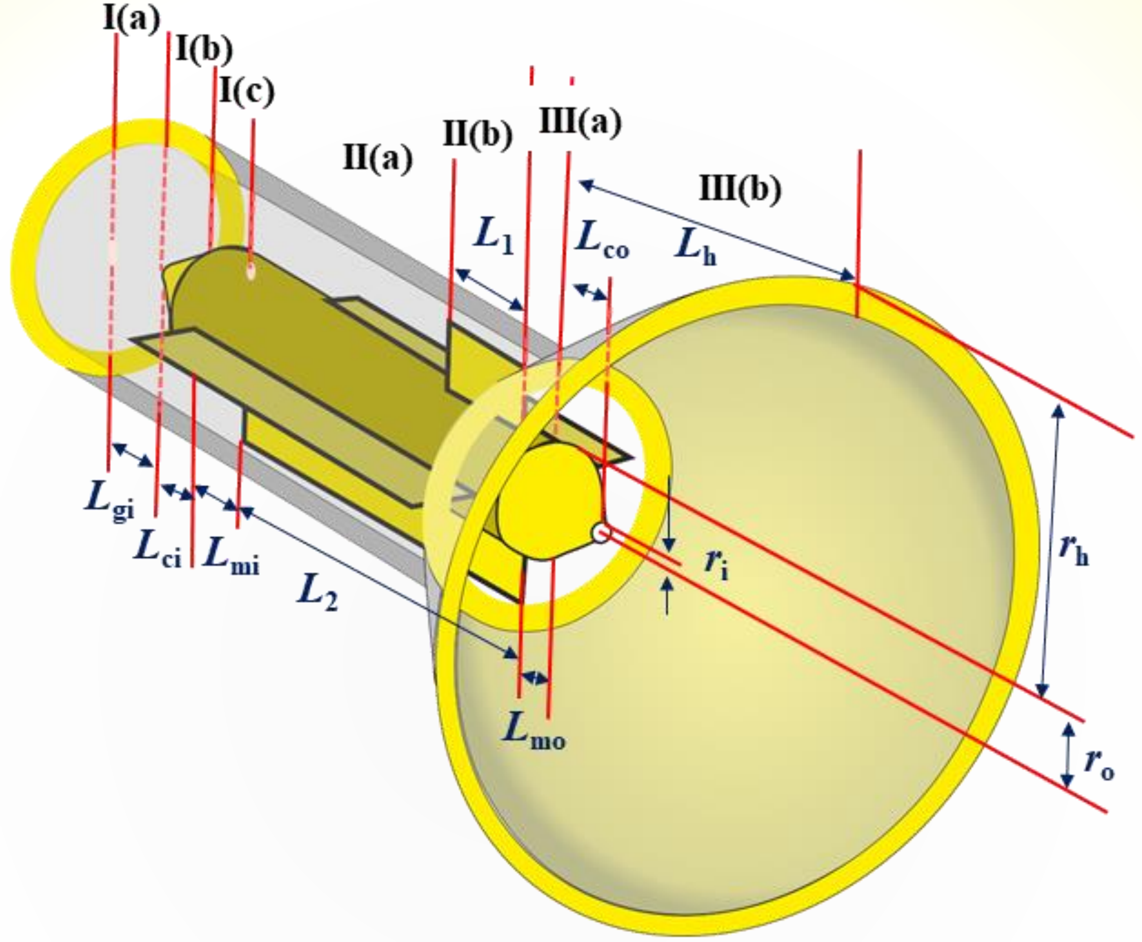


Fig 13 Design SWG mode converter TM_{01} to TE_{11}.

SWG length relation with propagation constant:

$$(L_2 - L_1) = \pi / (\beta_1 - \beta_2)$$

Developed design

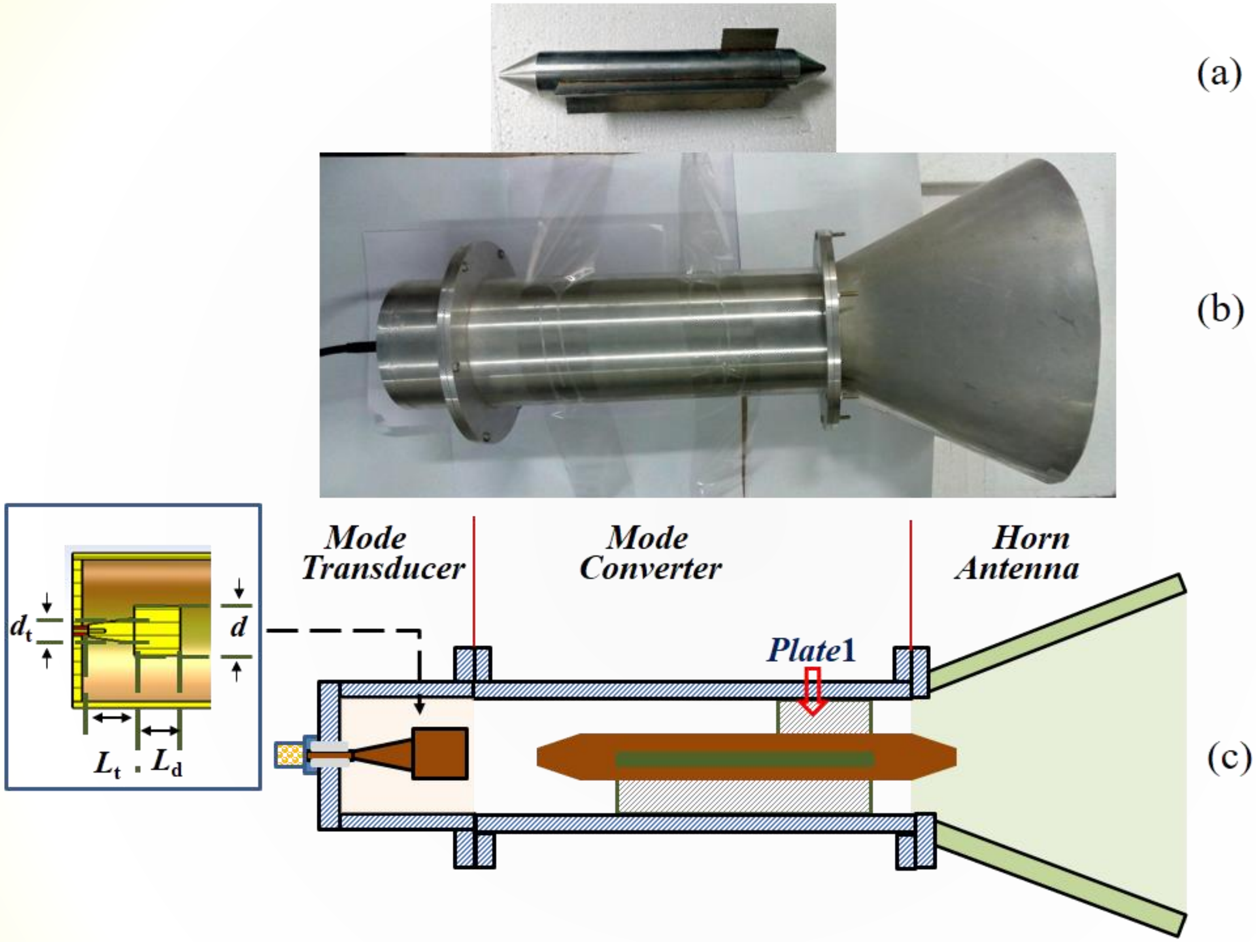
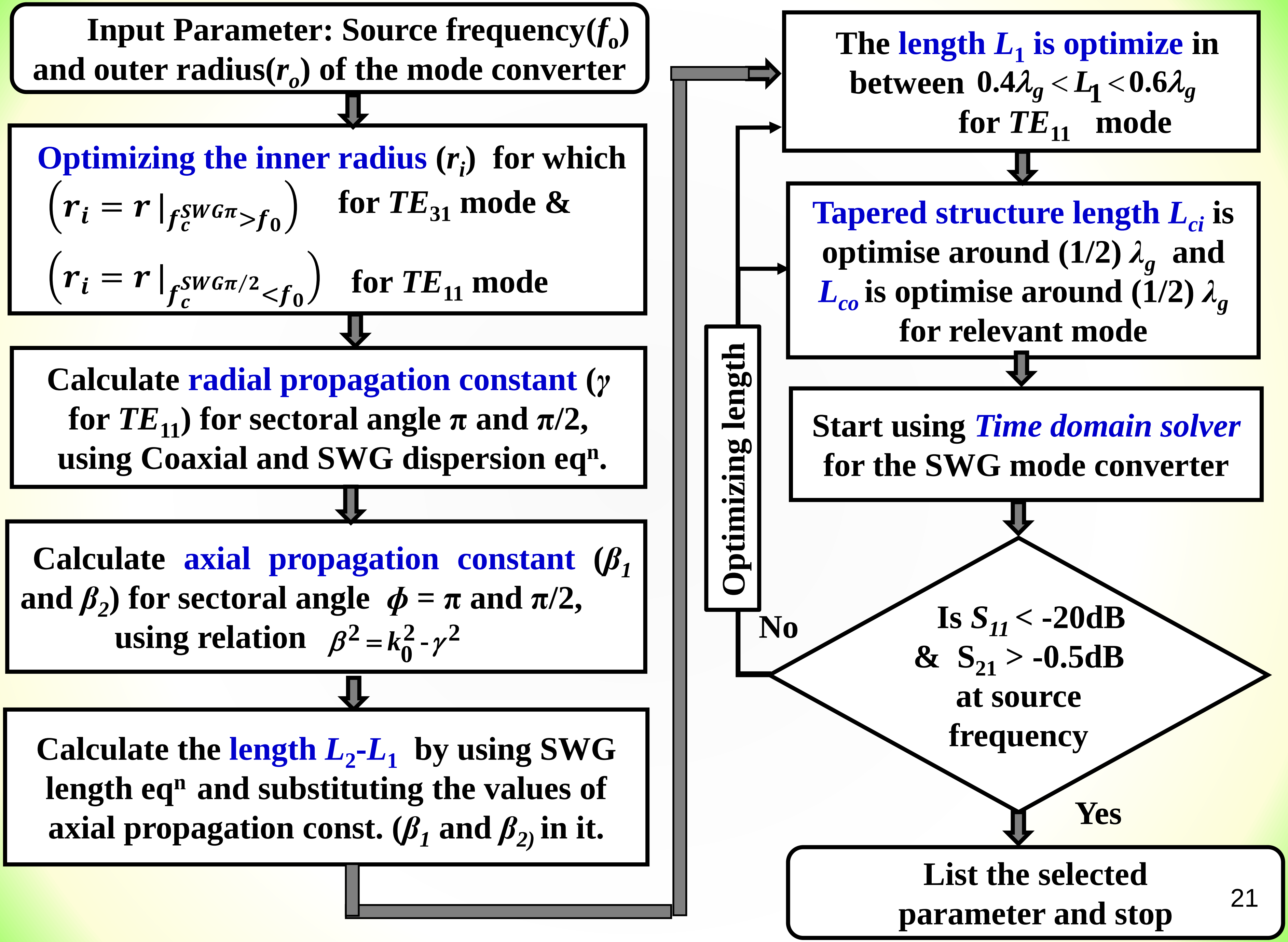
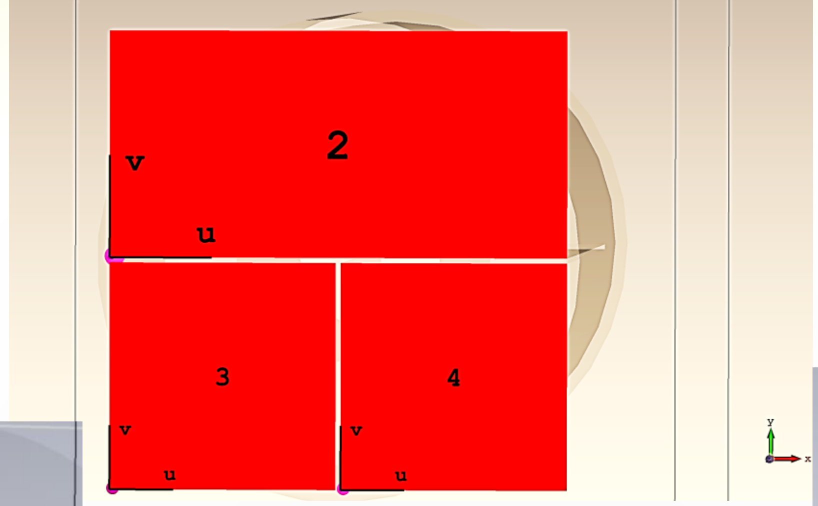
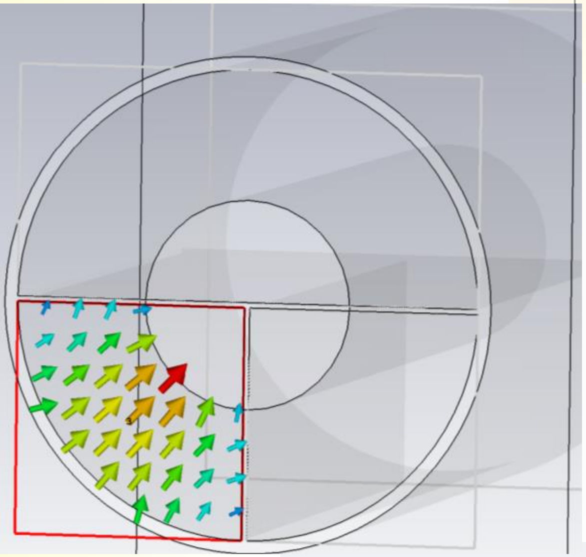
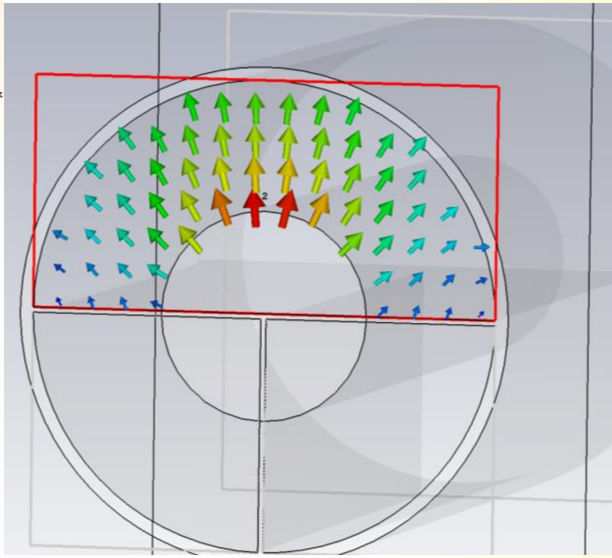


Fig 14 Typical model **(a)** Photograph of metallic plates fused with the inner conductor, **(b)** complete fabricated structure with a mode transducer and a conical horn antenna **(c)** Simulated design of TM_{01} to TE_{11} SWG mode converter.


Input Parameter: Source frequency(f_o) and outer radius(r_o) of the mode converter
Optimizing the inner radius (r_i) for which
$\left(r_i = r\,|_{f_c^{SWG\pi} > f_0}\right)$ for TE_{31} mode &
$\left(r_i = r\,|_{f_c^{SWG\pi/2} < f_0}\right)$ for TE_{11} mode
Calculate radial propagation constant (γ for TE_{11}) for sectoral angle π and π/2, using Coaxial and SWG dispersion eq^n.
Calculate axial propagation constant (β_1 and β_2) for sectoral angle $\phi = \pi$ and π/2, using relation $\beta^2 = k_0^2 - \gamma^2$
Calculate the length L_2-L_1 by using SWG length eq^n and substituting the values of axial propagation const. (β_1 and $\beta_{2)}$ in it.
The length L_1 is optimize in between $0.4\lambda_g < L_1 < 0.6\lambda_g$ for TE_{11} mode
Tapered structure length L_{ci} is optimise around (1/2) λ_g and L_{co} is optimise around (1/2) λ_g for relevant mode
Start using Time domain solver for the SWG mode converter
Is S_{11} < -20dB & S_{21} > -0.5dB at source frequency
No
Optimizing length
Yes
List the selected parameter and stop







Beeta (β)

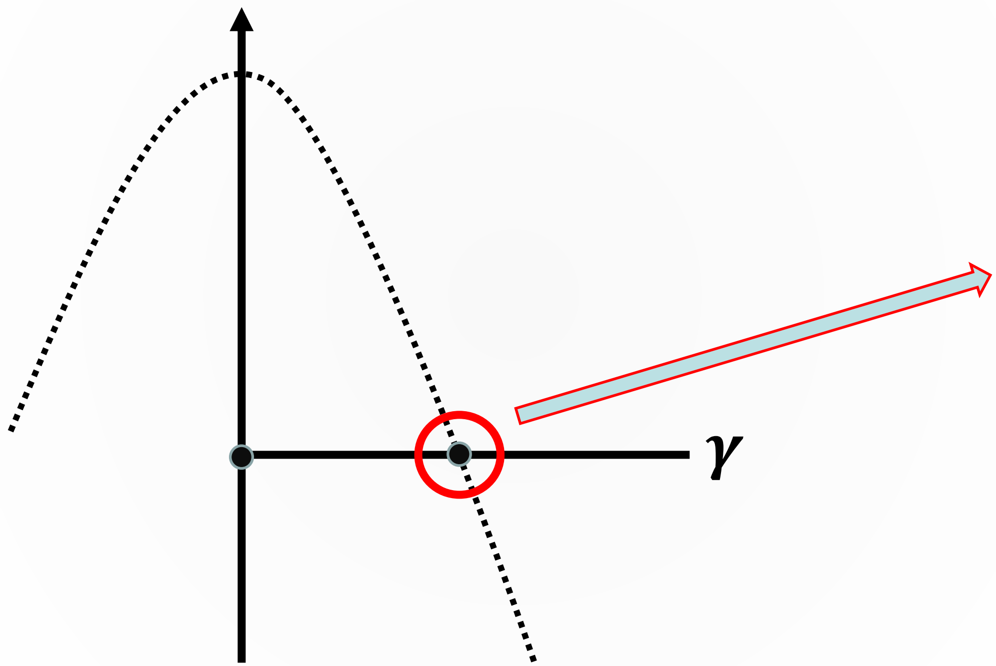
Fig 15(a) CST port selection

Port3_e1 (peak)	
Frequency:	1.9
Phase:	0
Wave Imp. [Ohms]:	611.6
Beta [1/m]:	24.53
Fcutoff:	1.497
Accuracy:	4.302e-14
Mode type:	TE
Maximum:	622.4
Plane at z	275.9

Port2_e1 (peak)	
Frequency:	1.9
Phase:	0
Wave Imp. [Ohms]:	410.6
Beta [1/m]:	36.54
Fcutoff:	0.7557
Accuracy:	4.405e-10
Mode type:	TE
Maximum:	415.7
Plane at z	275.9

Dispersion Relation

$$J'_{(p\pi/\phi)}\{\gamma r_o\}\, Y'_{(p\pi/\phi)}\{\gamma\, r_i\} - J'_{(p\pi/\phi)}\{\gamma\, r_i\}\, Y'_{(p\pi/\phi)}\{\gamma r_o\} = 0$$



Change in sign

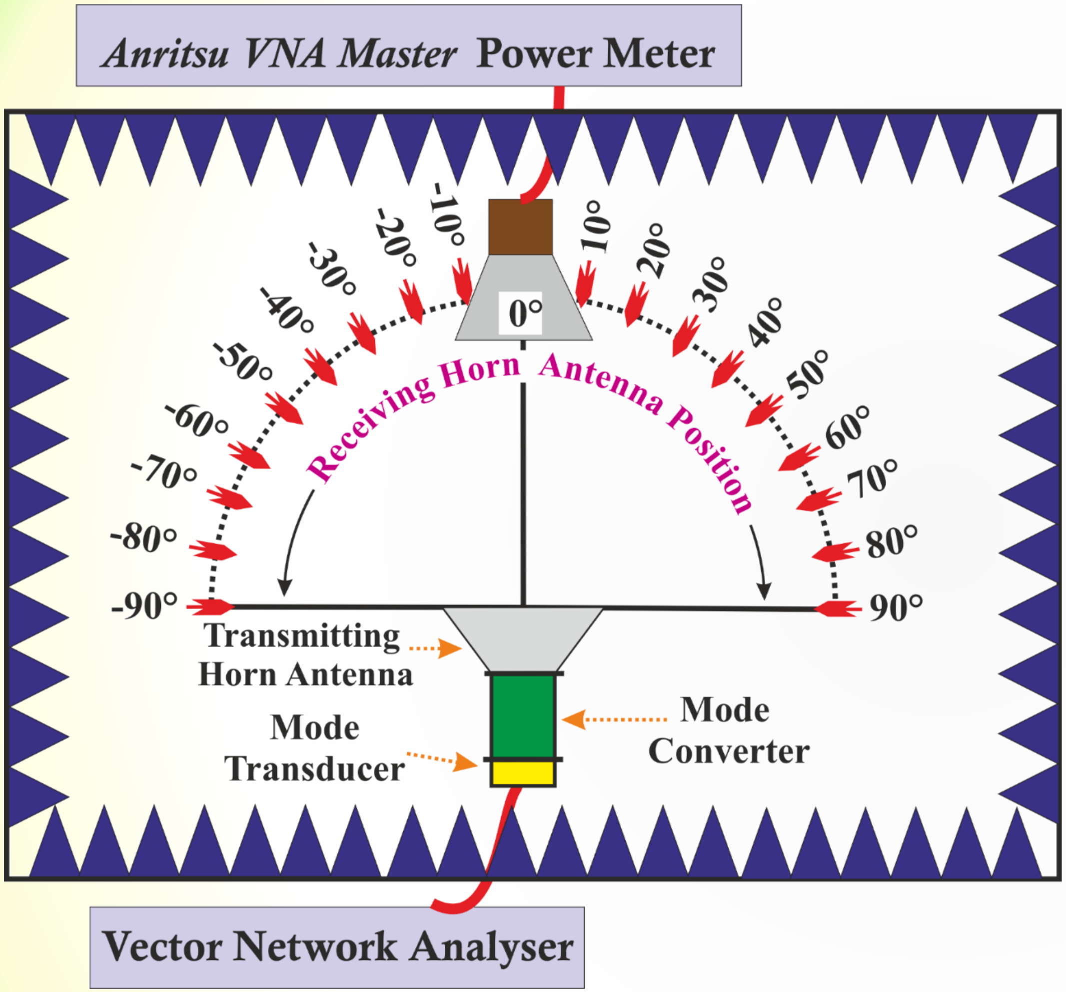
if S ~= S_initial
on. = sm. ;
break

Sm. Some thing
On. One thing

Fig 15(b) Role of dispersion relation in finding axial propagation constant (β)

$\gamma\,(=[k_0^2 - \beta^2]^{1/2})$ is the radial propagation constant

Radiation Pattern Measurement



- In the experiment, a Vector Network Analyser (VNA) is connected to a mode transducer and is supplying RF-power for a frequency 3 GHz in TM_{01} mode.
- A reflection coefficient (S_{11}) has calculated using this VNA.
- Mode transducer is connected with SWG mode converter and followed by a conical horn antenna, where they are converting and radiating electromagnetic wave in TE_{11} mode.

Fig 16 Schematic diagram of measurement of radiation pattern and identifying radiated mode by varying the azimuthal position of receiving antenna.

Experimental Setup

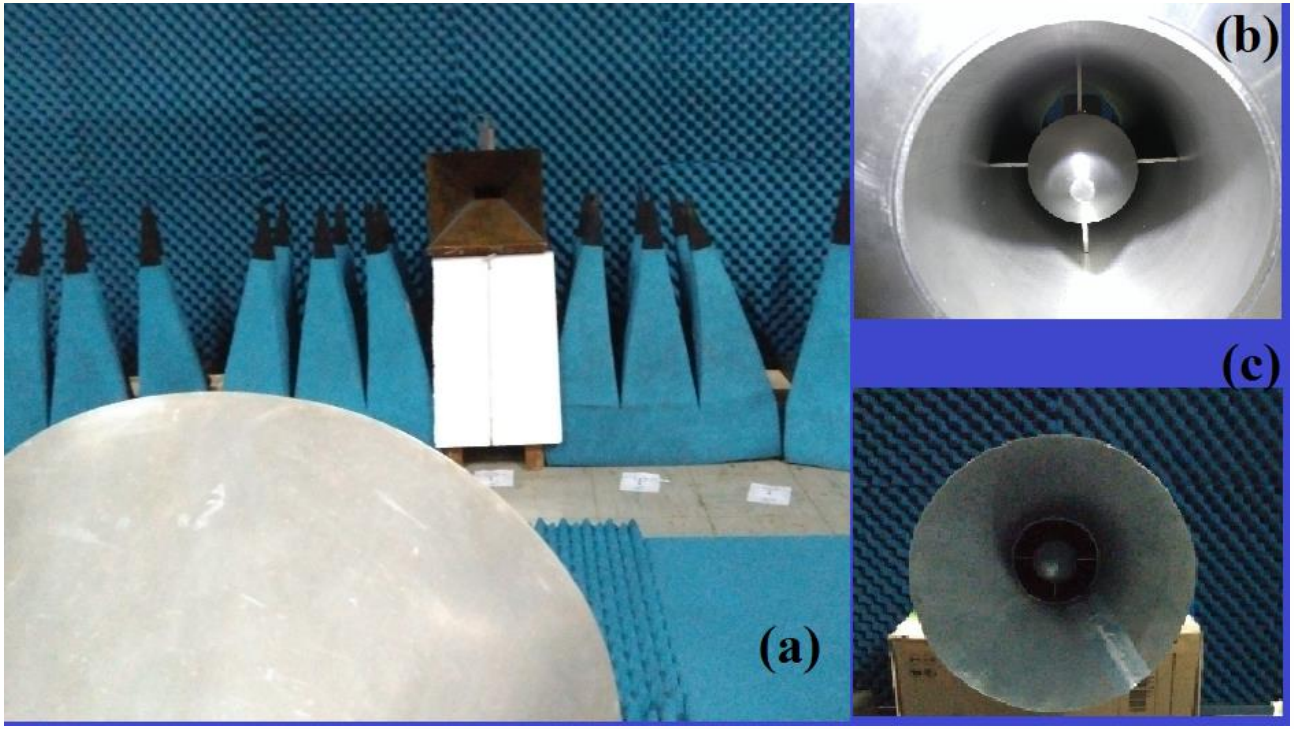


Fig 17 Snapshot of the experimental setup in a semi-anechoic chamber.

(a) Mode converter is at transmitting side, while an S-band standard horn antenna is at receiving side connected with a power meter,

(b) Tapered section and sectoral plates in SWG mode converter,

(c) Tapered section and conical horn antenna at transmitting side.

- At input end of Region *II(b)*, these electric field lines of SWG_{π} are in the same direction as the previous, while for $SWG_{\pi/2}$ field lines have the opposite orientation.
- The field lines of four $SWG_{\pi/2}$ combine at the output end of Region *II(b)* and constitute TE_{11} mode over the coaxial waveguide.

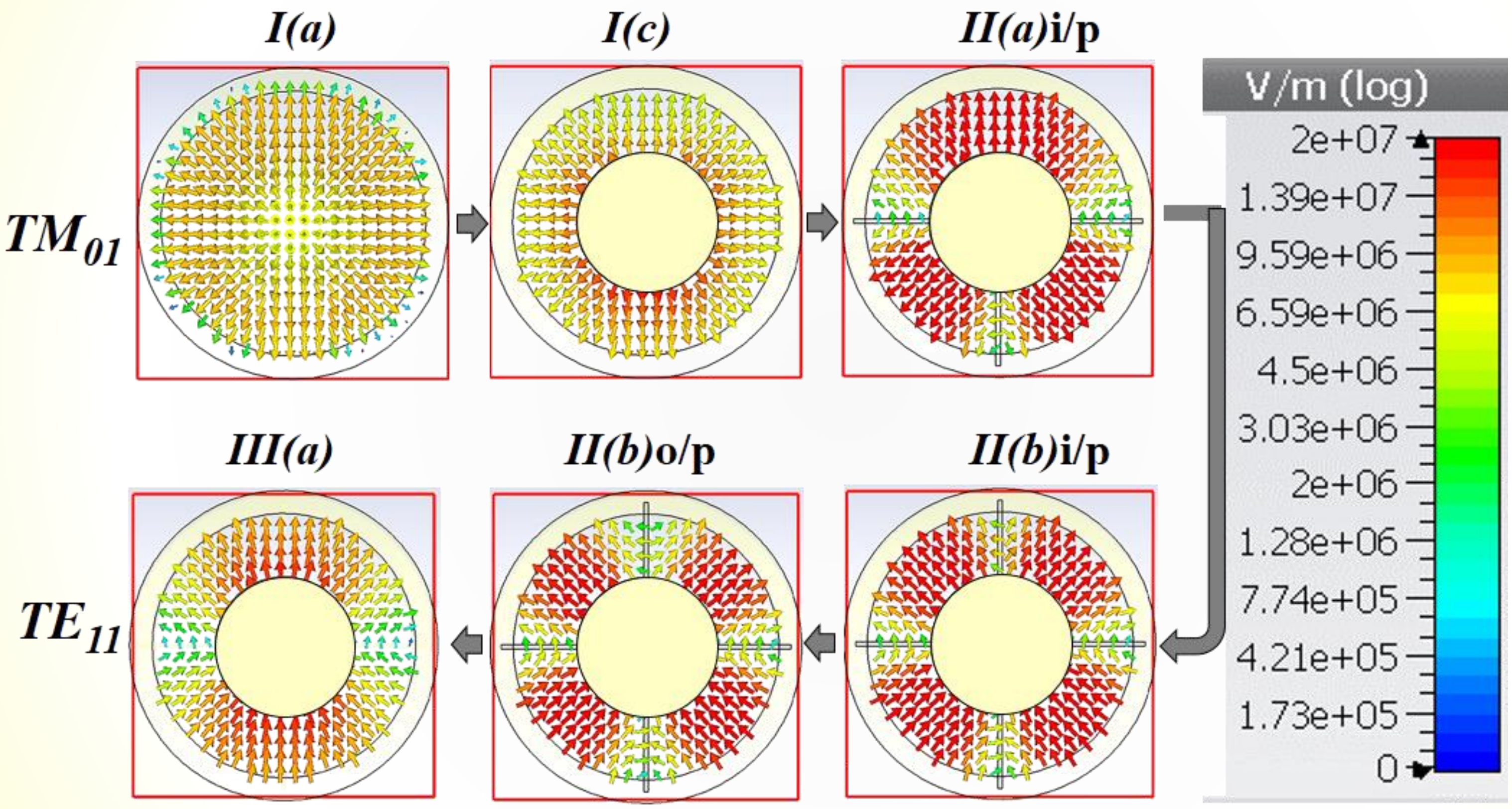
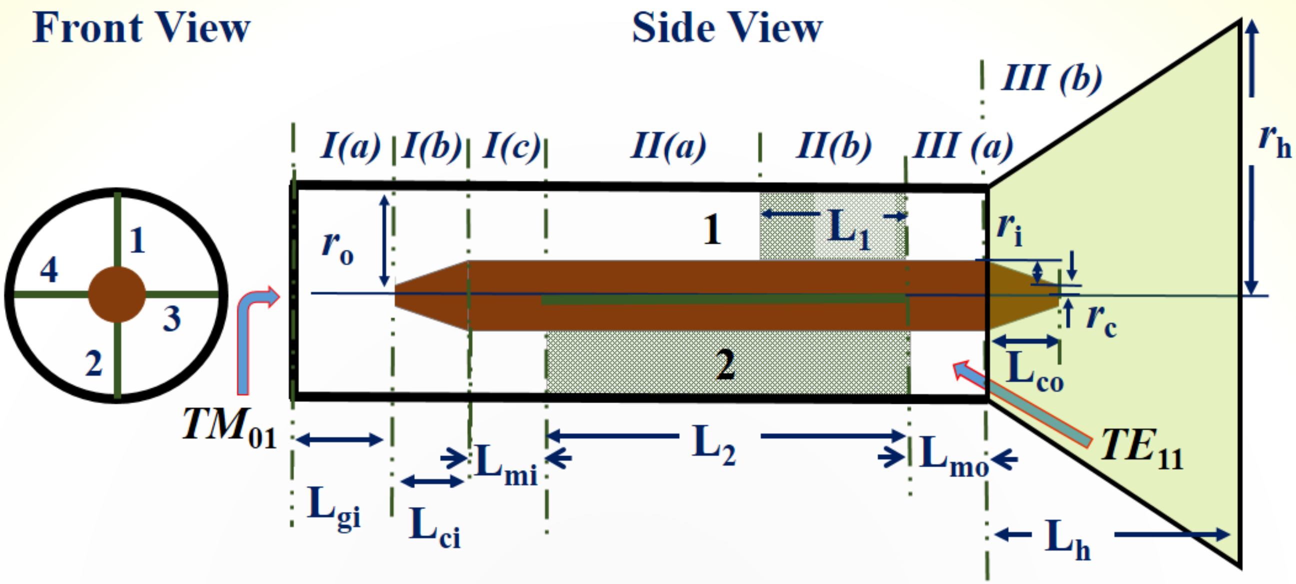
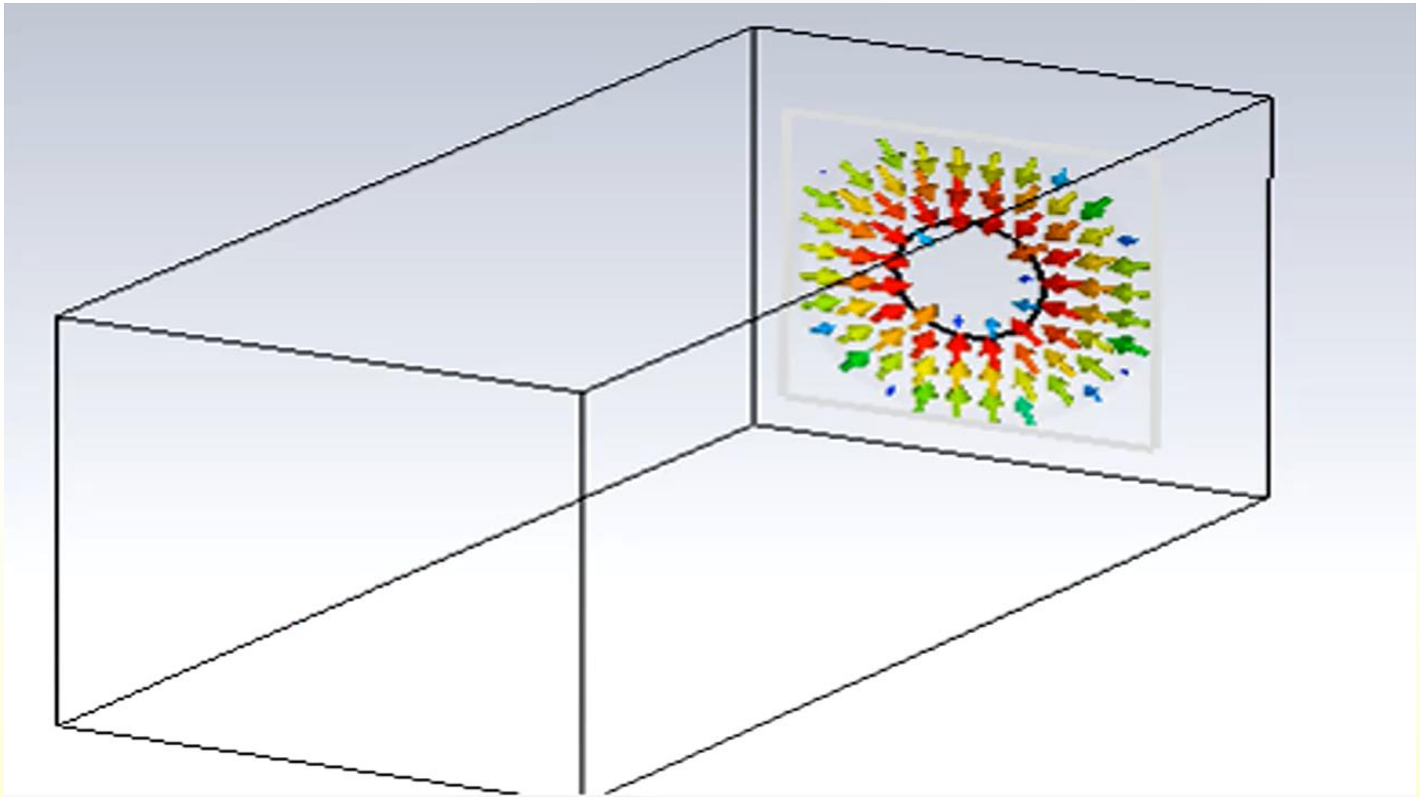


Fig 18 The procedure of mode conversion in SWG mode converter using *E* field monitors placed at different azimuthal positions in simulated design.


Front View
Side View
III (b)
I(a)
I(b)
I(c)
II(a)
II(b)
III (a)
r_h
1
4
3
2
r_o
1
L_1
r_i
r_c
2
L_{co}
TM_{01}
TE_{11}
L_2
L_{mi}
L_{mo}
L_{gi}
L_{ci}
L_h



- Due to the orthogonal orientation of TE_{21} likeness mode, they could not combine to excite TE_{21} mode over the Region *III*.
- Two neighbouring $SWG_{\pi/2}$ having the same electric field orientation, cancels the generation of TE_{21} mode in the coaxial waveguide and transfers its power in TE_{11} mode.

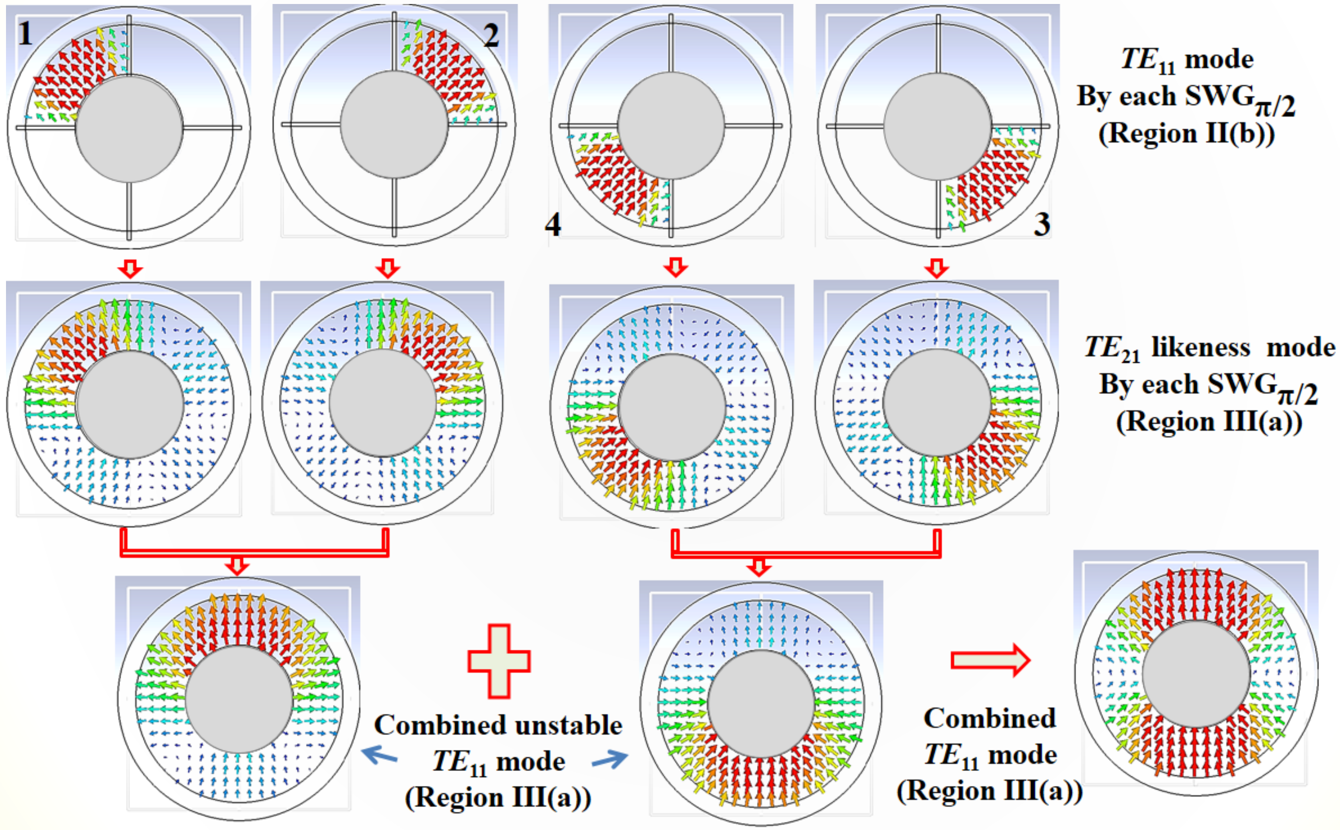


Fig 20 Combining electric fields through all $SWG_{\pi/2}$ (of Region *II(b)*) in the coaxial waveguide (of Region *III(a)*), and showing the advantage of using *Plate1* in the SWG mode converter.

RF Beam Stability

- The position of *Plate1* provides beam stabilization, where electric fields in the horn antenna are coming out with peak power stable along the axis of propagation.
- This ensures the operation of SWG mode converter to convert TM_{01} to TE_{11} mode.

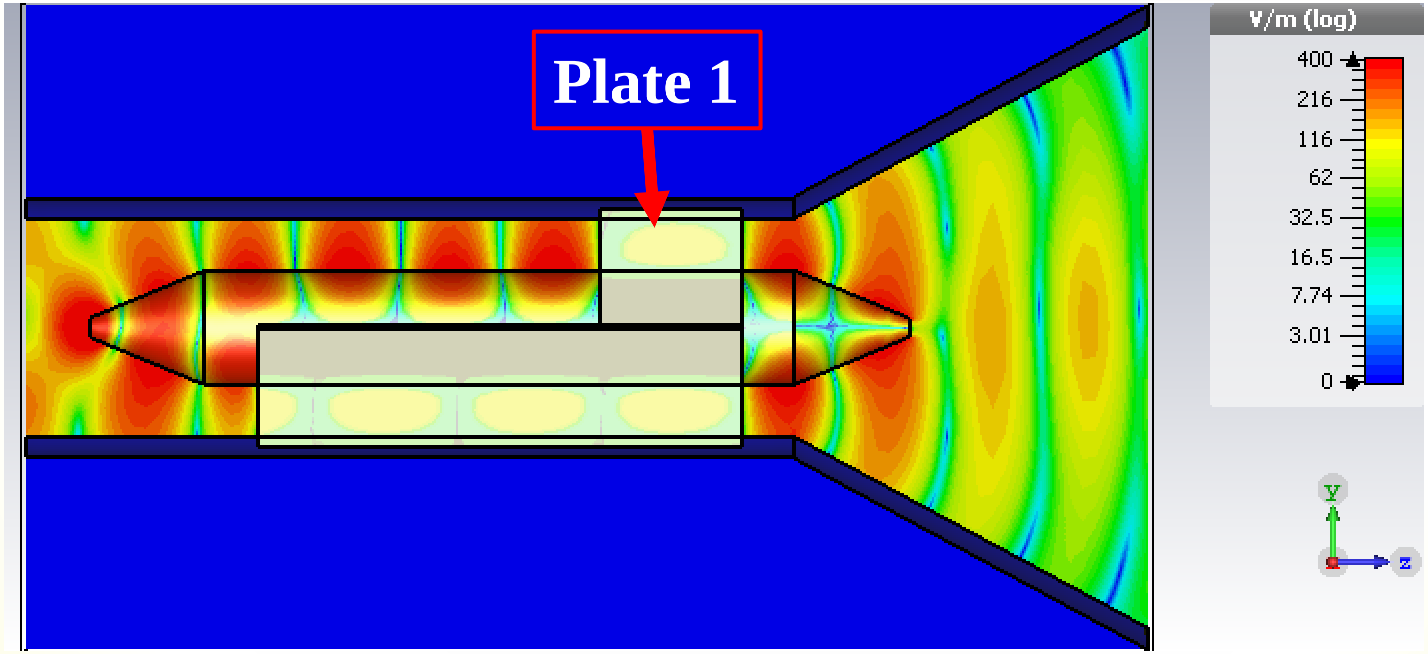
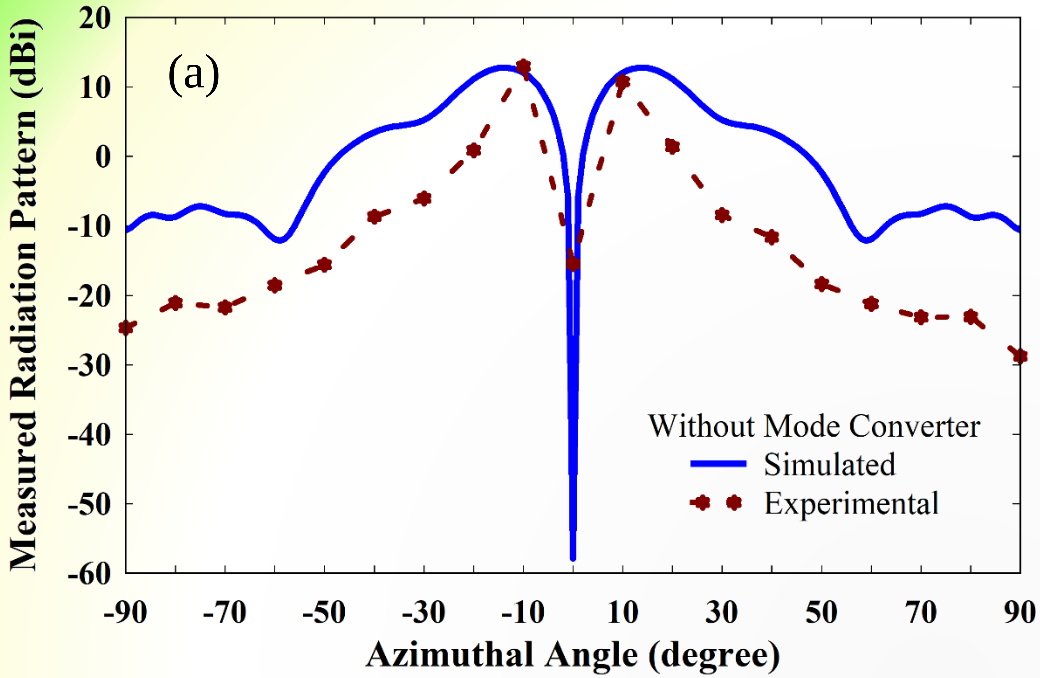
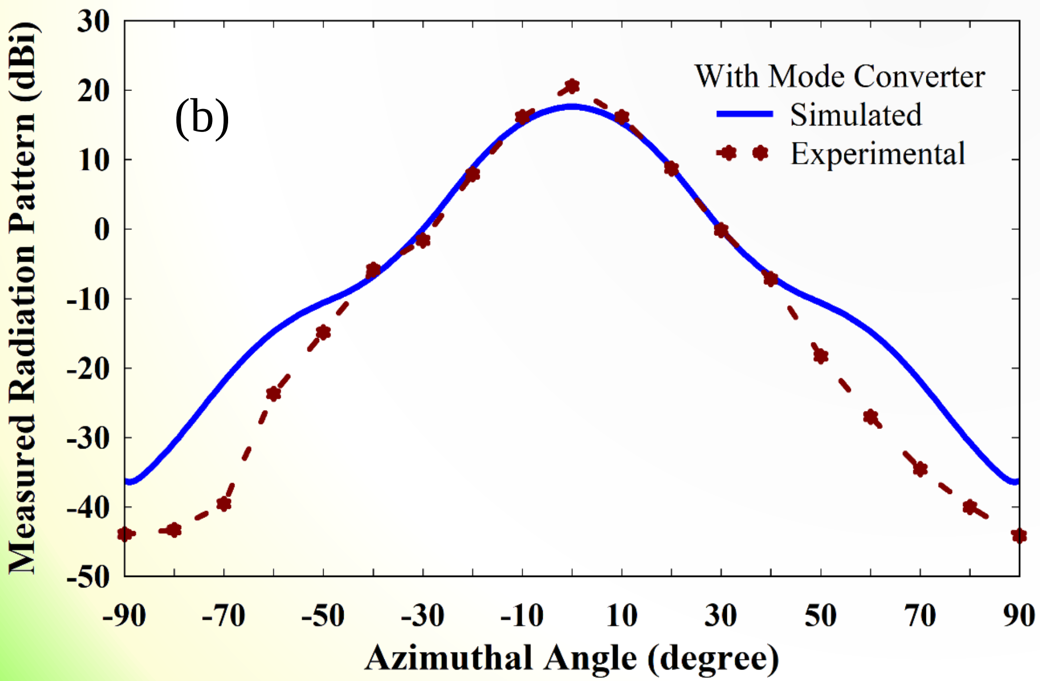


Fig 21 Simulated model of SWG mode converter with a contour plot of electric field distribution in x=0 plane at frequency 3GHz.





The radiation intensity at 0° azimuthal angle,

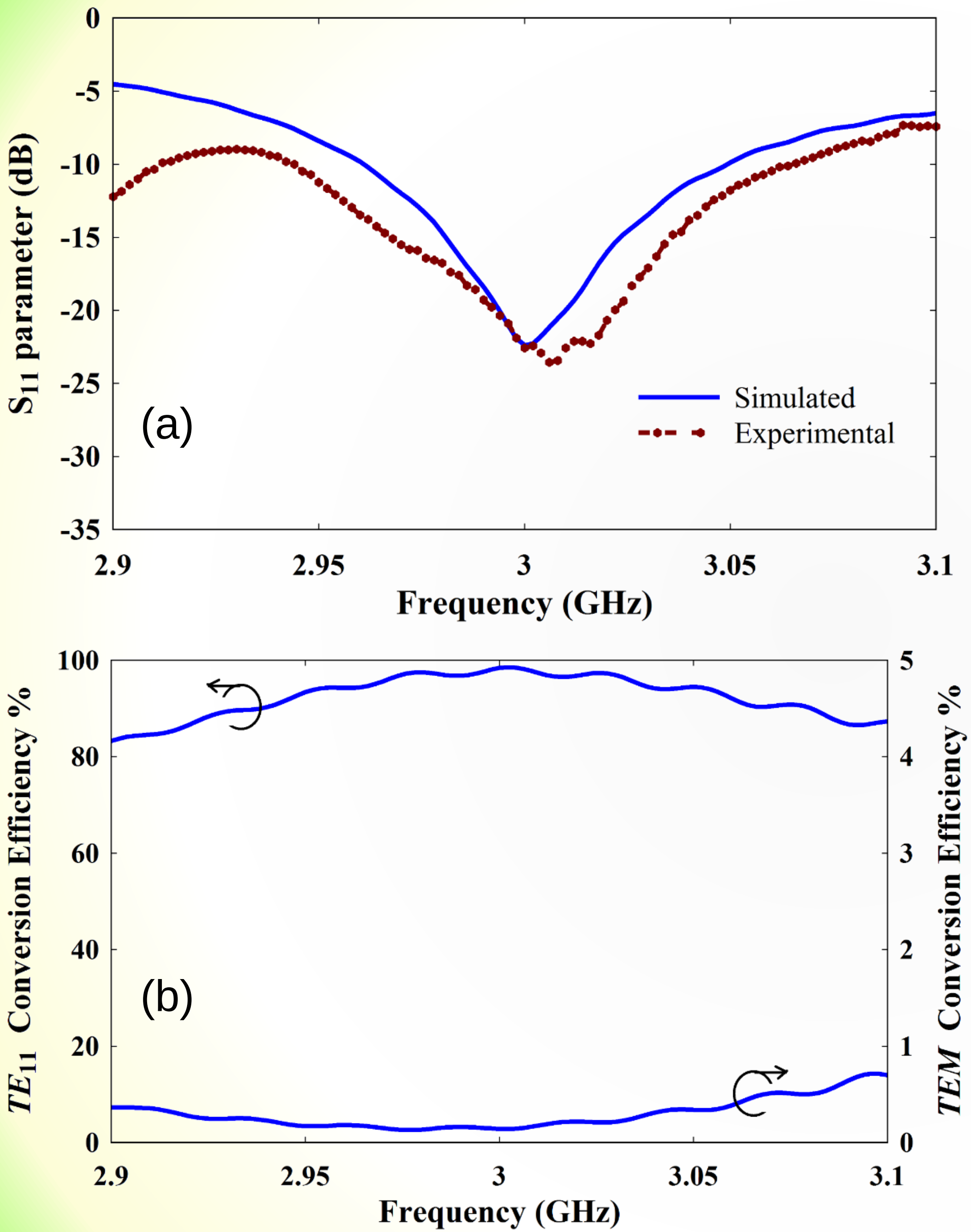
(a) from the simulation, is -57.90 dBi and by the experiment is -15.51 dBi.

(b) from the simulation is 17.29 dBi and by the experiment is 20.57 dBi.

Fig 22 Comparison of radiation pattern measurement (in H-plane), using simulation and experiment form -90° to +90° azimuthal angle, keeping 0° as a boresight, the radiation pattern obtained and measured for the system

(a) without the mode converter is showing the TM_{01} mode pattern.

(b) with the mode converter is showing the TE_{11} mode pattern.



At the frequency 3 GHz, the return loss are following

- ❖ Fabricated design has -22.57 dB
- ❖ The Simulation has -22.38 dB

The mode conversion efficiency for TE_{11} mode is 98.62% and for TEM mode is 0.18%.

Fig 23 (a) Comparison of reflection loss between simulated and measured at the input end of Region *I*(a) and the feed of mode transducer respectively.

(b) Mode conversion efficiency (in %) for desired TE_{11} mode and dominant mode TEM of the coaxial waveguide. The result is obtained in simulated design at the output end of Region *III*(a).

HPM Analysis

- Power handling capability is obtained by simulating the mode converter model with the 1.25 GW level signal at the input port of the mode converter.
- At 1-atm air pressure is used as a medium, the maximum electric field inside the mode converter is 61.8 kV/mm.
- The field values are within the breakdown limit of 100 kV/mm.
- Therefore the proposed mode converter has the ability to use for HPM systems at Giga-watt level.

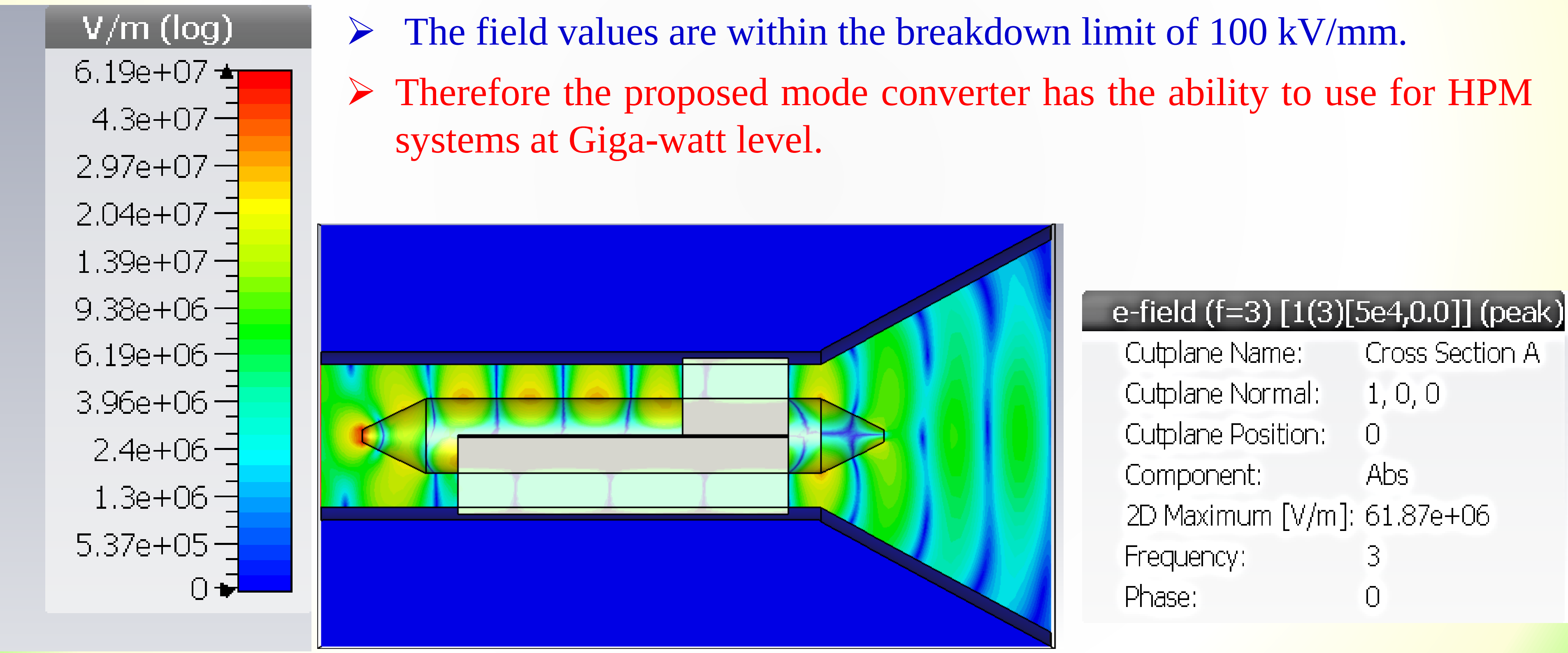
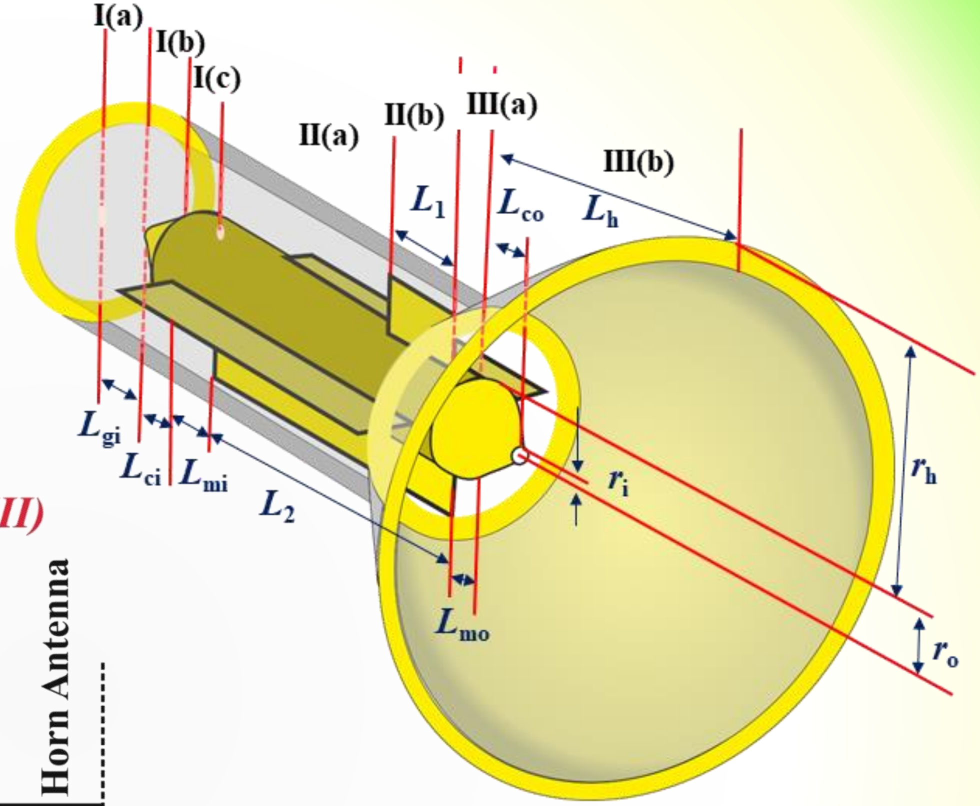


Fig 24 High Power capability evaluation of SWG mode converter.

Mode Matching Analysis

- Mode matching analysis is done to determine the scattering coefficients for all the modes excited in the system.
- The mode matching technique (MMT) is a rigorous analytical technique uses a coupling coefficient and wave impedances to determine the scattering coefficients.
- Since the amplitudes of higher order modes fall off rapidly, so it is reasonable to truncate such waveguide modes to a finite number of terms, as a fair approximation (Klaren 1994).
- So, this is an accurate and faster technique in determining the modal powers at the disturbance in the waveguide or its junctions.



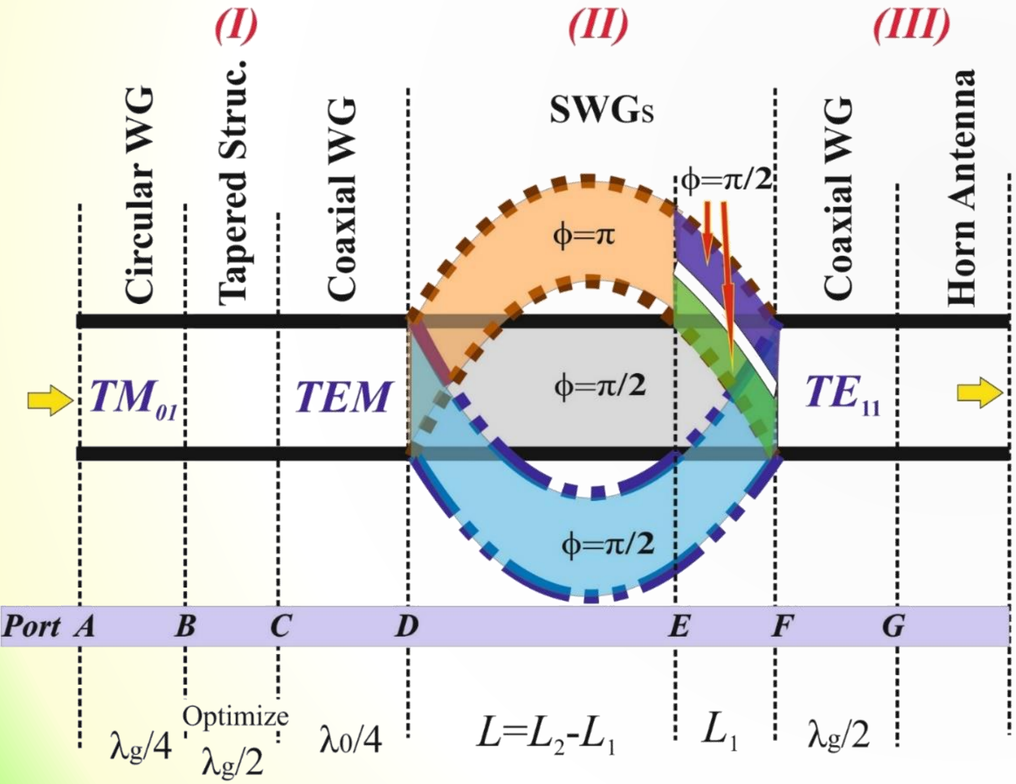


Fig 25 (a) The typical model of TM_{01} to TE_{11} SWG mode converter with a conical horn antenna.

(b) General view. (b) A typical model of TM01 to TE_{11} SWG mode converter along their axial length.

EM Expression for Each Segments

- Obtaining Electromagnetic (EM) expressions

Obtaining Normalised Field Amplitude

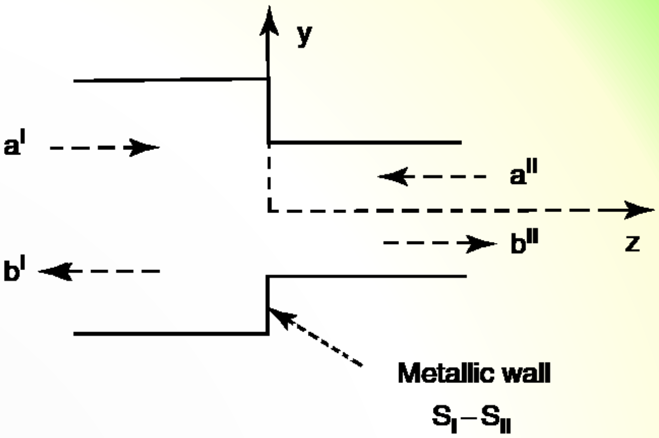
- By Power Calculation

Equating Coupling Coefficient

By Orthogonal Fields

Equating GSM

- Generalised Scattering Matrix (GSM)



Step Discontinuity

Fig 26 The flow chart of Mode Matching Technique. In inset basic key building blocks of MMT problem, the step discontinuity is apparent

Segmented Region, Delay lines and Their Respective Power

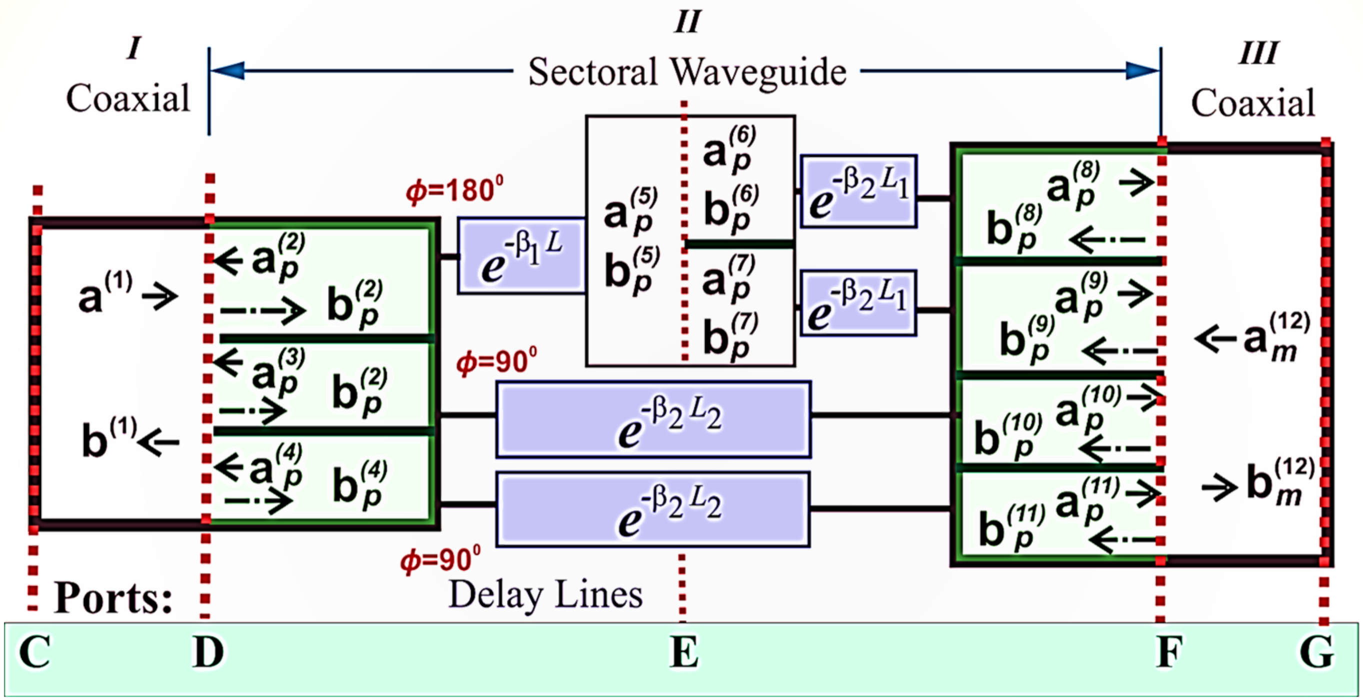
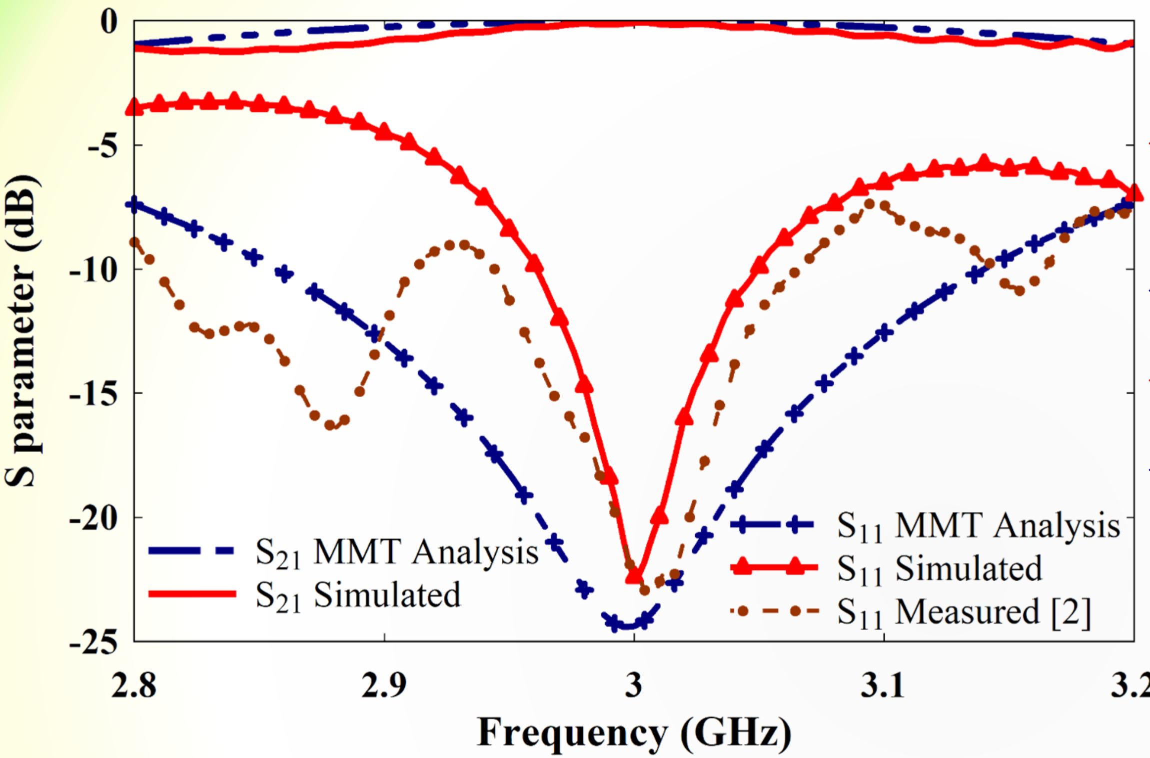


Fig 27 Scheme of the forward and backward wave at the different ports for the MMT. Fix delay length SWGs is cascaded with SWGs.

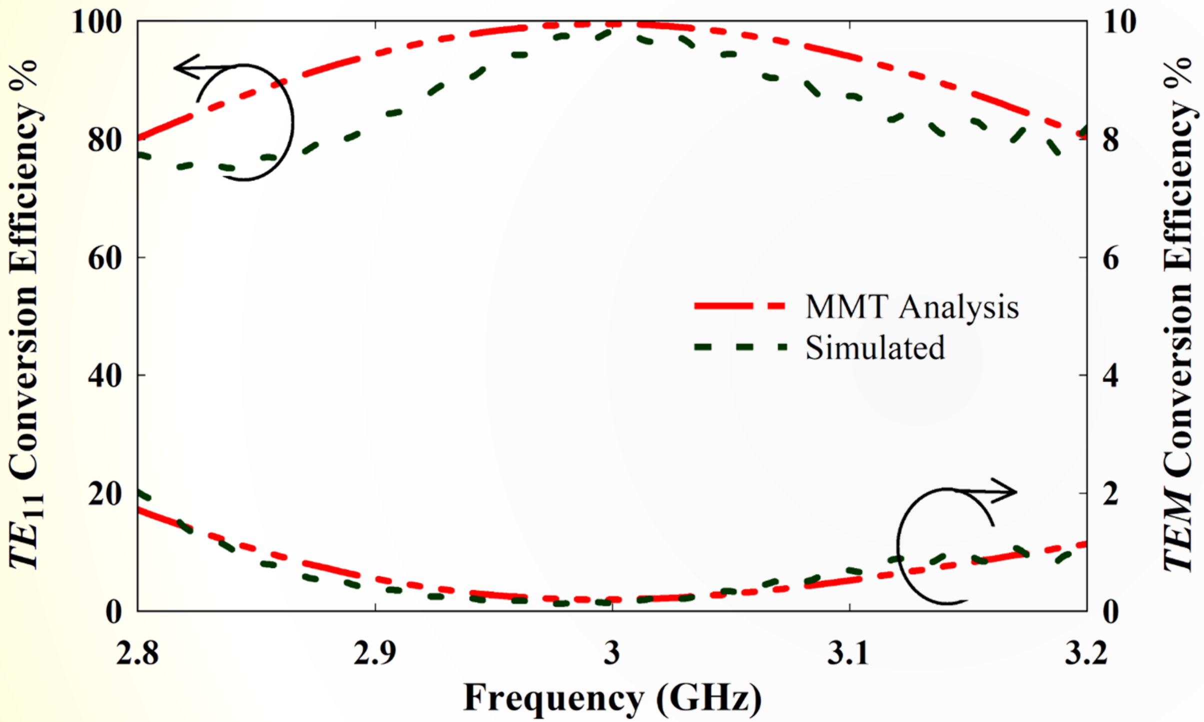
Reflection Loss



- ❖ At the frequency 3 GHz, the return loss are following
- ❖ Fabricated design has -22.57 dB
- ❖ The Simulation has -22.38 dB
- ❖ The MMT analysis has -24.38 dB

Fig 28 Transmission loss obtained from simulation between the input port-A to output port-G has compared with the result obtained from the analysis using input port-C to output port-G. Also, the reflection loss obtained from the simulation at the port-A has compared with the result obtained from analysis at the input port-C and with the measured value obtained at the input end.

Conversion Efficiency



- For TE_{11} mode conversion efficiency using mode matching analysis is 99.14% and by the simulation is 98.62%.
- For *TEM* at the output port, the mode conversion efficiency using mode matching method is 0.32% and by the simulation is 0.18%.

Fig 29 Comparison of conversion efficiency obtained from simulation between the input port-A to output port-G are compared with results obtained from the MMT analysis using input port-C to output port-G.

Conclusion

- The *Plate1* has proposed in order to overcome the high reflection and unstable radiating beam from the SWG mode converter.
- The present design for TM_{01} to TE_{11} SWG mode converter eliminates stub matching requirement, which further reduces the high variations in reflection loss.
- The SWG mode converter is capable to operate up to 1.25 GW microwave power.
- The reflection and transmission scattering coefficients for the different modes computed through the developed analysis has found to be good in agreement with simulation results.
- The mode matching analysis requires very less time than commercial simulation software.

Scope of Future Work

The SWG mode converter is an essential component for the HPM systems; the utility of mode converter depends upon the HPM source as well as a particular system application.

- In the future deep analytical study of HPM mode converter and its application-based study could be useful for further research.
- In addition, HPM system requires an efficient RF windowing which is also capable of focusing the radiated beam.
- The mode matching analysis of SWG mode converter can be extended for other n-furcation of the coaxial waveguides too.
- In future, both the mode converter design can be studied to keep HPM system thermally stable for effective performance.

References

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Thank

You

Annexure III:
Young Researcher's Talk-2 Slides

Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Ajith Kumar M M

13-03-2021

Outline

- **Introduction**
- **Tape-helix analysis of planar helix with straight-edge connections**
- **Interaction Impedance of Non-fundamental Space Harmonics**
- **W-Band Backward-Wave Oscillator**
- **Conclusions**

Outline

- **Introduction**
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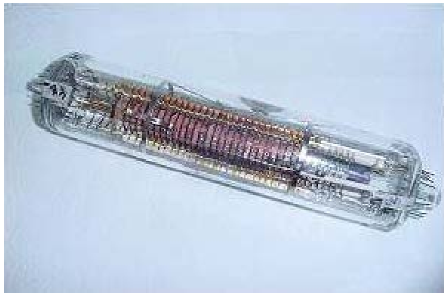
- **Conclusions**

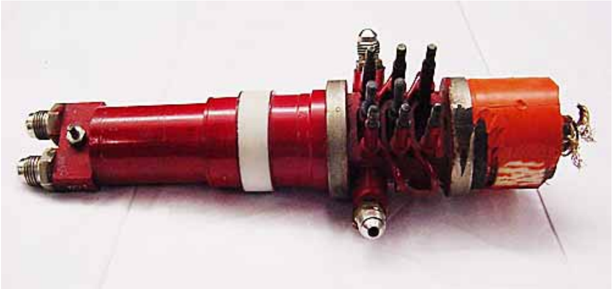
Introduction

- **Vacuum electron devices**

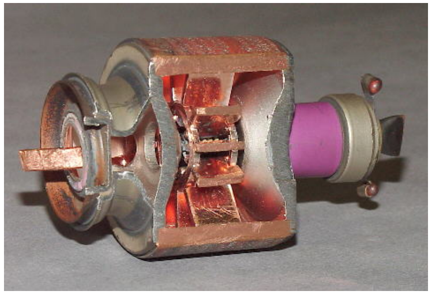
Traveling wave tubes



Klystrons

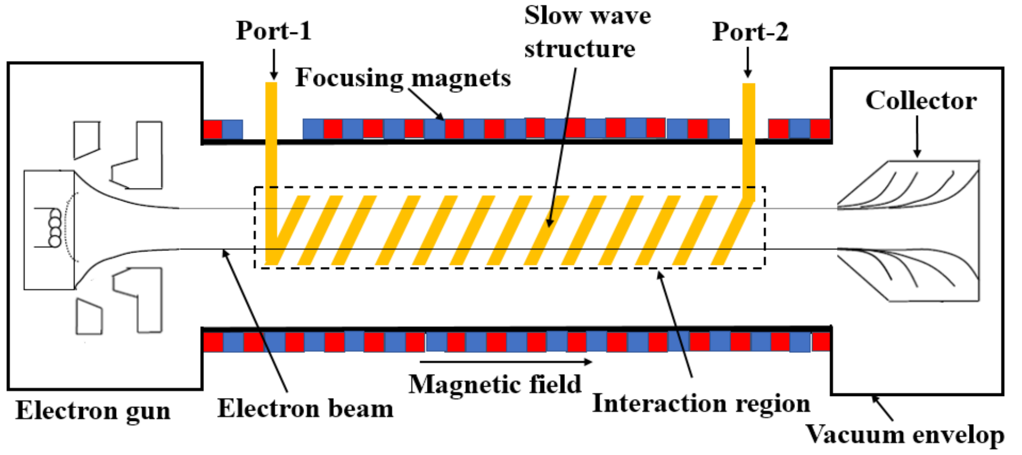


Magnetrons



- **Applications**
  - Satellite communications
  - Radar
  - Electronic countermeasures
  - Microwave heating
  - Accelerators

Traveling-wave tubes (TWT)



■ Main devices

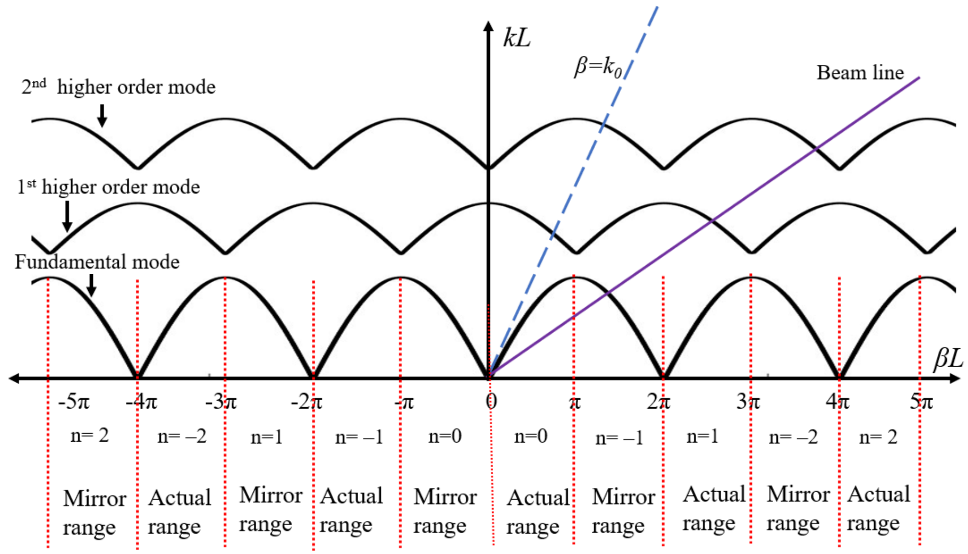
- Traveling-wave tube amplifier (TWTA)
- Backward-wave oscillator (BWO)
- Backward-wave amplifier (BWA)

■ Major components

- Electron gun
- Slow wave structure
- Focusing magnets
- Collector
- RF input/output

Slow-wave structure (SWS)-Dispersion Diagram

The periodicity of SWS produces space harmonics.



1. Phase velocity v_p

$$v_p = \frac{\omega}{\beta} \quad (\mathrm{m/s})$$

2. Group velocity v_g

$$v_g = \frac{d\omega}{d\beta} \quad (\mathrm{m/s})$$

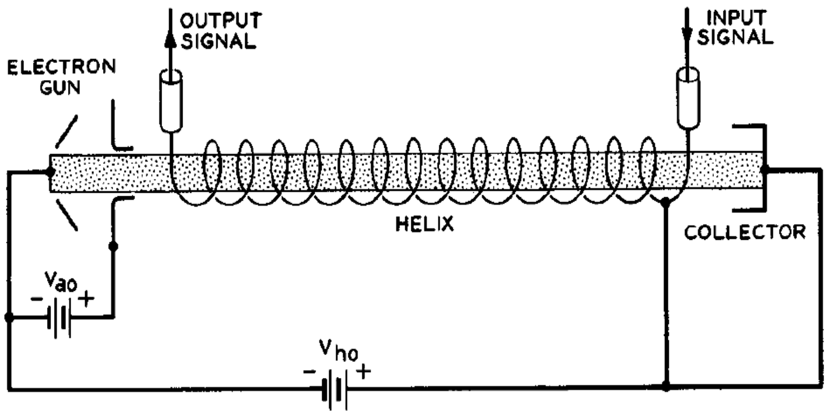
$$\beta_n = \beta_o + \frac{2\pi n}{Pitch} \;, \quad \text{where } n = 0, \pm 1, \pm 2\ldots\ldots$$

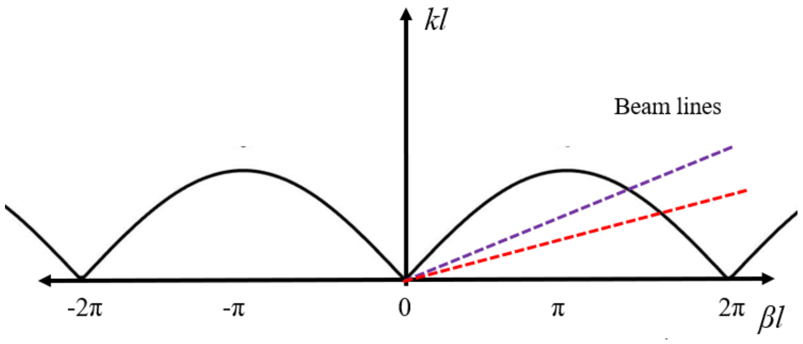
3. interaction impedance

$$K_n(r,\phi) = \frac{E_{z,n}^2(r,\phi)}{2P\beta_n^2} \quad \Omega$$

Operation of backward-wave amplifier (BWA), and backward-wave oscillator (BWO)

- Electron beam is synchronized with the n=−1 space harmonic.
- Efficiency of this narrow band amplifier increases with beam current.
- This device starts to oscillate at a particular beam current called "starting current".
- The BWO doesn't need any input signal to operate.

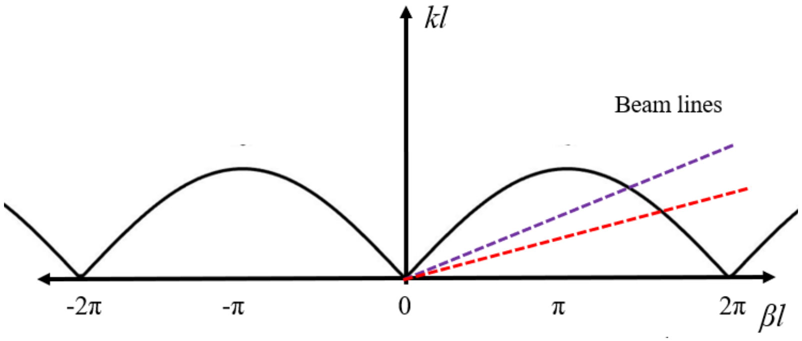




Backward-wave oscillator (BWO)

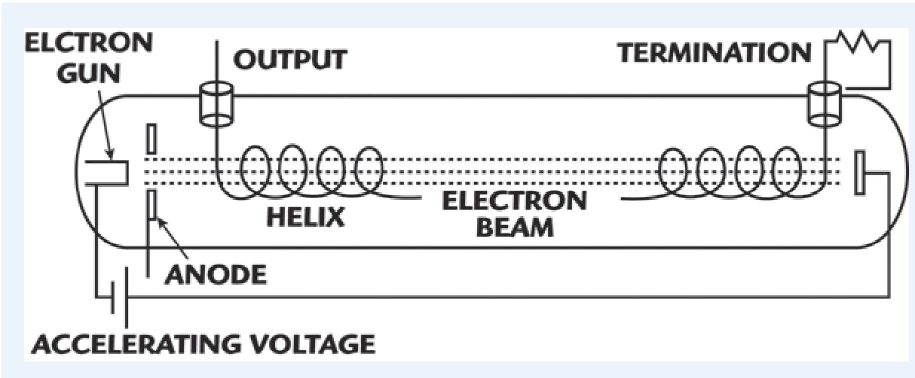
Advantages

1. Electronically tunable oscillator
2. Wide tunable bandwidth
3. Pure frequency spectrum

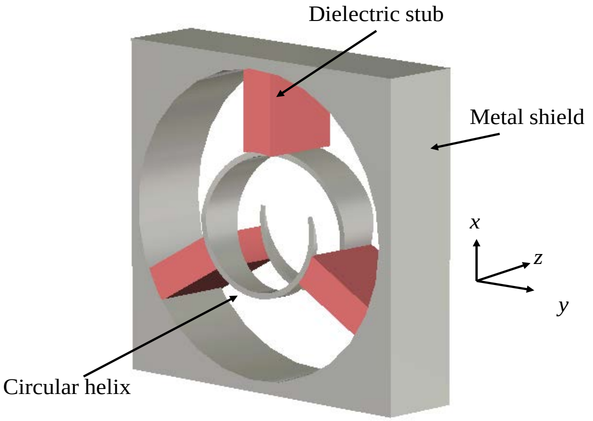


Applications

1. Receivers for low-background astronomy observations
2. Remote sensing
3. THz imaging
4. Spectroscopy



SWSs: Circular helix

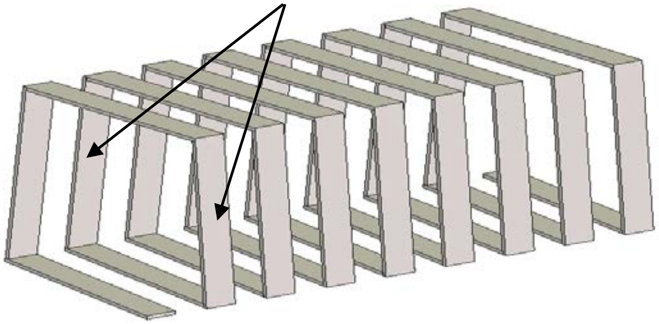


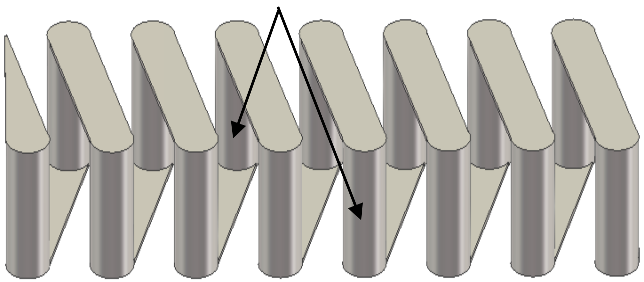
Frequency Band / Power level	Helix radius
C-band (3.4-4.2GHz/200W)	2.30 mm
Ku-band (10.7-13.0GHz/250W)	0.80 mm
K/Ka-band (18-32GHz/100W)	0.40 mm
Q-band (37-42GHz/50W)	0.24 mm
V-band (60-65GHz/30W)	0.16 mm
W-band (95GHz/10W)	0.10 mm
Sub-mm band (300GHz/1W)	0.032 mm

- **Advantages**
  - Broad bandwidth
  - High interaction impedance
- **Limitations**
  - Circular geometry is not amenable to microfabrication
  - Structure dimensions scale inversely with frequency [1]

[1] C. K. Chong, et al., "Latest advancements in high-power……", IEEE Trans. on Plasma Science, vol. 38, no. 6, June 2010.

SWSs: Planar helix with straight-edge connections (PH-SEC) [2]-[3]





- PH-SEC is a Planar version of circular helix and it is suitable for printed circuit or microfabrication

- PH-SEC offers broad bandwidth and the structure can incorporate sheet beam (high beam current at high frequencies)

[2] C. Chua, et al., "Microfabrication and characterization………," *IEEE Trans. Electron Devices*, vol. 58, no. 11, pp. 4098–4105, 2011

[3] C. S. Chua, et al., "Design and Fabrication of a ……..," *IEEE Trans. Components, Packag. Manuf. Technol.*, vol. 7, no. 10, pp. 1663–1669, 2017

Motivation & Objectives

- **Backward wave characteristics of PH-SEC have not been explored**

1. Obtain the dispersion characteristics and interaction impedance of PH-SEC using tape-helix analysis.
2. Evaluation of the interaction impedance of different space harmonics in a SWS.
3. Design and study of a W-band BWO using microfabrication-compatible PH-SEC.

Outline

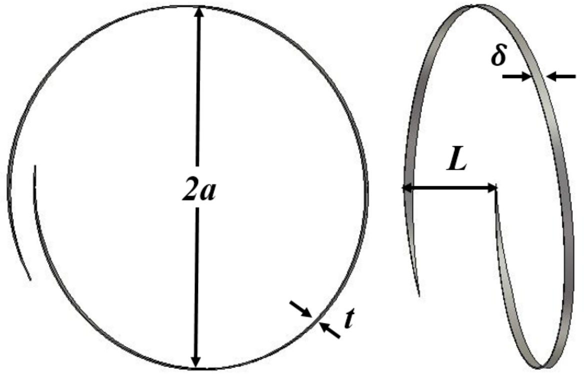
- Introduction
- **Tape-helix analysis of planar helix with straight-edge connections**
- Interaction Impedance of Non-fundamental Space Harmonics
- W-Band Backward-Wave Oscillator
- Conclusions

Tape-helix analysis

- Sensiper introduced the tape-helix analysis for circular helix

Tape-helix analysis uses following simplifying assumptions [5]:

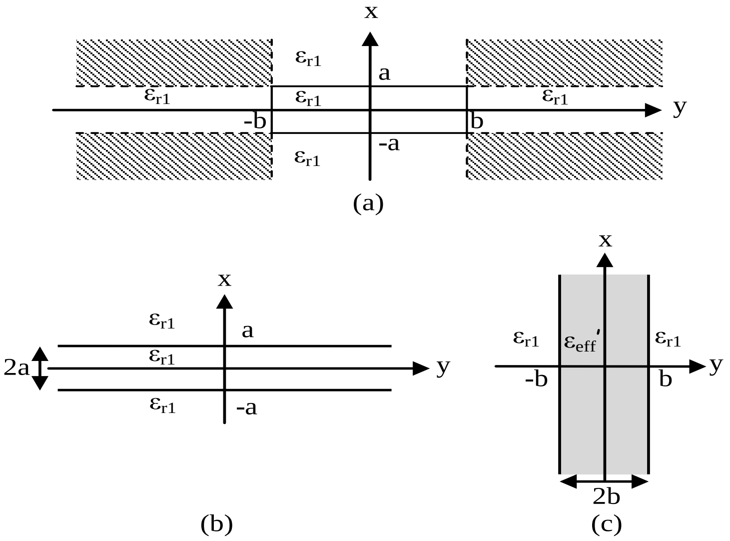
1. The helix is considered as a perfectly conducting tape with finite width and infinitesimal thickness.
2. The tape width is considered as much smaller than the pitch
3. The current is assumed to flow only in the direction of helix
4. The current is assumed to have a constant magnitude over the tape width, with phase variation according to fundamental space harmonic only.



[5] Sensiper, Samuel. "Electromagnetic wave propagation on helical ……." *Proceedings of the IRE* 43.2 (1955): 149-161.

Effective dielectric constant method [6]

- Developed for rectangular dielectric slab which is difficult to analyze accurately
- Original 3-D structure decomposed into two related 2-D structures
- Four corner regions are ignored
- Accurate at far-from-cutoff region

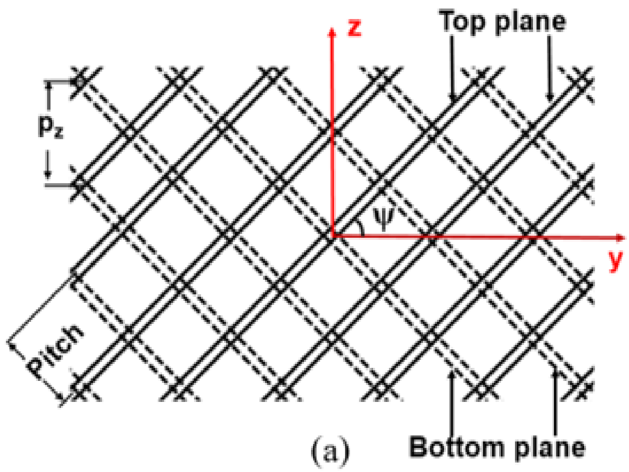


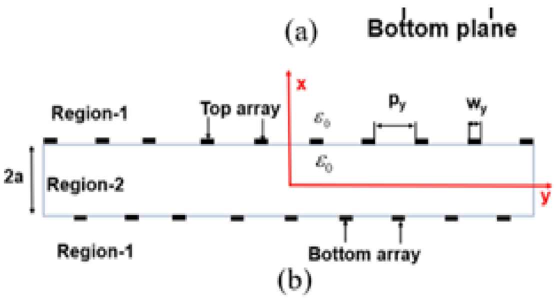
In present analysis

- *x*-dependent profile: tape-helix analysis of infinite planar helix
- y-dependent profile: infinite dielectric slab

[6] R. M. K. et al., "Integrated circuits for the millimetre'…," *Proc. Symp. submillim. Waves*, p. 497–516., 1970.

Tape-Helix analysis: Infinite planar helix





$$w_y = w/\sin\psi$$
$$w_z = w/\cos\psi$$

Symmetry properties

$$(x, y, z) \rightarrow (-x, -y, z)$$

$$(x, y, z) \rightarrow \left(x, y \pm \frac{p_y}{2}, z \pm \frac{p_z}{2}\right)$$

$$(x, y, z) \rightarrow (x, y, z \pm p_z)$$

$$(x, y, z) \rightarrow (x, y \pm p_y, z)$$

- The field is assumed to have a time dependence of $e^{j\omega t}$
- The field is assumed to be propagating through a lossless medium in the z-direction with a fundamental phase constant β_0.
- Solution for the longitudinal-symmetric field is analyzed with the help of Helmholtz's equation

- Solution for the fields in upper half ($x \geq 0$) is similar to the fields in the lower half ($x \leq 0$)

Tape-Helix analysis: Field expressions

General solution of the fields should be of the form

$$e^{-j\beta_0 z}\sum_{n=-\infty}^{\infty} C f(x) e^{j\left(\frac{2\pi n}{p_y}\right)y} e^{-j\left(\frac{2\pi n}{p_z}\right)z}$$

where $f(x)$ should satisfy $\frac{d^2 f(x)}{dx^2} + u_n^2 f(x) = 0$

which gives the field expressions for the upper half ($x \geq 0$) as:

$$E_{z1} = \sum_{n=-\infty}^{\infty} A_n e^{-(u_n(x-a))} e^{j\left(\frac{2\pi n}{p_y}\right)y} e^{-j\beta_n z}$$

$$H_{z1} = \sum_{n=-\infty}^{\infty} C_n e^{-(u_n(x-a))} e^{j\left(\frac{2\pi n}{p_y}\right)y} e^{-j\beta_n z}$$

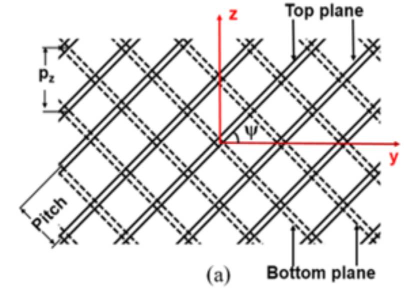
$$E_{z2} = \sum_{n=-\infty}^{\infty} B_n \cosh(u_n x) e^{j\left(\frac{2\pi n}{p_y}\right)y} e^{-j\beta_n z}$$

$$H_{z2} = \sum_{n=-\infty}^{\infty} D_n \cosh(u_n x) e^{j\left(\frac{2\pi n}{p_y}\right)y} e^{-j\beta_n z}$$

$$u_n^2 = \left(\frac{2\pi n}{p_y}\right)^2 + \beta_n^2 - {k_0}^2 \qquad \beta_n = \beta_0 + \frac{2\pi n}{p_z}$$

Tape-Helix analysis: Boundary conditions and assumptions for current

The boundary conditions are



$$E_{z1,n}(x=a) = E_{z2,n}(x=a)$$

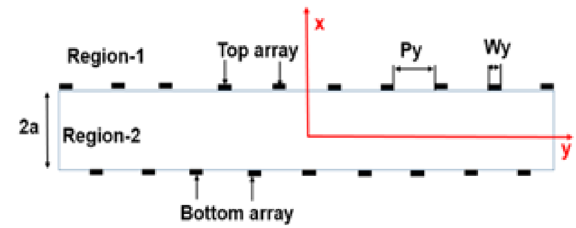
$$E_{y1,n}(x=a) = E_{y2,n}(x=a)$$

$$[H_{z2,n}(x=a) - H_{z1,n}(x=a)] = J_{y,n}$$

$$[H_{y1,n}(x=a) - H_{y2,n}(x=a)] = J_{z,n}$$

$$J_{z,n} = J_{\|n} \sin\psi$$

$$J_{y,n} = J_{\|n} \cos\psi$$



The assumption for current

Current density on helix: $= Je^{-j\beta_0 z}$ along the strip width; $= 0,$ at the remaining region

The Fourier components of this current are obtained as

$$J_{\|n} = \frac{Jw_z}{p_z} \operatorname{sinc}\left(\frac{\beta_n w_z}{2}\right)$$

Tape-Helix analysis: Characteristic equation for infinite planar helix

The characteristic equation is obtained by applying the condition

$$E_{1,\parallel}(x=a)=0$$

$$E_{1,\parallel}=\sum_{n=-\infty}^{\infty}E_{1,\parallel n}=\sum_{n=-\infty}^{\infty}E_{y1,n}\cos\psi+E_{z1,n}\sin\psi$$

The characteristic equation is obtained as

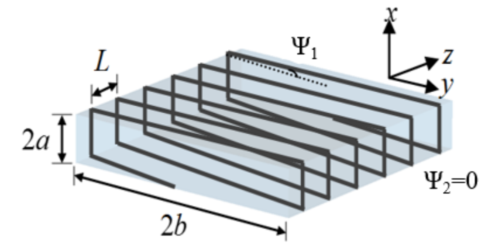
$$\sum_{n=-\infty}^{+\infty}\frac{(j\omega\mu_0)u_n\cos^2\alpha}{k_c^2e^{u_na}}\left[\sinh(u_na)-\frac{\cosh(u_na)}{u_n^2{k_0}^2}\left(\frac{2\pi n}{p_y}\beta_n+k_c^2\tan\psi\right)^2\right]\left(\frac{Jw_z}{p_z}\operatorname{sinc}\left(\frac{\beta_nw_z}{2}\right)\right)=0$$

where, $k_c^2={k_0}^2-\beta_n^2$

A converged numerical solution can be obtained by considering first five to seven space harmonics.

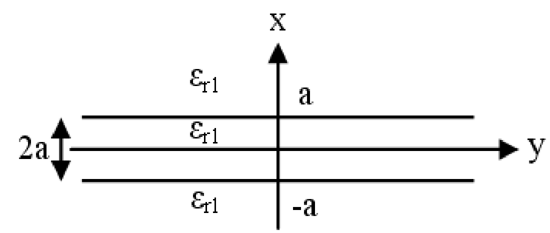
Tape-Helix analysis: Application of effective dielectric constant method

x-dependent profile



(c)

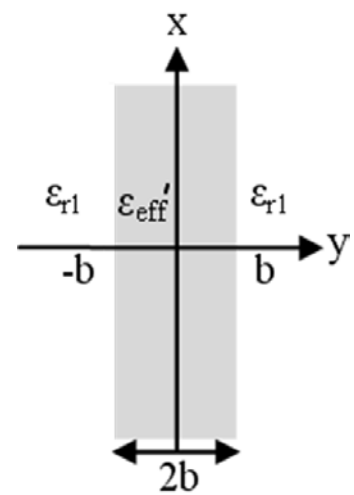
- This step uses effective pitch angle $\psi_{eff} = \tan^{-1}\left(\frac{pitch}{4a+4b}\right)$
- It gives the phase constant β_1 and ε'_{eff} for the second step, $\varepsilon'_{eff} = \left(\frac{\beta_1}{k_0}\right)^2$



y-dependent profile

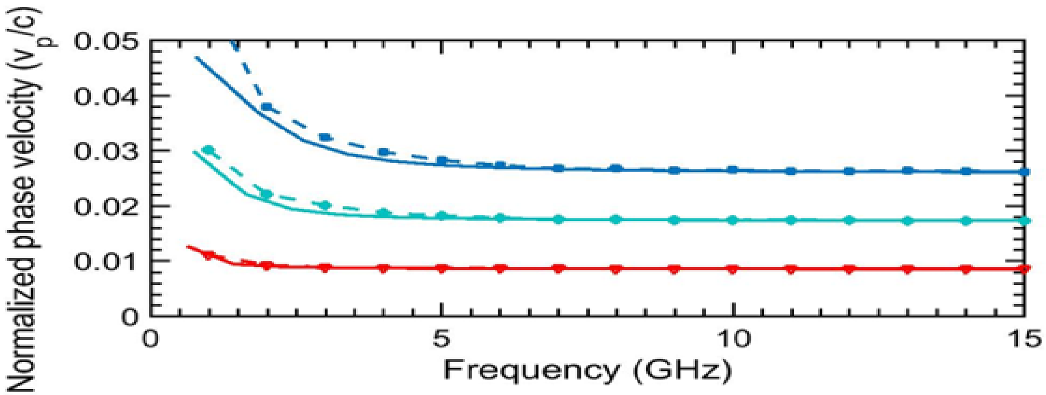
- This step consider an infinite dielectric slab with characteristic equation ${}^{v_1}/_{v_2} = \tan(v_2 b)$, where $\beta_2^2 = {v_1}^2 + {k_1}^2 = {k'}_{eff}^2 - {v_2}^2$
- The final phase constant is obtained by a weighted averaging of β_1 and β_2

$$\beta = \frac{b\beta_1 + a\beta_2}{a+b}$$

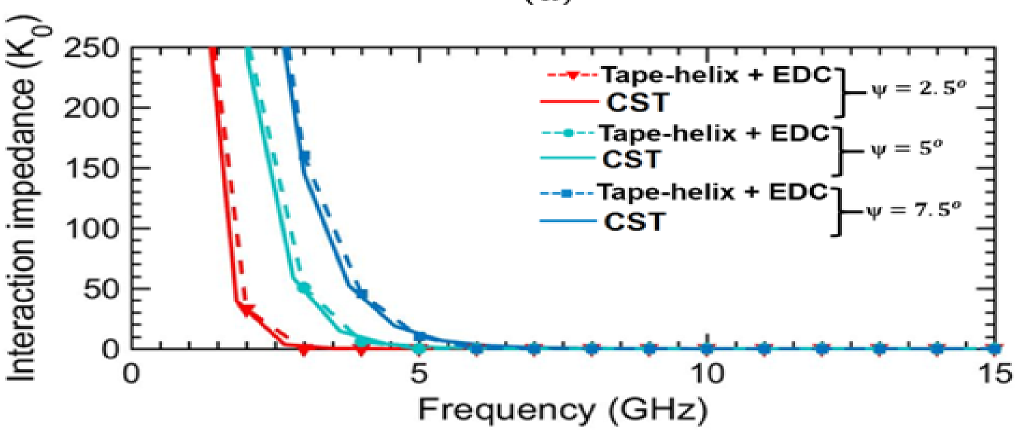


[7] R. M. K. et al., “Integrated circuits for the millimetre’…,” *Proc. Symp. submillim. Waves*, p. 497–516., 1970.

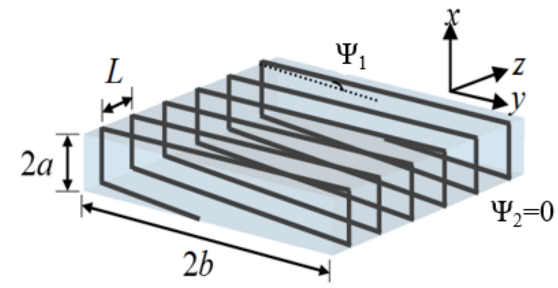
Tape-Helix analysis: Comparison of simulation results with tape-helix analysis (fundamental harmonic)



(a)



(b)

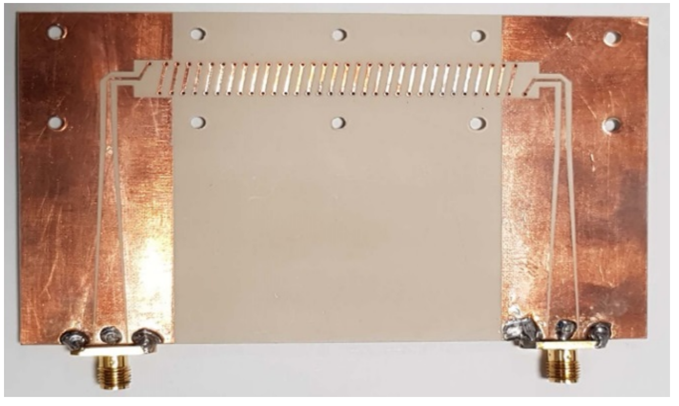


(c)

Good match of simulated and analytical results for a PH-SEC for three different pitch angles (ψ = 2.5°, 5°, 7.5°) with a/b = 4, a = 1.92 mm, and w/L = 0.2. (a) Normalized phase velocity, (b) Interaction impedance.

Tape-Helix analysis: Fabrication of prototype

Fabricated prototype of the SWS with 30 periods. (a) The SWS before assembling top and bottom dielectric sheets; (b) the assembled SWS.

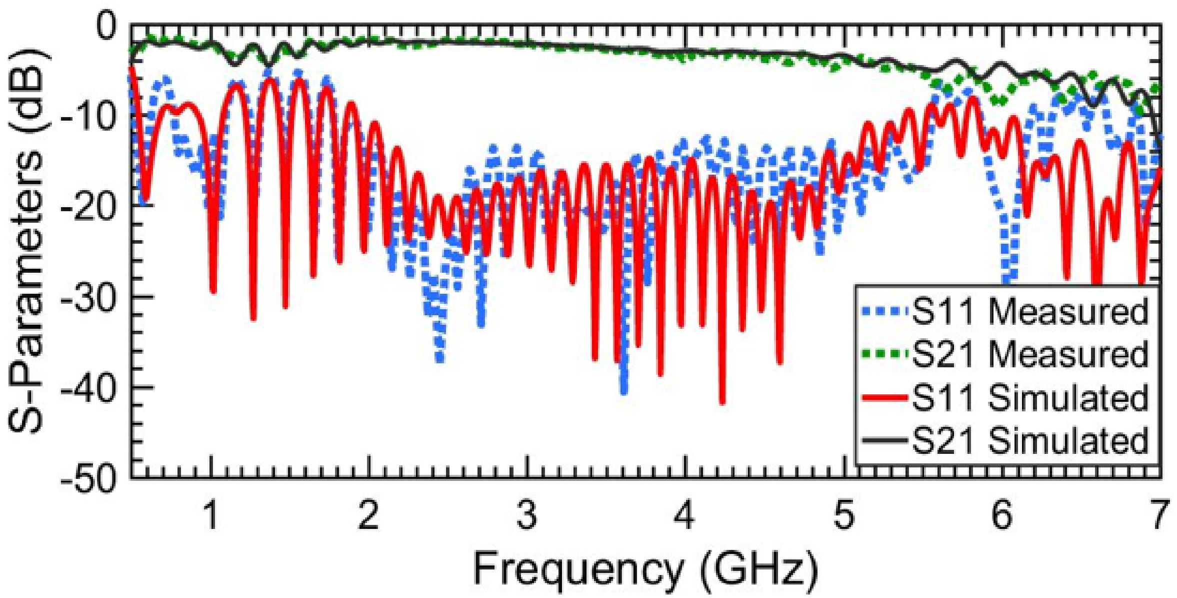


(a)

(b)

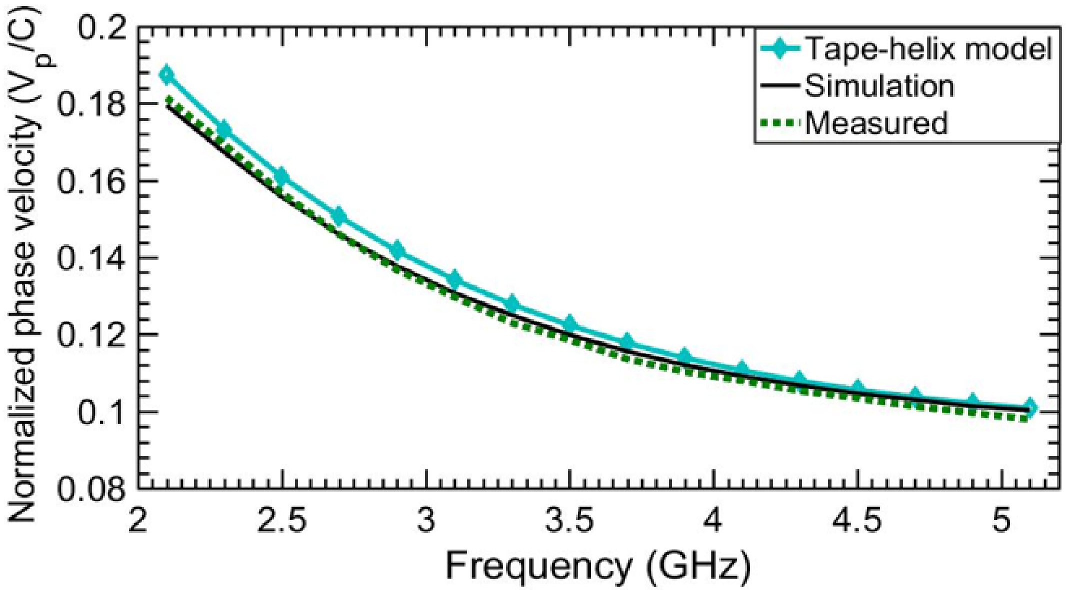
- RO3203 substrate with thickness of 1.524 mm is used
- SWSs with length of 25 and 30 periods are designed and fabricated
- Coplanar waveguide transitions are used to connect the SWS with the SMA connectors

Tape-Helix analysis: Comparison of measured results and simulation results



- Between 2-5 GHz, the simulated S11 is less than –15 dB while the measured S11 values are less than –12.5 dB.
- The measured S21 is slightly lower than the simulated results.
- The match is poor around the stop-band frequency (5.8 GHz)

Tape-Helix analysis: Comparison of measured results and simulation results with tape-helix analysis



- The measured phase velocity matches very closely with the values from simulation; match with analysis is reasonably good.
- The phase constant of the PH-SEC is determined by calculating the difference in phase of S21 values of the SWSs with two different lengths:

$$\beta = \frac{\Delta\angle S21}{\Delta Z} \qquad v_p = \frac{\omega}{\beta}$$

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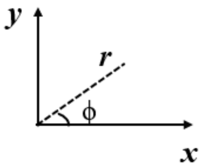
Estimation of interaction impedance

- Interaction impedance is essential to determine the shape and position of the electron beam for optimum performance in terms of gain and efficiency of travelling wave tubes.

$$K_n(r,\phi) = \frac{E_{z,n}^2(r,\phi)}{2P\beta_n^2} \quad \Omega$$

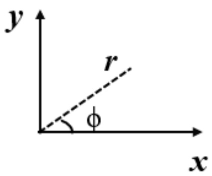


- Field theory analysis, measurement and simulations are the possible methods to estimate the interaction impedance.
- Measurement techniques for non-fundamental space harmonics are not developed yet.
- Field theory analysis and simulations remain the possible ways to determine Interaction impedance for non-fundamental space harmonics

Estimation of interaction impedance : Simulation using Fourier decomposition method

- The total longitudinal electric field in a periodic SWS can be expressed as

$$E_Z(r,\phi,z) = \sum_{n=-\infty}^{\infty} E_{z,n}(r,\phi)e^{-j\beta_n z}$$



- **Longitudinal Electric field ($E_{z,n}$) for the n^th space harmonic is**

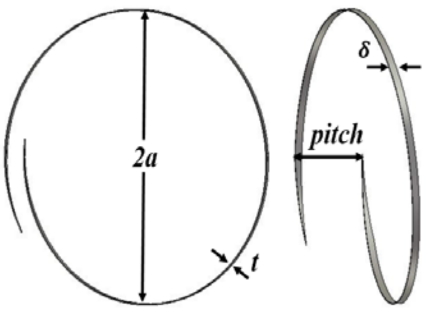
$$E_{z,n}(r,\phi) = \frac{1}{pitch}\int_0^{pitch} E_Z(r,\phi,z)e^{j\beta_n z}dz$$

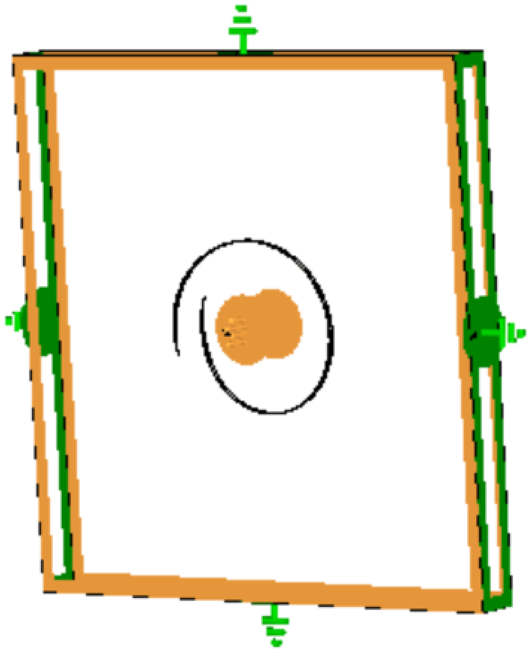
- This method has been used for finding the on-axis interaction impedance of fundamental space harmonic [8].
- The study in [8] proved that this method is more accurate than the measurement method.
- Here we are using this method for the non-fundamental space harmonics

[8] Kory, Carol L ,et al.. "Computational investigation of experimental
….." *IEEE Transactions on Electron Devices* 45.9 (1998): 2063-2071.

Estimation of interaction impedance : Simulation model

- A circular helix is modelled in CST eigenmode solver
- A narrow tape-helix, which satisfies the assumptions of tape-helix analysis is used in the simulation.
- The results from the simulation are compared with those from the tape-helix analysis.

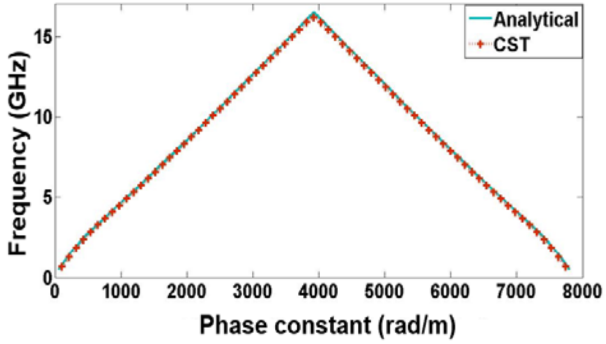




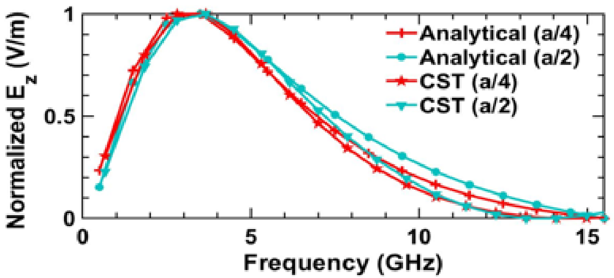
Parameter	Value (mm)
a	1.45
Pitch	0.8
δ	0.08
t	0.01

Estimation of interaction impedance: Comparison between Simulation & tape-helix analysis

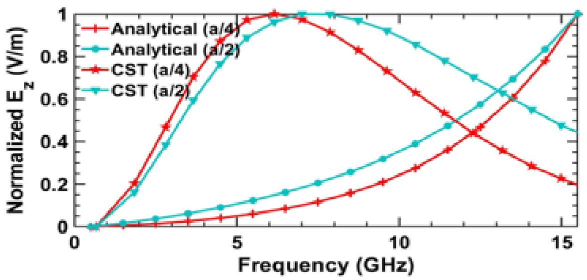
- The dispersion characteristics from both simulation and analysis show a close match.



- The normalized values of E_Z for the fundamental space harmonic also match quite well.



- The normalized values of E_Z vs. frequency for the n= –1 space harmonic do not match at all.



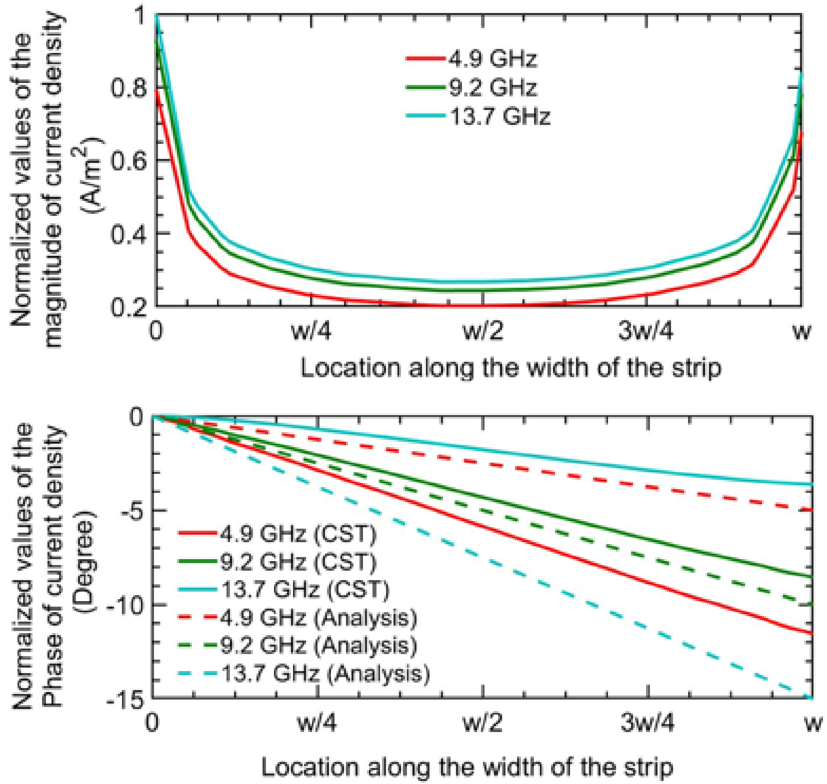
We conclude that the tape-helix analysis fails to give correct fields for the non-fundamental space harmonics

Estimation of interaction impedance: Assumptions in the tape-helix analysis

- The magnitude of the current along the width of strip is assumed as constant, but that assumption is not correct

- The phase of the current along the width of strip is assumed as varying only according to β_0.

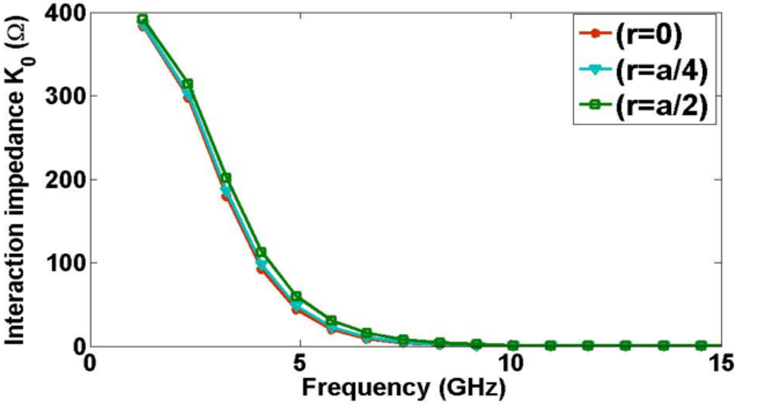
- But the results from simulation show that this assumption also is not correct.



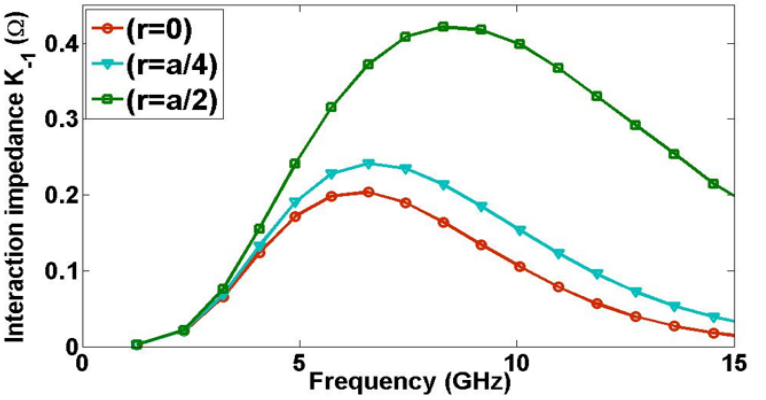
We conclude that the simulation is the only method to estimate the interaction impedance of n= –1 space harmonic in SWS.

Estimation of interaction impedance: Interaction impedance using simulations

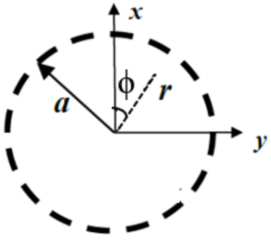
- Interaction impedance of fundamental space harmonic (K_0) is high at lower frequencies and gradually decreases as frequency increases.



- Interaction impedance of n= –1 space harmonic (K_{-1}) is relatively small at low frequencies; it first increases with frequency and then gradually decreases.



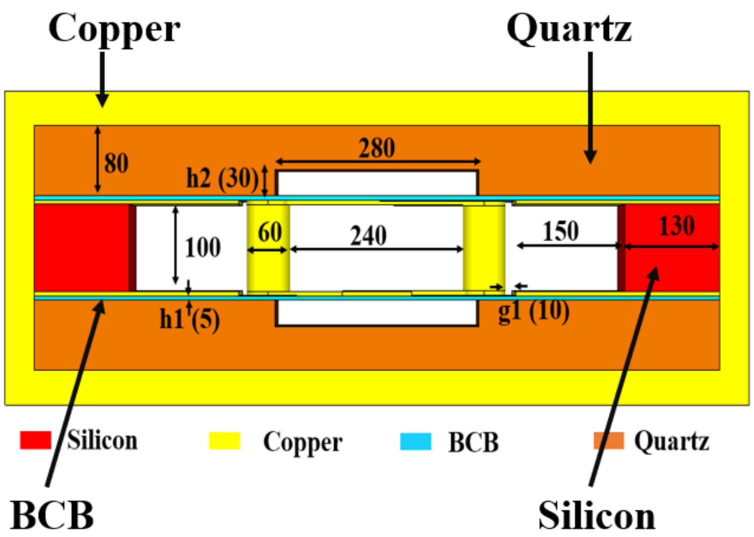
- K_{-1} increases as one moves away from the axis towards the helix

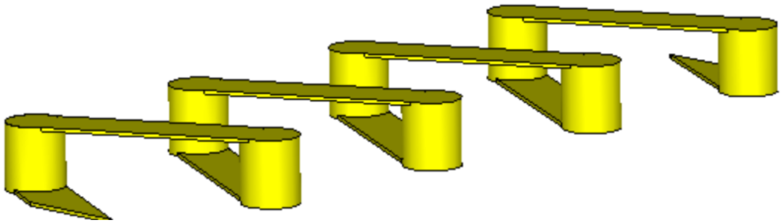


Outline

- Introduction
- Tape-helix analysis of planar helix with straight-edge connections
- Interaction Impedance of Non-fundamental Space Harmonics
- **W-Band Backward-Wave Oscillator**
- Conclusions

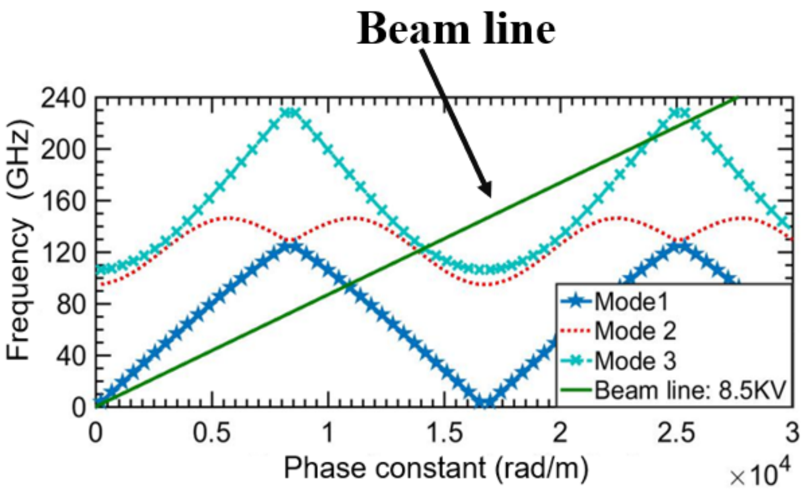
Microfabrication compatible PH-SEC SWS



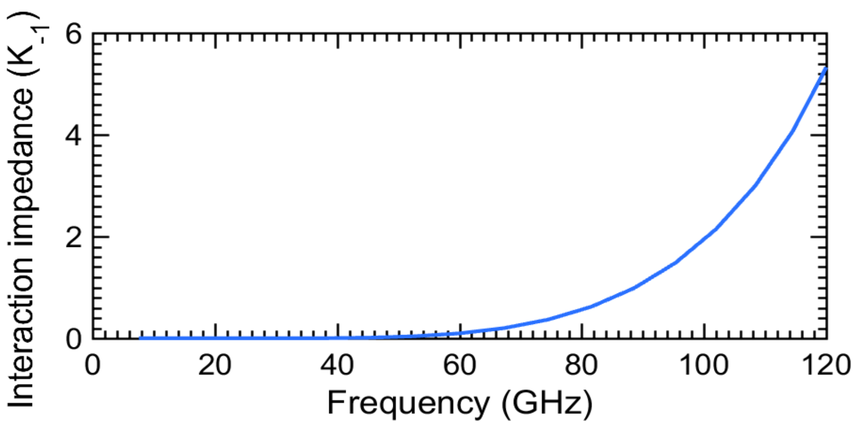


- Quartz substrates : ε_r = 4.43, $tan\delta = 5.1 \times 10^{-5}$
- B-staged bisbenzocyclobutene (BCB): ε_r = 2.65
- Silicon :ε_r = 11.9, $tan\delta$ =2.5 $\times 10^{-4}$
- Copper : conductivity = 2×10^7 S/m.

Microfabrication compatible PH-SEC SWS: Dispersion Characteristics (Simulation results)



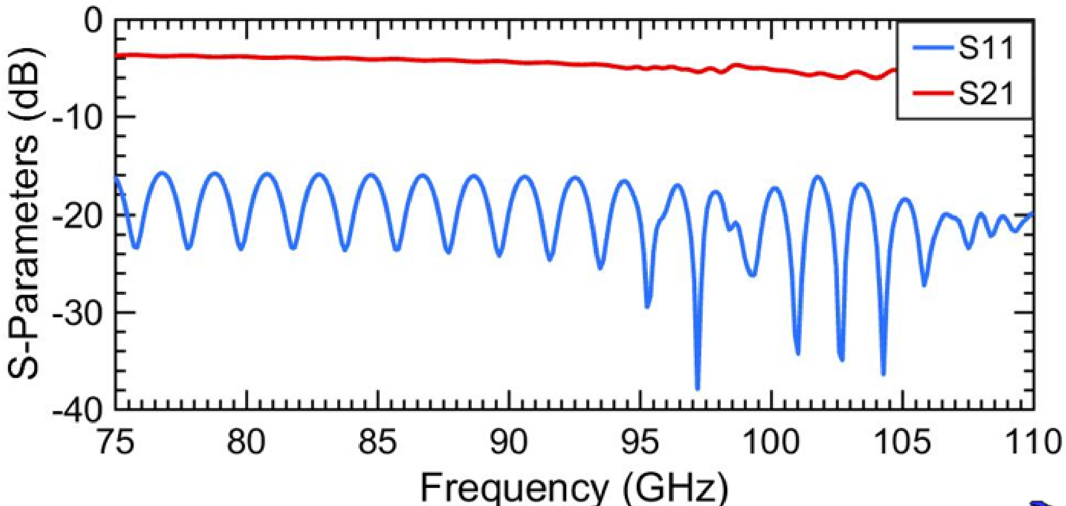
Dispersion characteristics of the PH-SEC



On-axis interaction impedance of n= –1 space harmonic

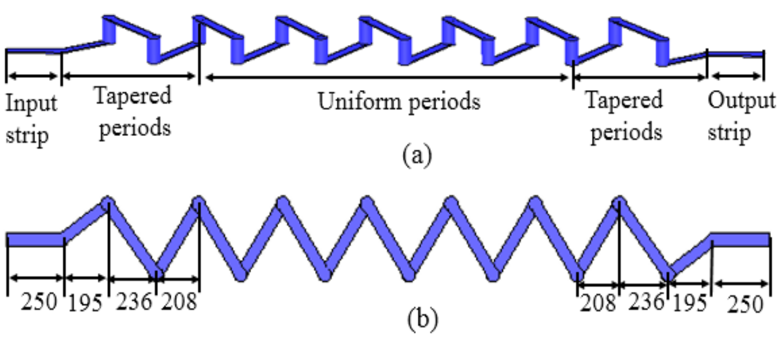
Microfabrication compatible PH-SEC SWS : Transmission Characteristics (Simulation results)

- 62 periods of the PH-SEC are connected to form SWS for BWO.
- Stripline feeds are connected at both ends of the SWS.

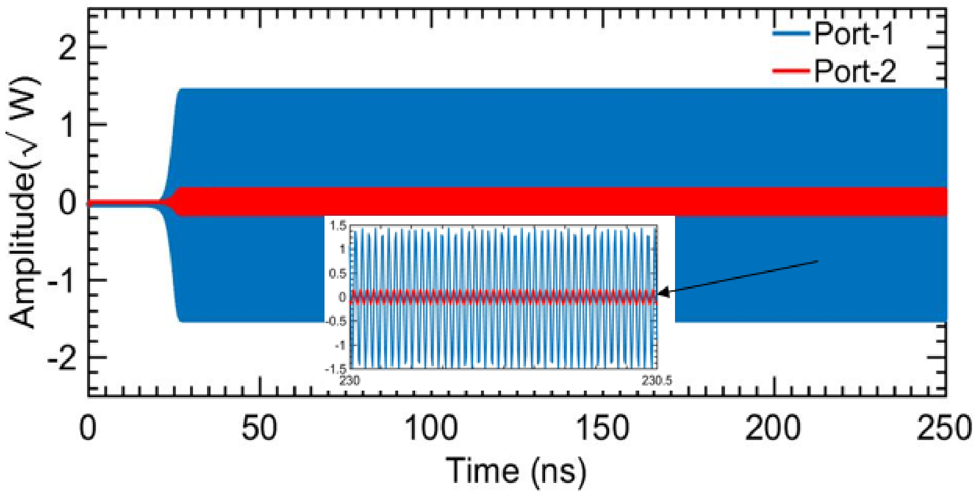


- S21 is better than −6.5 dB
- S11 less than −16 dB

PH-SEC SWS with 4 periods and stripline feeds

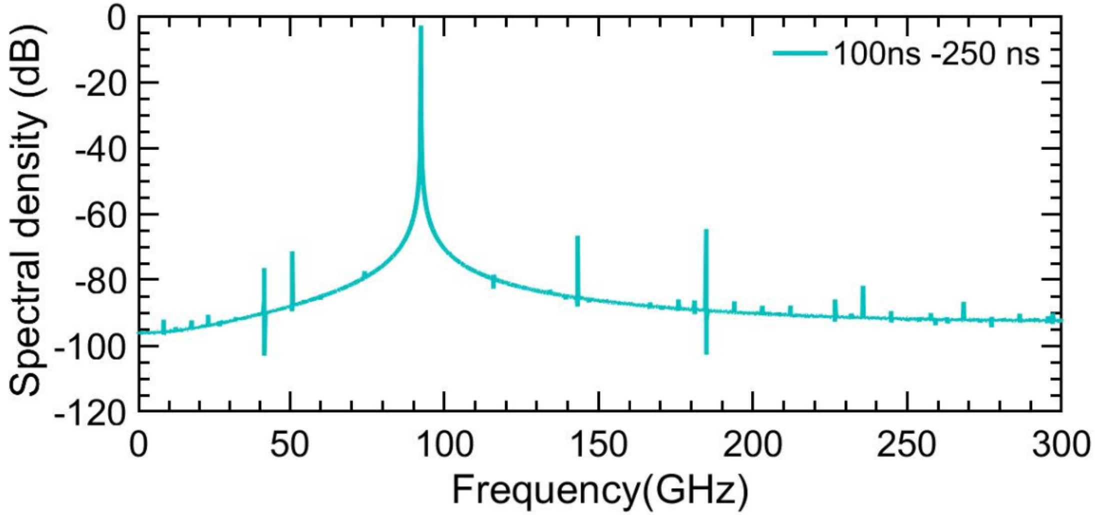


Particle-in-cell (PIC) simulation results: output signal



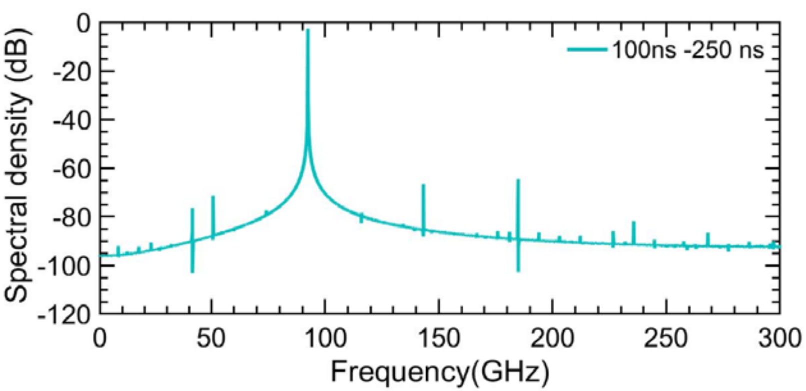
The output signal from the BWO with its spectrum for 8.5 KV beam voltage and 20 mA beam current

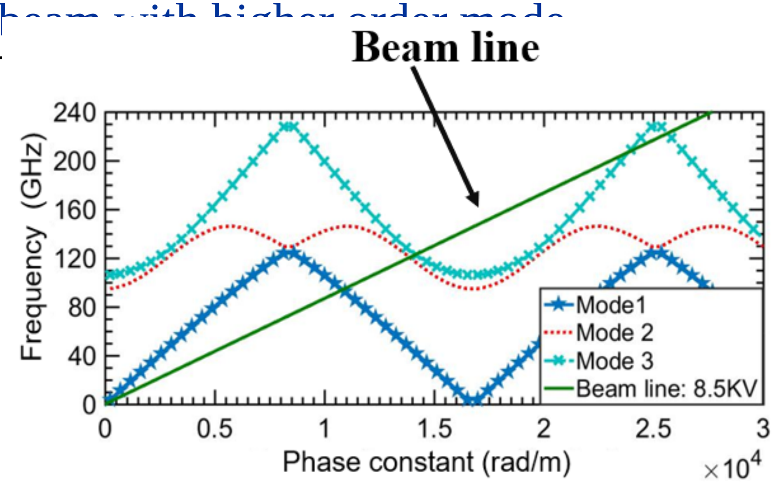
Peak frequency is 92.46 GHz



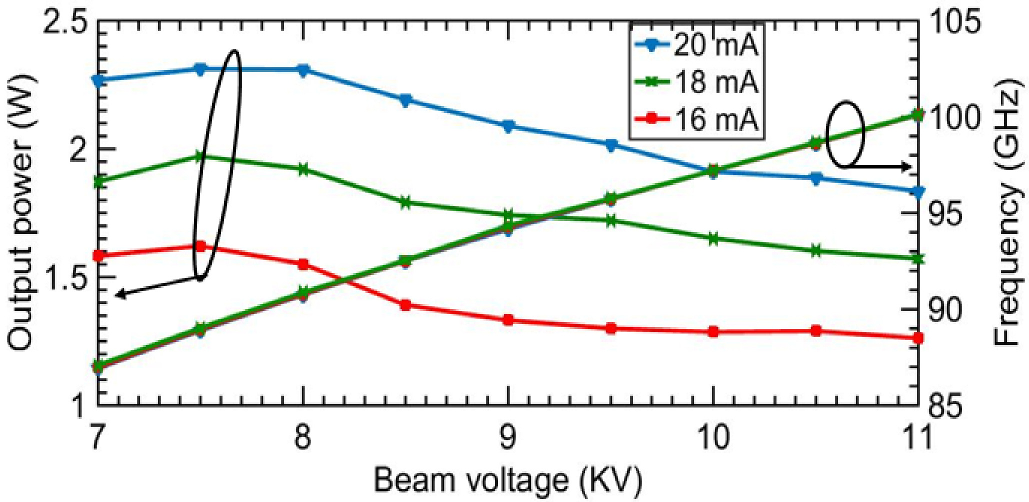
Particle-in-cell (PIC) simulation results: Fourier transform of output signal

Frequency of the peak (GHz)	Explanation
92.46	Interaction of beam with fundamental mode
184.9	Second harmonic of 92.46 GHz
143.2	Intermodulation between 92.46 GHz and 235.6 GHz
50.7	Intermodulation between 235.6 GHz and 184.9 GHz
41.7	Intermodulation between 92.46 GHz and 50.7 GHz
235.6	Interaction of beam with higher order mode



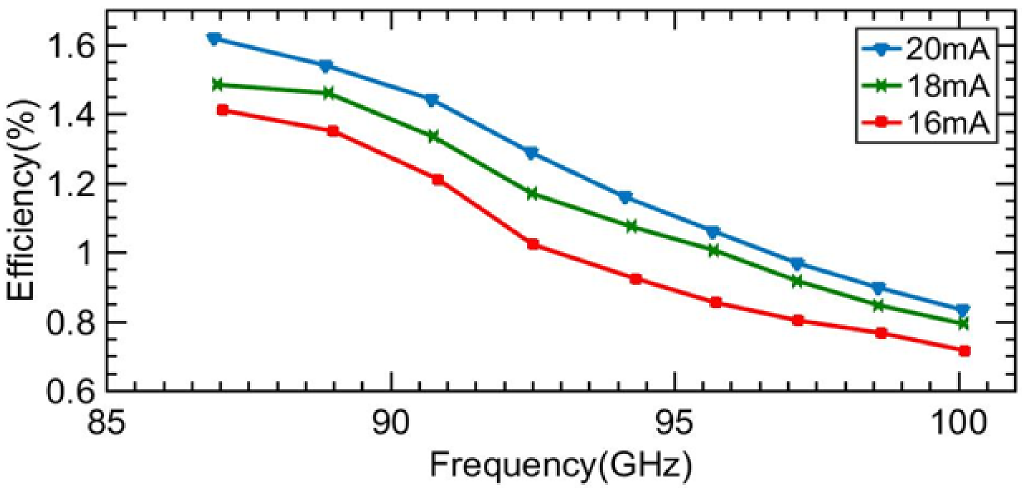


PIC simulation results: output power and efficiency for different beam currents



Output power and frequency versus beam voltage

Electronic efficiency of the BWO versus frequency



$$\eta = \frac{Output\ RF\ power}{DC\ power\ of\ electron\ beam} \times 100$$

Outline

- Introduction
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- W-Band Backward-Wave Oscillator
- **Conclusions**

Conclusion

- The dispersion characteristics and the interaction impedance of the fundamental space harmonic of the PH-SEC have been determined using more accurate tape-helix approximation.
- Introduced a new approach for obtaining fields and interaction impedance for different space harmonics of SWSs. This approach provides more accurate values of the fields and interaction impedance than available so far.
- The microfabrication-compatible PH-SEC SWS has been used to design a BWO operating at W-band. The frequency of the oscillator can be tuned from 86.9 GHz to 100 GHz.

Publications: Journals

1. M. M. Ajith Kumar., S. Aditya and C. Chua, "Interaction Impedance for Space Harmonics of Circular Helix Using Simulations," *IEEE Transactions on Electron Devices*, vol. 64, no. 4, pp. 1868-1872, April 2017.

2. M. M. Ajith Kumar and S. Aditya, "Vacuum Electronic Two-Beam Oscillator–Amplifier," *IEEE Transactions on Plasma Science*, vol. 45, no. 8, pp. 2260-2267, Aug. 2017.

3. M. M. Ajith Kumar and S. Aditya, "Simplified Tape-Helix Analysis of the Planar Helix Slow Wave Structure with Straight-Edge Connections," *IEEE Transactions on Electron Devices*, vol. 65, no. 6, pp. 2280-2286, June 2018.

4. M. M. Ajith Kumar, S. Aditya and S. Wang, "AW-Band Backward-Wave Oscillator Based on Planar Helix Slow Wave Structure," *IEEE Transactions on Electron Devices*, vol. 65, no. 11, pp. 5097-5102, Nov. 2018.

Publications: Conferences

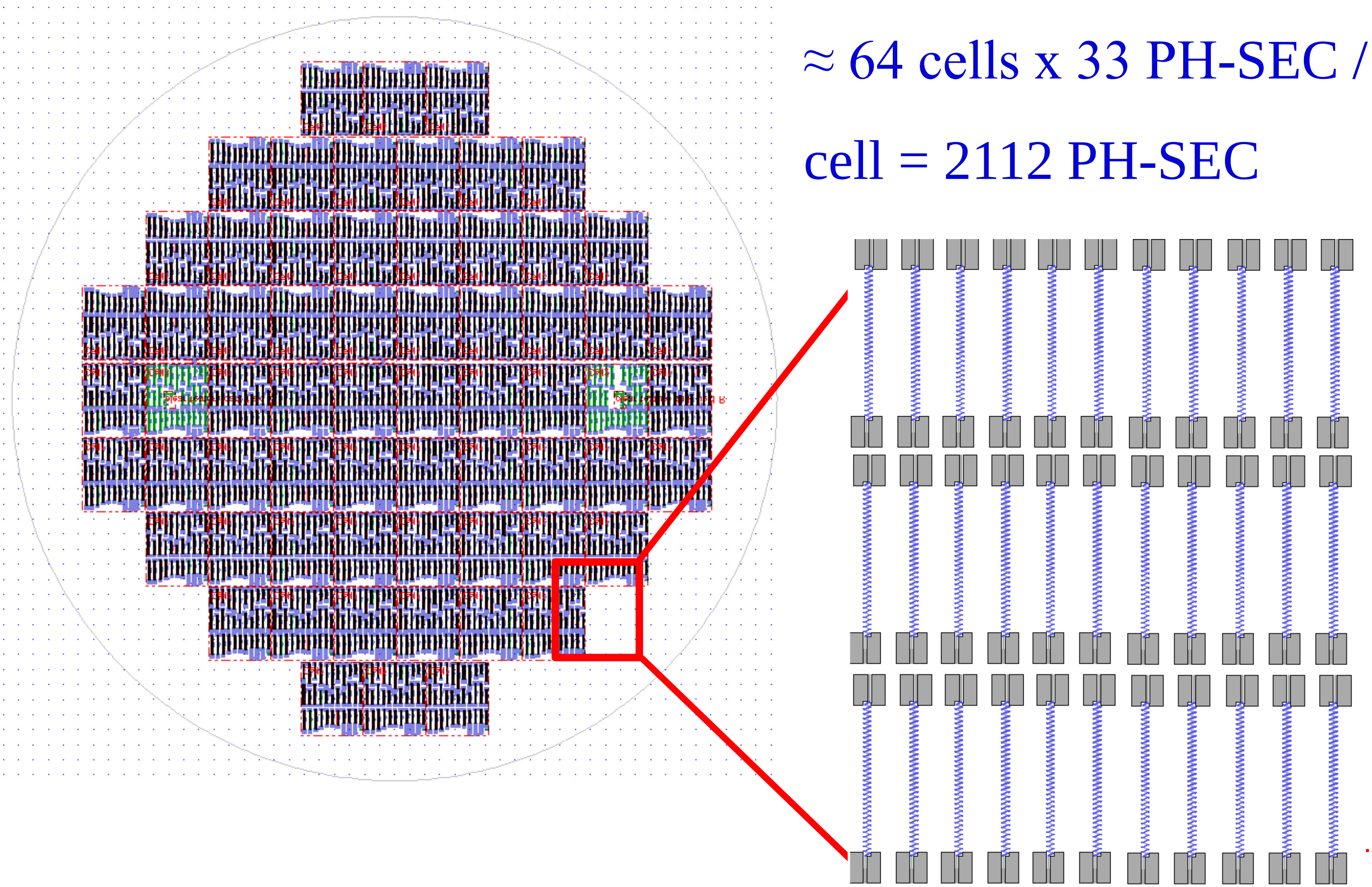
1. M. M. Ajith Kumar, Chen Zhao, Shaomeng Wang and S. Aditya, "Backward wave oscillator using a planar helix slow-wave structure with straight-edge connections," *2016 IEEE International Vacuum Electronics Conference (IVEC)*, Monterey, CA, 2016, pp. 1-2
2. M. M. Ajith Kumar and S. Aditya, "Simplified tape-helix analysis of planar helix slow-wave structure using effective dielectric constant method," *2017 Eighteenth International Vacuum Electronics Conference (IVEC)*, London, 2017, pp. 1-2.
3. M. M. Ajith Kumar, S. Aditya and C. Zhao, "Transmission characteristics of planar tape-helix: Simulation and measurements," *2018 IEEE International Vacuum Electronics Conference (IVEC)*, Monterey, CA, USA, 2018, pp. 343-344.
4. M. M. Ajith Kumar and S. Aditya, "Dispersion characteristics of planar tape-helix using effective dielectric constant method," *2018 IEEE International Vacuum Electronics Conference (IVEC)*, Monterey, CA, USA, 2018, pp. 381-382.
5. M. M. Ajith Kumar and S. Aditya, "Tape-Helix Analysis of Shielded Planar Helix Slow-Wave Structure," *2019 International Vacuum Electronics Conference (IVEC)*, Busan, Korea (South), 2019, pp. 1-2.
6. M. M. Ajith Kumar and S. Aditya, "Two-Beam Ku-Band Oscillator-Amplifier Using a Planar Helix Slow-Wave Structure," *2019 International Vacuum Electronics Conference (IVEC)*, Busan, Korea (South), 2019, pp. 1-3.

THANK YOU

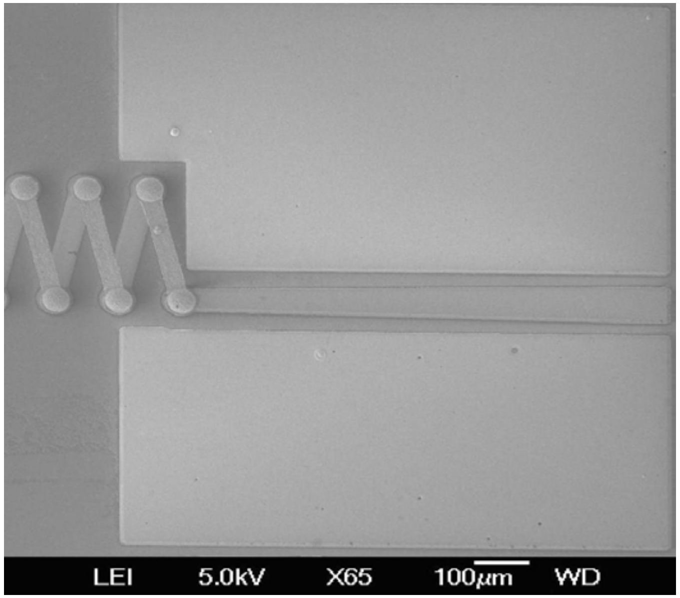
APPENDIX-I

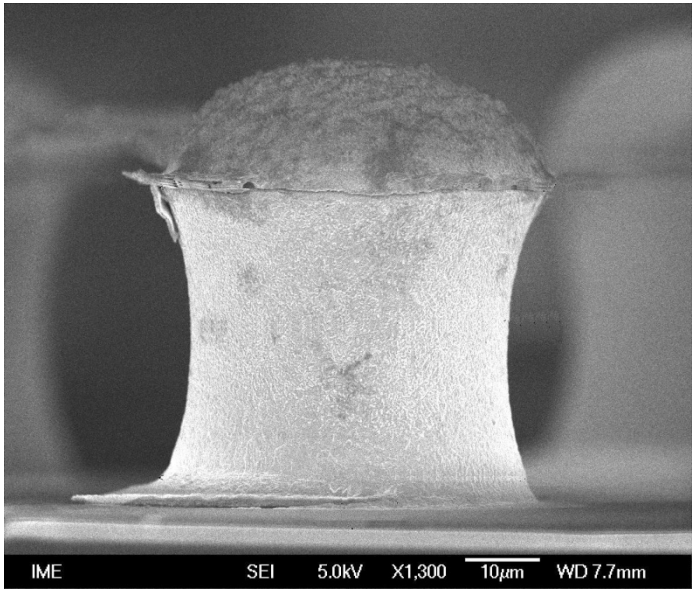
Microfabricated PH-SEC at W-Band

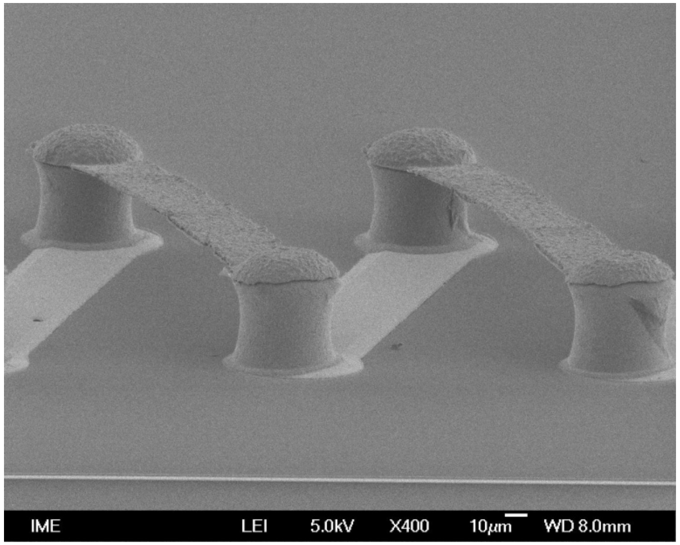
≈ 64 cells x 33 PH-SEC / cell = 2112 PH-SEC

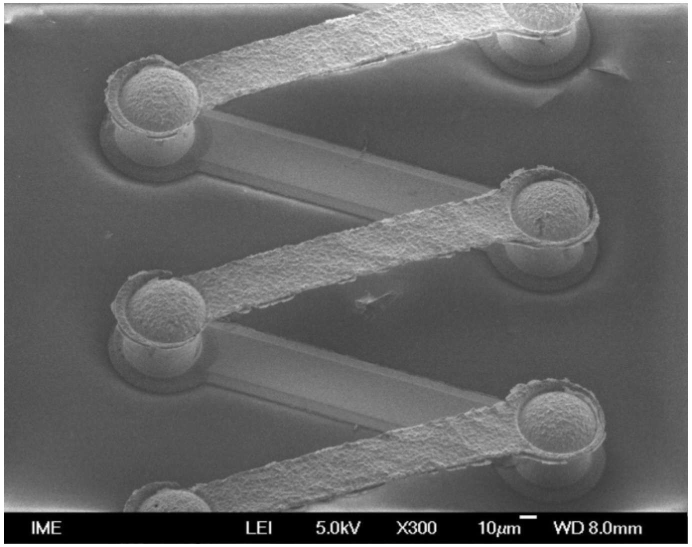


Microfabricated PH-SEC at W-Band









Tape-Helix analysis: Evaluation of interaction impedance

- The Interaction impedance of the fundamental space harmonic is calculated using:

$$K_0 = \frac{E_{z,0}^2(0)}{2P\beta_0^2}$$

The total RF power propagating through the SWS is calculated as follows:

$$P_{uw,n} = \frac{1}{2} Re\left[\int_x \left(E_{x,n} \cdot H_{y,n}^* - E_{y,n} \cdot H_{x,n}^*\right) dx\right]$$

- $P_{uw,n}$ is the power flow per unit width corresponding to the n^{th} space harmonic for an infinitely wide planar helix
- *T*he power flow for the n^{th} space harmonic in a PH-SEC is calculated as: $P_n = P_{uw,n} \times 2b$
- The total RF power is obtained by taking the sum of the P_n for first five to seven space harmonics

Annexure IV:
Typical WhatsApp Chats with Thinkers in VED

05/02/2021, 13:47 - BNBasu Prof: Check out this job at Chalmers University of Technology: PhD student position in terahertz communication

https://www.linkedin.com/jobs/view/2376147998

05/02/2021, 19:56 - BNBasu Prof: I attach an overview on cathodes from a book, the manuscript of which was handwritten by me, typeset by Professor PK Jain and proofread by Dr. PK Dalela, and published under the imprint of World Scientific with the initiative of Professor Akhlesh Lakhtakia.

06/02/2021, 08:45 - BNBasu Prof: Nice that you consider the material to be informative. However, it was written as an appendix to chapter of the book (Chapter 6) on the formation of an electron beam (synthesis of the Pierce electron gun). It is a brief introduction to directly and indirectly heated cathodes (oxide-coated and dispenser types) including L-, A-, B-, M-, MM (mixed-metal)- types, CPC (coated particle cathode)-type , etc. This has excluded cold field emission array cathodes (such as carbon nanotubes) for high frequency (THz/sub-THz) VEDs. The abstract of the paper, which Dr. Ranjan Barik posted recently, deals with nanoparticle-based cathodes for such high frequency VEDs. My write-up in the appendix to the chapter referred to also excludes the field emission explosive and non-explosive cathodes for HPM VEDs.

06/02/2021, 10:45 - BNBasu Prof: I believe Dr. KS Bhat, Dr M Ravi, and Dr. R Barik can elaborate on my above point. Moreover, we are looking forward to the expert talk on cathodes by Dr RS Raju in the 5th Webinar on 13th March 2021.

06/02/2021, 15:54 - Dr. Sarit Pal: The following is theYou tube link for the webinar on "R&D Opportunities in the Country - A Case Study on Microwave Tubes" by Dr. S.N.Joshi. on January 30, 2021 organized by Dr. B. C. Roy Engineering College, Durgapur

https://www.youtube.com/channel/UCRSD0M49CuYhqPVT0BvWXEw

06/02/2021, 16:29 - BNBasu Prof: As requested by Subhradeep, I am posting the tentative programme of the fifth webinar of our group. Mr. Raj Singh will announce the final programme in the first week of March, as he informed me.

06/02/2021, 16:30 - BNBasu Prof: WEBINAR#5 ON 13TH MARCH 2021: TENTATIVE PROGRAMMES

CONVENER: Mr. Raj Singh

HOST OF WEBINAR: Dr Vishant Dwivedi/ Ms Nalini Pareek

WEB MANAGEMENT: Dr Vishant Gahlaut, Dr Uttam K Goswami, and their team

13TH MARCH 2021

FROM 4.00 PM TO 6:00 PM

FIRST SESSION: EXPERT TALK

Duration of first session: 1 hr 10 min

Chair of first session: Dr KS Bhat

Coordinator of first session: Dr. Ranjan Barik/Mr. Sushil Shukla

Speaker of first session: Professor RS Raju

Topic: Some Aspects of the Development of Cathodes for Microwave Tubes

Duration of talk plus discussion: 55 min + 15 min

SESSION 2: RESEARCH CONTRIBUTIONS OF YOUNGER RESEARCHERS IN VEDS

Duration of second session: 50 minutes

Chair of second session: Dr Hasina Khatun

Coordinator of second session: Dr Richards Joe Stanislaus/Dr S Yuvaraj

Speaker of second session:

1. Dr. Vikram Kumar

Topic: Sectoral Waveguide HPM Mode Converters

Duration of talk plus discussion: 20 min + 5 min

2. Dr. Ajith Kumar MM

Topic: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

Duration of talk plus discussion: 20 min + 5 min

VOTE OF THANKS: Professor KP Ray

06/02/2021, 18:00 - SNJoshi CEERI: It is a matter of great pleasure that this vibrant group is organising a Webinar on March 13, 2021. I also see that this matter is already being discussed in this forum by varous experts that shows the importance of this very small component of any device, but at the same time very critical and crucial for that particular device like a heart in human beings.

Though the expertise of different kinds of cathodes is available in the Country, even then, as on today, we are mostly dependent on outside sources. So we have to strengthen ourselves to become self sufficient in this vital area having strategic importance also.

This matter needs a debate between different organizations, without that it would be difficult to proceed to the desired extent.

I express my best wishes to all our experts this vital area.

07/02/2021, 02:18 - Ajesh Palliwar:

https://www.world-nuclear-news.org/Articles/First-ITER-solenoid-module-completed

07/02/2021, 10:34 - BNBasu Prof: Thank you Dr Joshi for your valuable comment on the effort in the development of cathodes! The cathode activities in India were initially encouraged in India by Dr SSS Agarwala and Dr MD Raj Narayan, and many others including you, and these activities were spearheaded by Mr AK Chopra, Dr RS Raju and Dr KS Bhat. One such an effort was showcased a couple of days ago through group-posting by Dr RK Barik. He posted the abstract of the paper on the development of nanoparticle-based cathode for THz devices. The paper abstracted appears to be so relevant following the lecture delivered on this group forum by Professor Claudio Paolini on sub-THz wireless communications enabled by travelling-wave tubes.

07/02/2021, 10:38 - BNBasu Prof:

https://www.techbriefs.com/component/content/article/tb/pub/techbriefs/electronics-and-computers/19551

07/02/2021, 12:07 - Nalini Pareek CEERI: Thank you very much for sharing the information on cathodes Sir. Being a part of CEERI, to some extent, we are acquainted with the work that has been shared in the group. I would request if we could also get to know about the activities going at other institutes.

07/02/2021, 12:18 - BNBasu Prof: Yes. Elsewhere Dr. Bhat has reported the work of his team. For instance, see the easily accessible link as follows:

07/02/2021, 12:18 - BNBasu Prof:

https://ieeexplore.ieee.org/author/37413634000

07/02/2021, 12:24 - BNBasu Prof: Mostly these are Conference papers. Dr Bhat and his team have journal papers, too. Thank you Nalini motivating me to point out the work reported elsewhere.

07/02/2021, 12:27 - BNBasu Prof: Certainly, the Group will enjoy these discussions as a prerequisite for the webinar lecture by Dr. RS Raju on cathodes in the 5th webinar to be held on 13th March 2021.

07/02/2021, 12:37 - BNBasu Prof:

https://ieeexplore.ieee.org/author/37413634000

07/02/2021, 12:59 - Uttam Goswami CEERI: Sir, we may please add the Mysore based Indian industry Glowtronics, headed by Dr Gupta. He has nice set up for cathode technologies as well as heaters for microwave tubes.

09/02/2021, 01:20 - Ajesh Palliwar: "Try This at Home! Fusion in the Basement" https://spectrum.ieee.org/energywise/energy/nuclear/try-this-at-home-fusion-in-the-basement.amp.html

09/02/2021, 12:48 - Barik CEERI: S. K. Shukla, A. K. Singh, T. P. Singh, S. K. Saini R. K. Poonia, R. S. Raju, and R. K. Barik,

"Study and Development of Yttrium-Doped Nanoscandate Cathode for High-Power VEDs," IEEE Transactions on Electron Devices, vol.63, no.12, pp. 4975 - 4980, Dec 2016.

DOI: 10.1109/TED.2016.2619353

ABSTRACT: Nanoscandate cathode (NSC) has several advantages over a conventional scandate cathode in terms of emission uniformity, resistance to ion bombardment, and long life. In the present technology of "Yttrium-doped NSC," yttrium oxide (Y2O3) is codoped with tungsten powder, scandium oxide, and other impregnant materials to make nanopowder using the solgel technique. The pellets, made out of powder, were integrated with potted heaters. The cathodes were analyzed in an analytical chamber containing: 1) Auger electron spectroscopy for surface analysis; 2) anode for emission measurements; and 3) thermionic emission microscope (THEM) for studying emission uniformity. It was found that by adding a small amount of yttrium oxide of 3%–5% by weight increases the emission uniformity of cathode significantly as observed through THEM. Emission current density of more than 80 A/cm2 was drawn from these cathodes under deep space charge conditions.

09/02/2021, 18:31 - Dr. Vishal Kesari: Please find proceedings of webinar#4. Thanks to all for their motivation and support.

Regards

Vishal Kesari

09/02/2021, 19:59 - BNBasu Prof: I request Dr. Gupta to post a few words about the activities of Glowtronics in the development of oxide- coated and dispenser cathodes.

09/02/2021, 21:12 - SNJoshi CEERI: Dear Vishal good evening. Thanks a lot for sharing the proceedings of Webinar #4. I admire you and your entire team under the able guidance of Prof. BN Basu for bringing out a very exhaustive proceedings, which must have needed very hard work from you all and you in particular.

With best wishes,

09/02/2021, 22:04 - Dr. Vishal Kesari: Thank you very much Sir for your best wishes and appreciations.

Regards.

09/02/2021, 23:21 - BNBasu Prof: Indeed it is meticulously and scholarly done by Dr. Kesari. Hats off to him.

10/02/2021, 01:50 - Ajesh Palliwar: "How Does Nuclear Fusion Work? How Do Fusion Reactors Work?" https://phoenixwi.com/nuclear-fusion/how-does-nuclear-fusion-work/

10/02/2021, 19:36 - Dr. Vishal Kesari: Join on Wednesday, 24 February 2021, at 3 p.m. IST, for an online workshop on

Modeling Conjugate Heat Transfer with COMSOL Multiphysics ®.

During this workshop, we will discuss how to model heat transfer between solids and fluids. We will also cover conduction, convection (natural and forced), radiation, shell and thin layers, and applications such as heat exchangers, heat sinks, and cooling systems.

To register, please visit: https://www.comsol.co.in/c/bek1

I hope to "see" you there! Feel free to invite your colleagues too.

10/02/2021, 20:46 - BNBasu Prof:

https://hr-jobs.lancs.ac.uk/Vacancy.aspx?ref=A3276

11/02/2021, 07:29 - Dr. Vishal Kesari: Thanks to all who have already supported the family of Late Jeevan. This is the further appeal to extend the helping hands to the family. The details may be found in attached Appeal for Support to Late Jeevan's Mother.

Regards.

11/02/2021, 10:10 - BNBasu Prof: No problem. One good news. Regading the details of the Glowtronics company manufacturing cathodes I contacted the helm of the Department. He assured me to post the details before the lecture of Dr. RS Raju in our next webinar in March.

11/02/2021, 10:54 - BNBasu Prof: Maybe it's not a mistake. Perhaps there are supporting information for the relevance of the application of VEDs.

11/02/2021, 11:28 - Subhradeep Chakraborty CEERI: I could appreciate the concern of Professor Basu. I should have posted it along with its relevance to our group. My following postings will now clarify my intentions. We are all dedicated to the cause of the group as discussed in the first webinar of the group which started from the initiative of the CEERI Director and by the support of Professor Basu.

11/02/2021, 11:28 - Subhradeep Chakraborty CEERI: "The trajectory of the probe will expose it to these extreme temperatures with a maximum of 1 400°C. On the approach to its target destination, the solar panels will initially fold back and thanks to a carbon-composite shield 4.5 inches thick, the probe will be protected from the powerful heatwaves of the Sun. Its temperature should be maintained at around 30°C with only the X-band Travelling Wave Tube in operation during this time. As it gradually moves away from the extreme temperatures of the Sun, the probe will be reactivated. With the solar panels back in action, the Ka-band TWT TH4606C will be able to broadcast back to Earth all the scientific data it has collected during its observation phase.

The flight plan is simple, 7 flybys using the gravity of Venus to bring its orbit closer and closer to the Sun. In total, 6 TWTs produced by Thales are present on board the Parker Solar Probe, allowing the transmission of all of NASA's new discoveries. To this day, the Sun has never been studied in situ and the probe is expected to come over seven times closer than any spacecraft has come before. Parker Solar Probe is entering a new chapter of spatial discovery, seeking to solve the mysteries of the solar atmosphere."

11/02/2021, 11:28 - Subhradeep Chakraborty CEERI:

https://www.thalesgroup.com/en/market-specific/microwave-imaging-sub-systems/news/parker-solar-probe-route-sun

11/02/2021, 11:52 - BNBasu Prof: The message from Subhradeep has immense relevance to our group. This evidences the role of TWTs that is impossible to be paralleled by their solid state counterparts.

11/02/2021, 12:05 - Dr. Alok Gupta Glotronics: Vacuum tube has quite a bit of life left for them, Glowtronics has confirmed orders from NASA, British

Aerospace and European defence subcontractors for heaters and oxide cathodes for next 13 years.

11/02/2021, 13:02 - Raj Singh IPR: Persons from IPR are requested to contribute for this noble cause and let me know the details. We have assured Dr. Vishal and Prof. Basu that we will try to contribute at least one lakh from IPR. Let's try to the best of our capacity.

11/02/2021, 13:45 - Dr. Lalit Kumar: Dear Dr Alok Glad to hear from you after such a long time. We should work to leverage the Indian technology of dispenser Cathodes for commercial use. Let us make a resolve to take it forward and the means would follow

12/02/2021, 15:29 - Subhradeep Chakraborty CEERI: Distinguished Members,

I have just received the message and so shared in this group for your kind perusal.

With regards

Subhradeep

12/02/2021, 21:27 - BNBasu Prof: WEBINAR#5 ON 13TH MARCH 2021: TENTATIVE PROGRAMME

CONVENER: Mr. Raj Singh

HOST OF WEBINAR: Dr N Purushothaman

WEB MANAGEMENT: Dr Vishant Gahlaut, Dr Uttam K Goswami, and their team

13TH MARCH 2021

FROM 4.00 PM TO 6:00 PM

SESSION 1: EXPERT TALK

Duration of session 1: 1 hr 10 min

Chair of session 1: Dr KS Bhat

Coordinator of session 1: Dr. Ranjan Barik/Mr. Sushil Shukla

Speaker of session 1: Professor RS Raju

Topic: Some Aspects of the Development of Cathodes for Microwave Tubes

Duration of talk plus discussion: 55 min + 15 min

SESSION 2: RESEARCH CONTRIBUTIONS OF YOUNGER RESEARCHERS IN VEDS

Duration of session 2: 50 minutes

Chair of session 2: Dr Hasina Khatun

Coordinator of session 2: Dr Richards Joe Stanislaus/Dr S Yuvaraj

Speakers of session 2:

First speaker of session 2: Dr. Vikram Kumar

Topic: Sectoral Waveguide HPM Mode Converters

Duration of talk plus discussion: 20 min + 5 min

Second speaker of session 2: Dr. Ajith Kumar MM

Topic: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

Duration of talk plus discussion: 20 min + 5 min

VOTE OF THANKS: Professor KP Ray

12/02/2021, 21:30 - BNBasu Prof: Commendable gesture from Mr. Raj Singh

14/02/2021, 01:02 - BNBasu Prof: MCQ: The credit of practically demonstrating the first ever remote signalling with radio waves goes to

(a) Alexander Stepanovich Popov.

(b) Jagadis Chunder Bose.

(c) Guglielmo Marconi.

(d) Nikola Tesla.

Answer: (b)

14/02/2021, 01:13 - BNBasu Prof: Thought of the Day:

The inventor of TWT is

(a) R. Kompfner.

(b) Andrei Haeff.

(c) J. R. Pierce.

(d) N. E. Lindenblad.

Answer: (b)

14/02/2021, 01:27 - BNBasu Prof: In 1895 Bose gave his first public demonstration of electromagnetic waves, using them to ring a bell remotely and to explode some gunpowder. In 1896 the Daily Chronicle of England reported: "The inventor (J.C. Bose) has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel."

"Popov in Russia was doing similar experiments, but had written in December 1895 that he was still entertaining the hope of remote signaling with radio waves."

"The first successful wireless signaling experiment by Marconi on Salisbury Plain in England was not until May 1897."

Source: D. T. Emerson, "The work of Jagadis Chunder Bose: 100 years of mm-wave research," IEEE Trans. Microwave Th. Tech. December 1997, 45, No. 12 (2267-2273).

14/02/2021, 01:33 - BNBasu Prof: The TWT is known as the Kompfner tube eventhough it was invented by Haeff.

14/02/2021, 09:45 - BNBasu Prof: WEBINAR#5 ON 13TH MARCH 2021: TENTATIVE PROGRAMME

CONVENER: Mr. Raj Singh

HOST OF WEBINAR: Dr N Purushothaman

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Topic: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

Duration of talk plus discussion: 20 min + 5 min

VOTE OF THANKS: Professor KP Ray

14/02/2021, 11:54 - BNBasu Prof: WEBINAR#5 ON 13TH MARCH 2021: TENTATIVE PROGRAMME

CONVENER: Mr. Raj Singh

HOST OF WEBINAR: Dr N Purushothaman

WEB MANAGEMENT: Dr Vishant Gahlaut, Dr Uttam K Goswami, and their team

13TH MARCH 2021

FROM 4.00 PM TO 6:00 PM

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Duration of session 1: 1 hr 10 min

Chair of session 1: Dr KS Bhat

Coordinator of session 1: Dr. Ranjan Barik/Mr. Sushil Shukla

Speaker of session 1: Professor RS Raju

Topic: Some Aspects of the Development of Cathodes for Microwave Tubes

Duration of talk plus discussion: 55 min + 15 min

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Duration of talk plus discussion: 20 min + 5 min

VOTE OF THANKS: Professor KP Ray

14/02/2021, 12:03 - BNBasu Prof: Future wireless communications will extensively employ sub-terahertz TWTs.

14/02/2021, 16:57 - BNBasu Prof: The picture is taken from the lecture slide of a research student at CEERI-Pilani. Professor Subal Kar and Dr N Purushothaman will deliver webinar lectures in the area of metamaterial on this forum tentatively on 8th May 2021.

15/02/2021, 01:53 - Ajesh Palliwar: "Nuclear Fusion – NORVENTO" https://www.norvento.com/en/nuclear-fusion/

15/02/2021, 02:30 - Ghanshyam Singh: This article very interesting for the researchers particularly those who are working or interested to work in the terahertz regime of the spectrum. How the terahertz bands (0.1-10THz, 0.3-3THz, 0.3-30THz) are defined? Which one is correct and why? I am confident that many of you know it but you must check for your correctness.

16/02/2021, 01:50 - Ajesh Palliwar: "Scientists Use Lithium To Control Heat In Nuclear Fusion Reactors | OilPrice.com" https://oilprice.com/Latest-Energy-News/World-News/Scientists-Use-Lithium-To-Control-Heat-In-Nuclear-Fusion-Reactors.amp.html

17/02/2021, 18:47 - Dr. Vishal Kesari: COMSOL is organizing an online workshop on 'Modeling Conjugate Heat Transfer with COMSOL Multiphysics ®', on Wednesday, 24 February 2021 at 3 p.m. IST, and they hope to see you there!

In this workshop, they will discuss how to model heat transfer between solids and fluids. They will cover conduction, natural and forced convection, radiation as well as modeling heat transfer in shell and thin layers, for applications such as heat exchangers, heat sinks, and cooling systems.

To register, please visit: https://www.comsol.co.in/c/bek1

18/02/2021, 13:07 - BNBasu Prof: Shyam works in the area of gyro-twystron in the doctoral programme of IIT-BHU with Dr. Thottappan as his mentor.

18/02/2021, 13:14 - Dr. Lalit Kumar: An interesting Thesis on Metamaterials for VED'shttps://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=5272&context=gradschool_dissertations

19/02/2021, 02:14 - Ajesh Palliwar:

https://www.youtube.com/watch?v=ekub_xEiUww

21/02/2021, 13:22 - BNBasu Prof: We have an available postdoctoral position in the Micro-Millimeter-Wave Laboratory of Prof. Sungjoon Lim at CAU (https://www.mmw.cau.ac.kr/), Seoul, South Korea on intelligent metasurfaces, electro-mechanically programmable metasurfaces, and 4D printing technologies. Recent works from Prof. Lim's lab have been published in leading journals such as IEEE TAP, IEEE AWPL, IEEE Access, Advanced Optical Materials, Scientific Reports, Extreme Mechanics Letters, Physics of Fluids, Additive Manufacturing, etc.

Interested candidates may apply soon at sungjoon@cau.ac.kr (cover letter and their well-prepared CV).

Good Luck!!

21/02/2021, 20:52 - Dr. Sarit Pal: Invitation Letter

R&D Cell,

Dr. B. C. Roy Engineering College, Durgapur,

Organizing

One-day Webinar on "Journey from Vacuum Tube to Carbon Nanotube"

Dear All,

Greetings from Dr. B. C. Roy Engineering College, Durgapur.

It gives us immense pleasure to announce that we are going to organize a National Webinar on "Journey from Vacuum Tube to

Carbon Nanotube" on 27th February 2021 from 3:30 pm onwards.

Please share it with the Faculty of your respective branch.

There is no registration fee for the Webinar.

The E-Certificate will be given to the participants who will attend and submit feedback of the webinar.

Kindly register at:

https://forms.gle/XRPNV3gGhiBaCXr57

Please join our whatsapp group of the webinar:

https://chat.whatsapp.com/HYmEsyNmU4YGWtF33qgmGI

For more information kindly contact:

Prof. (Dr.) SARIT PAL

Dr. B. C. Roy Engineering College, Durgapur

Contact: 9800765952

E-mail: pal.sarit@gmail.com, sarit.pal@bcrec.ac.in

Regards

Dr. Sarit Pal

22/02/2021, 15:55 - BNBasu Prof: Tetiana I. Tkachova, Vitalii I. Shcherbinin, Viktor I. Tkachenko, Zisis C. Ioannidis, Manfred Thumm and John Jelonnek, "Starting currents of modes in cylindrical cavities with mode-converting corrugations for second-harmonic gyrotrons, Journal of Infrared, Millimeter, and Terahertz Waves (2021), https://doi.org/10.1007/s10762-021-00772-z

Abstract

A self-consistent system of equations (known as single-mode gyrotron equations) is extended to describe the beam-wave interaction in a cylindrical gyrotron cavity with mode-converting longitudinal corrugations, which produce coupling of azimuthal basis modes. The system of equations is applied to investigate the effect of corrugations on starting currents of the cavity modes. For these modes, eigenvalues, ohmic losses, field structure, and beam-wave coupling coefficients are investigated with respect to the corrugation parameters. It is shown that properly sized mode-converting corrugations are capable of improving the selectivity properties of cylindrical cavities for second-harmonic gyrotrons.

23/02/2021, 16:30 - BNBasu Prof: The following book is of immense value to VED Thinkers:

Richard G. Carter, "Microwave and RF Vacuum Electronic Power Sources," Cambridge University Press, April, 2018, DOI: 10.1017/9780511979231.

We have cited the book in the following paper:

"Raktim Guha, A. K. Bandyopadhyay, A. K. Varshney, S. K. Datta, and B. N. Basu, "Investigations into helix slow-wave structure assisted by double-negative metamaterial," IEEE Trans. Electron Devices, vol. 65, pp. 5082-5088 (2018)."

24/02/2021, 05:40 - Dr. Vishal Kesari: Tomorrow, 24 February 2021, at 3 p.m. IST online workshop on 'Modeling Conjugate Heat Transfer with

COMSOL Multiphysics ®.'

In this workshop, we will discuss how to model heat transfer between solids and fluids. We will cover conduction, natural and forced convection, radiation as well as modeling heat transfer in shell and thin layers, for applications such as heat exchangers, heat sinks, and cooling systems.

To register, please visit: https://www.comsol.co.in/c/bek1

25/02/2021, 10:53 - Subhradeep Chakraborty CEERI: Dear All,

IEEE India Council is planning to create a directory of domain Experts within India. All IEEE Life Fellows/Fellows/Life Senior/Senior members are requested to provide their details. Based on willingness, this database will be shared with MeitY, DST, CSIR and other government departments for possible inclusion in various expert committees. IC will also be able to suggest some experts for various committees within and outside IEEE.

You are requested to provide your details at:

https://forms.gle/Q5ESaopNSoxo87P87

Looking forward to hear from you.

WR

Puneet Kumar Mishra

Vice Chair (Professional Activities), IEEE India Council

25/02/2021, 13:14 - BNBasu Prof: S. K. Datta; K. S. Bhat, V. Srivastava, Y. Choyal; P. K. Jain, Baidyanath Basu, "Initiatives in new generation high power microwave sources in India, 2011 IEEE Applied Electromagnetics Conference (AEMC), Kolkata, 18-22 Dec. 2011. DOI: 10.1109/AEMC.2011.6256907

Abstract:

Over the last five decades, R&D, industry and academia in India have contributed significantly to electromagnetic analysis, numerical modelling and simulations and technologies in the area of microwave vacuum electronic sources, that culminated in the development and productionisation of a number of microwave tubes in India and enabled the concerned community to venture towards a number of new generation sources. This talk proposes to highlight the initiatives in India in the area.

25/02/2021, 16:51 - Dr. Sarit Pal: Invitation Letter

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The E-Certificate will be given to the participants who will attend and submit feedback of the webinar.

Kindly register at:

https://forms.gle/XRPNV3gGhiBaCXr57

Please join our whatsapp group of the webinar:

https://chat.whatsapp.com/HYmEsyNmU4YGWtF33qgmGl

For more information kindly contact:

Prof.(Dr.) SARIT PAL

Dr. B. C. Roy Engineering College, Durgapur

Contact: 9800765952

E-mail: pal.sarit@gmail.com

sarit.pal@bcrec.ac.in

Regards

Dr. Sarit Pal

27/02/2021, 14:21 - Dr. Sarit Pal: The link for Google Meet is

https://meet.google.com/gvz-gzfb-tiw

28/02/2021, 07:09 - BNBasu Prof: WEBINAR#5 ON 13TH MARCH 2021: TENTATIVE PROGRAMME

CONVENER: Mr. Raj Singh

HOST OF WEBINAR: Dr N Purushothaman

WEB MANAGEMENT: Dr Vishant Gahlaut, Dr Uttam K Goswami, and their team

13TH MARCH 2021

FROM 4.00 PM TO 6:00 PM

SESSION 1: EXPERT TALK

Duration of session 1: 1 hr 10 min

Chair of session 1: Dr KS Bhat

Coordinator of session 1: Dr. Ranjan Barik/Mr. Sushil Shukla

Speaker of session 1: Professor RS Raju

Topic: Some Aspects of the Development of Cathodes for Microwave Tubes

Duration of talk plus discussion: 55 min + 15 min

SESSION 2: RESEARCH CONTRIBUTIONS OF YOUNGER RESEARCHERS IN VEDS

Duration of session 2: 50 minutes

Chair of session 2: Dr Hasina Khatun

Coordinator of session 2: Dr Richards Joe Stanislaus/Dr S Yuvaraj

Speakers of session 2:

First speaker of session 2: Dr. Vikram Kumar

Topic: Sectoral Waveguide HPM Mode Converters

Duration of talk plus discussion: 20 min + 5 min

Second speaker of session 2: Dr. Ajith Kumar MM

Topic: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

Duration of talk plus discussion: 20 min + 5 min

VOTE OF THANKS: Professor KP Ray

28/02/2021, 07:11 - BNBasu Prof: The final programme will be announced by the Convener soon.

02/03/2021, 01:21 - Ajesh Palliwar: https://youtu.be/97DMTPmvMil

03/03/2021, 07:42 - BNBasu Prof: WEBINAR#5 ON 13TH MARCH 2021: TENTATIVE PROGRAMME

CONVENER: Mr. Raj Singh

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Duration of talk plus discussion: 20 min + 5 min

VOTE OF THANKS: Professor KP Ray

04/03/2021, 13:37 - BNBasu Prof: I am happy from the announcement of the tentative programme of webinar#5 to be convened by Mr. Raj Singh on 13th March 2021 on this platform that one of the lectures is on cathodes. The self reliance in the area of vacuum electron devices (VEDs) depends much on the self reliance in the area of cathodes. The area encompasses thermionic cathodes (such as M-type, MM-type, Scandate, controlled porosity dispenser (CPD) cathodes, etc) and field emission (explosive and non-explosive) cathodes (such as Spindt, CNT, and graphene-based emitters, etc). Interestingly, the area includes the plasma cathode (typically, a hollow enclosure filled with helium or hydrogen at 5-50mTorr) of VED developers interested in the areas of plasma-assisted VEDs (one such VED, namely, pasotron having been already developed by CEERI).

04/03/2021, 14:09 - Raj Singh IPR: As Prof. Basu rightly said in his above post "The self reliance in the area of VEDs depend much on the self reliance in the area of Cathode". Keeping this importance of Cathodes in mind, we are organising an expert talk on Cathode by Prof R S Raju in our coming webinar on 13th March. Please book your date. We r sure you will enjoy this enlightened talk. The discussion and question answer after the talk among our esteemed group members will also give an extended understanding of this area of cathode development. We will also have two more talks by our young researchers Dr. Vikram and Dr. Ajith Kumar. I am sure like all our past webinars, this webinar will also mesmerize you all who must be eagerly waiting for this bimonthly science festival.

04/03/2021, 14:09 - Raj Singh IPR: WEBINAR#5

Tentative Program

Date: 13th March, 2021

Time: 4:00 to 6:00 PM

Total Two Sessions

Host of Webinar: Dr N. Purushothaman

Web Management: Dr Vishant Gahlaut, Dr Uttam K Goswami and their team

Session 1: Expert Talk

Duration: 1 hr 10 min

Chair: Dr K S Bhat

Coordinator: Dr. Ranjan Barik / Mr. Sushil Shukla

Speaker: Professor R S Raju

Topic: Some Aspects of Development of Cathodes for Microwave Tubes

Duration of talk plus discussion: 55 min + 15 min

Session 2: Research Contributions of Younger Researchers in VEDS

Two Talks

Total Duration: 50 minutes

Chair: Dr Hasina Khatun

Coordinator: Dr Richards Joe Stanislaus / Dr S Yuvaraj

Speakers

First Talk. Dr. Vikram Kumar

Topic: Sectoral Waveguide HPM Mode Converters

Duration of talk plus discussion: 20 min + 5 min

Second Talk: Dr. Ajith Kumar MM

Topic: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

Duration of talk plus discussion: 20 min + 5 min

Vote of Thanks: Professor KP Ray

Convener: Mr. Raj Singh

04/03/2021, 20:27 - BNBasu Prof: R. K. Barik, A. K. Singh, S. K. Shukla, T. P. Singh, R. S. Raju, and G.-S. Park, "Development of Nanoparticle-Based High Current Density Cathode for THz Devices Application," IEEE Transactions on Electron Devices, vol.63, no.4, pp. 1715 - 1721, April 2016.

DOI: 10.1109/TED.2016.2524539

ABSTRACT: Scandia (Sc_2O_3)-doped tungsten nanoparticle-based high current density cathode is developed for the application in terahertz (THz) devices. This paper involves synthesis of scandia doped tungsten nanoparticle powder using chemical technique, estimation of optimum porosity, and development of pellet with required porosity by optimizing process parameters. The cathode, made out of the above pellet, is tested in an analytical system containing Auger electron spectroscope and anode. The results show that the cathode can deliver more than 100 A/cm2 current density with stable emission—strongly recommending it as a candidate for the use in a THz device. Theoretical estimates show that the void porosity is to be kept at 21% for proper surface coverage to produce good emission with long life.

04/03/2021, 20:29 - BNBasu Prof: S. K. Shukla, A. K. Singh, T. P. Singh, S. K. Saini R. K. Poonia, R. S. Raju, and R. K. Barik,

"Study and Development of Yttrium-Doped Nanoscandate Cathode for High-Power VEDs," IEEE Transactions on Electron Devices, vol.63, no.12, pp. 4975 - 4980, Dec 2016.

DOI: 10.1109/TED.2016.2619353

ABSTRACT: Nanoscandate cathode (NSC) has several advantages over a conventional scandate cathode in terms of emission uniformity, resistance to ion bombardment, and long life. In the present technology of "Yttrium-doped NSC," yttrium oxide (Y_2O_3) is codoped with tungsten powder, scandium oxide, and other impregnant materials to make nanopowder using the solgel technique. The pellets, made out of powder, were integrated with potted heaters. The cathodes were analyzed in an analytical chamber containing: 1) Auger electron spectroscopy for surface analysis; 2) anode for emission measurements; and 3) thermionic emission microscope (THEM) for studying emission uniformity. It was found that by adding a small amount of yttrium oxide of 3%–5% by weight increases the emission uniformity of cathode significantly as observed through THEM. Emission current density of more than 80 A/cm2 was drawn from these cathodes under deep space charge conditions.

04/03/2021, 21:05 - BNBasu Prof: 1. Asish Kumar Singh, Sushil Kumar Shukla, Meduri Ravi, and Ranjan Kumar Barik," A Review of Electron Emitters for High-Power and High-Frequency Vacuum Electron Devices," IEEE Transactions on Plasma Science, vol. 48, No. 10, pp. 3446 - 3454, Sept 2020.

DOI: 10.1109/TPS.2020.3011285

Abstract— This work reviews the progress in the area of high current density electron emitters, specifically for use in high frequency and high-power microwave vacuum electron devices. The review is divided into two subsections: 1) thermionic cathodes and 2) field emission cathodes. The thermionic cathode section includes the discussion on the M-type, MM-type, Scandate and the CPD cathodes. CPD cathode promises better usability in a practical device as compared to the Scandate cathodes which are limited by emission nonuniformity, poor resistance to poisoning/ ion bombardment and low life. With the increasing demand for miniaturized and high power VEDs in the near future, the development of high current density field emission cathodes is of immediate interest to the VED community. The Spindt, CNT, and graphene-based emitters are the potential candidates in the field emitters section. Graphene-based film cathodes, when compared to the Mo/Si FEAs and the CNTs, offer larger emission area as well as high current carrying capability. This review includes the evolution of the emission capabilities of the emitters, state-of-the-art performances, and possible future developments.

2. S. K. Shukla, A. K. Singh, R. K. Barik, "Synthesis of Rhenium–Scandia doped tungsten nanoparticles for shrinkage investigation," Journal of Sol-Gel Science and Technology, volume 95, pages, 384–392, Feb. 2020.

DOI: 10.1007/s10971-020-05253-8

Abstract:

Scandate cathode made out of tungsten nanoparticles have several advantages such as high current density, uniform emission, and long life over conventional cathode. Fabrication of porous tungsten pellet out of tungsten nanoparticles by pressing and sintering is a critical challenge. Cold pressing followed by sintering of nanoparticles results shrinkage of pellet size and uncontrolled porosity, which motivate us to work on sintering of nanoparticle. A new chemical synthesis approach was adopted for precisely controlling the powder particle parameters. The present technology relates to the preparation of an ultra-fine nano-scandate powder using chemical route, dissolving tungsten, and rhenium powder in special solvent under ultra-agitation, wherein the other constituents (such as Ba, Ca, Sc, and alumina) are uniformly distributed throughout the powder. Dissolving tungsten and rhenium in the solution, and further sol–gel process, resulted in the formation of spherical shaped particles. Nanoparticles were characterized using: (1) X-ray diffraction (XRD) for phase purity of powder, (2) Field Emission Scanning Electron Microscopy (FE-SEM) for particle size and distribution, (3) Scanning Electron Microscopy (SEM) to study the surface micro-features such as pore dimension and pore distribution and (d) Energy Dispersive Analysis of X-rays (EDAX) for elemental composition. The results showed that the powder has uniform grain size with an average particle diameter of ~100 nm. In this proposed work, rhenium has been co-doped with scandia doped tungsten nanoparticles in order to improve shrinkage. Addition of rhenium in scandia doped tungsten nanoparticles showed about 10% less shrinkage compared with scandia doped tungsten nanoparticle.

04/03/2021, 21:29 - BNBasu Prof: The message above containing two abstracts have been sent by Dr. Ranjan Barik of CEERI. I will post similar messages from him in due course.

05/03/2021, 12:34 - SNJoshi CEERI: Dear all,

It is a matter of great pleasure that the announcement of Webinar #5 has been made by Sh Raj Singh of IPR. I expressmy best wishes to him and his entire team under the overall domain of Prof.BN Basu.

The subject Cathode has great relevance to researchers working in the areas of Microwave Tubes, linear Accelerators, Vacuum Microelectronics etc. The Cathode is considered as a very key element of any such device like heart of human beings. If Cathode has a problem, everything is likely to fail.

In our Country lot of efforts are being made by different organizations and success has also been achieved to some extent. However, the requirements are enormous and it requires dedicated and sustained efforts by concerned organizations. As on today, by and large we are still dependent on foreign suppliers to meet our requirements.

However, we have to be positive in our thinking and should strive hard to achieve the goals.

The subject is so important that it requires intervention of higher authorities as well support to private agencies engaged in this or related areas.

I once again express my best wishes for the great success of the Webinar and expect that in particular, our young and dynamic researchers will make best use of the deliberations in the Webinar.

05/03/2021, 13:24 - LMJoshi CEERI: Good afternoon. It is heartening to note that the schedule for Webinar # 5 has been fixed. The major focus of the event is on Cathode, the heart of every VED. There has been tremendous progress in cathode science and technology since early days of oxide coated versions. Looking forward listening to expert talk by Dr. RS Raju, one of the most well known experts of this field. Most of the VEDs being developed in our country still use imported cathodes. It will be nice if some light may be thrown on status of indigenous manufacturing and involvement of industry in this very important area. 🙏🙏

05/03/2021, 15:19 - BNBasu Prof:

Glowtronics Pvt. Ltd. (www.glowtronics.com)

Oxide Cathode and Heater Journey

In 1985, Bharat Electronics Ltd. (BEL) decided to embark on the path of indigenising as many parts of B&W TV picture tubes as possible by finding private companies who might have the knowledge and inclination for such a venture.

Broadly TV picture tube CRT was divided into following main sub sections for indigenisation effort:

1. Glass parts for the main shell
2. Phosphor for image generation
3. Getters
4. Electron Gun consisting of:
    a. Stamped metal parts (Grids)
    b. Glass base (Stems)
    c. Sintered glass holders (Side Rods)
    d. Emissive products (Cathodes and Heaters)

Glass parts for the main shell required large investments so BEL set up a suitable plant at Taloja, Maharashtra themselves.

Phosphors and Getters involved very high chemical technologies so these were abandoned.

One Indian player attempted to manufacture metal stamped grids but because of requirements of very tight tolerances and miniature apertures, gave up.

Glass Stems and Sintered side rods were taken up by a Bangalore based company, Amitronics Pvt. Ltd., who successfully developed these parts and in due course of time became world player in this field.

BEL heard from some sources that one Alok Gupta, who is Joint Managing Director of a lamp filament manufacturing company in Mysore, was associated with Dr. Roberto Levi, inventor of M Dispenser Cathode, has some knowledge of emissive products and might be able to develop emissive products for TV picture tube.

BEL top management was very apprehensive about the quality of locally made Cathodes because the normal 20-30 year lifespan of a picture tube is predominately dependent on the continued proper emission from the cathode. Therefore another condition put up by BEL was that GPL must get technical knowhow from some outside company for Cathodes.

Since none of the major companies like RCA, Sony, Samsung, LG, Philips, NEC etc were willing to transfer technology, a small relatively unknown company South West Vacuum Devices (SWVD), came forward to collaborate provided they were given 40% equity in the company.

Glowtronics (GPL) was thus established in 1986 with an MOU with BEL to produce Heaters and Cathodes for B&W TV picture tube. The understanding was that if GPL can develop Heaters and cathodes equivalent to Japanese products at a cheaper price, then BEL will buy those from GPL.

SWVD was making cathodes but had no knowledge about heaters, so GPL decided to develop the heater technology in-house based on tungsten lamp filament knowledge.

Cathode making process given by SWVD also had to undergo major overhaul at GPL for the cathodes to fulfil the Japanese technical requirements. This was acknowledged by SWVD and very soon they stopped making cathodes themselves and became GPL customers. In early 1990's GPL was able to buy back SWVD 40% stake and became fully Indian owned company.

GPL supplied Heater and cathodes to Indian B&W Picture tube makers Like BEL & Teletube till these got phased out.

GPL was also supplier for heaters and cathodes used in monochrome CRT's for professional applications like medical and high resolution imaging to many overseas customers including China.

GPL developed Heaters and cathodes for Colour picture tube in 1992 and were suppliers to Samtel and JCT till they shut down their factories in India.

Overseas supply of Colour Heaters and Cathodes started with LG, continued with Thai CRT and ended in 2018 with the last Chinese customer making Colour tubes in the world.

In 1994, GPL developed special cathodes and Heaters used in Space and Avionics CRT's and over time GPL has become the sole supplier of these products in the free world at the present time.

NASA subcontractor has placed order on GPL for Oxide Cathodes and Heaters for next 13 years along with advance payment; recently delivered Rafael Jet Fighters to India have GPL Heaters and Cathodes used in the Helmet Displays made by Thales, France.

For technical intrigue of some of the readers, I have attached a small sketch of Oxide Cathode Basics; will be glad to interact with anybody having further queries.

Dr. Alok Gupta Ph.D. (gupta.alok@glowtronics.com)

05/03/2021, 17:52 - Rahul Sadhu: Have anybody procured keysight N8976B noise figure analyzer?

Up to 40 GHz operation!

05/03/2021, 21:46 - Uttam Goswami CEERI: You may contact to Diagnostic Group of IPR, that lab is having up to 40 GHz

05/03/2021, 22:54 - BNBasu Prof: I have already posted on this group forum the abstracts of some of the papers of CEERI on the subject of cathodes. You can have a glimpse of some of the work on cathodes carried out under the leadership of Dr. KS Bhat at MTRDC by visiting the Website:

https://ieeexplore.ieee.org/author/37413634000

06/03/2021, 10:31 - BNBasu Prof: I found that while Dr. RS Raju is going to deliver his lecture on cathodes in the first session of Webinar#5 of our group on 13th March 2021, Dr. Vikram Kumar and Dr. Ajith Kumar MM in the second session of the webinar are going to present their talks in two different topics, respectively. I have already posted the abstracts of a few papers on cathodes related to the subject of the first session. Now, I take the privilege of posting the abstracts of a few papers related to the subject of the second session of the webinar, as follows.

06/03/2021, 10:32 - BNBasu Prof: Vikram Kumar, Smrity Dwivedi, and Pradip K. Jain, "Mode-matching analysis for characterization of the sectoral waveguide mode converters," Microwave and Optical Technological Letters, Vol. 61, Issue: 11, pp. 2619-2627 (2019).

https://doi.org/10.1002/mop.31941.

Abstract:

An S-band sectoral waveguide (SWG) mode converter was presented for simulation and electromagnetic analysis. A mode-matching technique (MMT) for the electromagnetic analysis of an SWG mode converter has been proposed. The problem of trifurcation of the coaxial waveguide to shape SWGs and bifurcation of SWGs is discussed. In this framework, the selections of appropriate testing modes at each junction are justified. The simulation time has improved and the complexity of the proposed problem has reduced by the proposed approach. The numerical results of the MMT are compared against simulation results and are found to be in good agreement. The efficiency of both the simulated and analyzed results shows mode conversion efficiency higher than 98.0%. An experimental evaluation shows the mode conversion of TM01 to TE11 mode using far-field radiation patterns and has been compared with simulation results. Also, the MMT and simulation validate the mode conversion of TM01 to TE11 mode.

Kumar, A. M. M., Aditya, S., and Wang. S., "A W-Band backward-wave oscillator based on planar helix slow-wave structure," IEEE Transactions on Electron Devices, Vol 65, Issue: 11, pp. 5097 – 5102 (2018). doi:10.1109/TED.2018.2871785.

Abstract:

A backward-wave oscillator (BWO) operating at W-band is presented. The BWO is based on a microfabrication-compatible planar helix slow wave structure with straight-edge connections (PH-SECs). The oscillator is designed to operate with a beam current of 20 mA and a beam voltage

varying from 7 kV to 11 kV. Dispersion characteristics and their sensitivity to some of the geometrical parameters are presented. The particle-in-cell simulation results show that the oscillator frequency tunes from 86.9 GHz to 100.07 GHz with a tunable bandwidth of 14%. The oscillator provides a maximum peak output power of 2.3 W and a peak efficiency of 1.62%. Results of oscillator performance with a beam current of 18 mA and 16 mA are also presented. To validate the simulation results of the PH-SEC, a scaled version of the PH-SEC operating at X-band is fabricated. The measured S-parameters and the phase velocity for the fabricated structure match very well with the simulation results.

Ciersiang Chua, Julius M. Tsai, Sheel Aditya, Min Tang, Soon Wee Ho, Zhongxiang Shen, and Lei Wang, "Microfabrication and characterization of W-band planar helix slow-wave structure with straight-edge connections," IEEE Transactions on Electron Devices, Vol 58, Issue: 11, pp 4098 – 4105 (2011). DOI: 10.1109/TED.2011.2165284.

Abstract:

A slow-wave structure (SWS) consisting of a planar helix with straight-edge connections and incorporating a coplanar waveguide feed has been designed for operation at W-band and has been fabricated using microfabrication technique. On-wafer cold measurements have been carried out on a number of fabricated SWSs, and the results are reported here for the first time. The parameters measured are return loss, attenuation, and phase velocity, and the results cover a frequency range of 70-100 GHz. Cold-test parameters of the SWS have been also obtained using simulations, and the effects of fabrication, such as surface roughness, have been accounted for by estimating effective conductivity of different parts of the microfabricated structures. The measured and simulated results match well. The effects of silicon wafer resistivity have been also discussed. Planar helical SWSs fabricated in this manner have application in traveling-wave tubes operating at millimeter wave and higher frequencies.

Chen Zhao, Sheel Aditya, Shaomeng Wang, Jianmin Miao, and Xin Xia, "A wideband microfabricated KA-band planar helix slow-wave structure," IEEE Transactions on Electron Devices, Vol 63, Issue: 7, pp 2900 – 2906 (2016). DOI: 10.1109/TED.2016.2563480.

Abstract:

A Ka-band planar helix slow-wave structure (SWS) which is suitable for microfabrication is proposed and its design is described in this paper. A wideband design is achieved by using dispersion control techniques. The design shows an S11 better than −20 dB over a 42.8% cold-test bandwidth with discrete input and output ports. Cold-test results for coplanar waveguide ports are also presented. The hot-test parameters of the SWS with discrete ports are investigated using CST Particle Studio. For an elliptical cross-sectional electron beam with the beam voltage of 3.72 kV and the current of 50 mA, a 3-dB small-signal gain bandwidth of 48.5% and a maximum gain of 42 dB are achieved. Saturated power of 26.5 W is achieved by using pitch

tapering. Hot-test performance of the proposed SWS including a sever for high gain applications is also presented. Thermal simulations using CST have been carried out showing that the proposed SWS can have very good thermal dissipation properties. RF electric field values at some critical locations in the SWS have also been examined from the point of view of dielectric breakdown.

Krithi Swaminathan; Chen Zhao; Ciersiang Chua; Sheel Aditya,

"Vane-Loaded Planar Helix Slow-Wave Structure for Application in Broadband Traveling-Wave Tubes," IEEE Transactions on Electron Devices, Vol. 62, Issue: 3, pp. 1017 – 1023 (2015).

Abstract:

Dispersion control of a planar helix slow-wave structure (SWS) using vane loading for applications in traveling-wave tubes has been studied. The addition of metal vanes and coplanar ground planes to the planar helix structure has been investigated with the help of simulations aimed at achieving low or negative dispersion. It is shown that, similar to the case of circular helix, the addition of metallic vanes to the planar helix can produce a flatter dispersion curve or negative dispersion characteristics. Furthermore, it is shown that even stronger dispersion control can be achieved by the use of metal vanes together with extended coplanar ground planes on the dielectric substrates that support the planar helix. As a proof of concept, one of the designs of the planar helix SWS including metal vanes and operating at S-band frequencies has been fabricated and tested; the measured phase velocity results match the simulation results very well. DOI: 10.1109/TED.2014.2386338.

06/03/2021, 17:05 - Dr. Alok Gupta Glotronics:

Glowtronics Dispenser Cathode Journey

Historical Background:

In late 1960's there were 4 manufacturers of Dispenser Cathodes in USA:

1. Spectra-Mat, California – Headed by Mr. Leo Cronin
2. Semicon, Kentucky – A division of Varian
3. Kometco, Florida – Headed by Dr. Otto Koppius
4. Philips Metalonics, New York – Headed by Dr. Roberto Levi

In 1972, Dr. Levi decided to retire and sold Philips Metalonics (Metalonics) to Philips Elmet (Elmet), where Alok Gupta had joined as a young engineer, recently emigrating from India.

Alok Gupta was given the responsibility to work with Dr. Levi for several months, learn the technology, move the plant to Elmet, Maine, and then run this division as Operations Head.

Alok Gupta ran this Dispenser Cathode division for 2 years after which Elmet decided to sell the business to Spectra-Mat because they wanted to concentrate on their core business of Tungsten and Molybdenum products.

Since Elmet-Metalonics was one of the key suppliers to US Defence system, Elmet was asked to document the manufacturing technology before transferring the operations. Alok Gupta authored "Technology of Manufacture of M Type Dispenser Cathode" along with Mr. C.O. Young. This document was published in a booklet form in 1977 by US Defence for internal use of their suppliers.

Alok Gupta continued to work with Elmet as Chief Engineer, R&D, till 1979, the year when he returned to India.

Glowtronics Journey:

Alok Gupta established Glowtronics Pvt. Ltd. (GPL) in 1986 to manufacture Oxide Cathodes and Heaters for TV Picture Tubes, based on a MOU with Bharat Electronics Ltd. (BEL).

While dealing with BEL, some interactions took place about local manufacture of Dispenser Cathodes but nothing concrete came out because of very low volume requirements of the country and therefore economic un-viability.

In 1997, Dr. Avinash Kulkarni of Litex, Pune, approached GPL to set up facility for manufacturing Dispenser Electrodes to be used in Medical Laser Lamps that they had recently started manufacturing.

Dr. Kulkarni also mentioned that Kometco, Florida, equipment was available for sale, if GPL was interested.

In November 1997, GPL purchased Kometco equipment from Catho-Tronics, who were owners of this equipment since 1980.

GPL commissioned the facility in Mysore and stated supplying Dispenser Electrodes to Litex in 1998.

In mid 1998, GPL also took up development of M type Dispenser Cathodes for vacuum tube applications by installing Os-Ru sputtering equipment.

First successfully developed cathodes were for CRT application operating with 1.5 Watt heater. This development did not go far commercially because of its cost as compared to Oxide Cathodes.

Several future studies to examine the economic viability of Dispenser Cathodes for Microwave, TWT and such applications resulted in negative conclusions and as such GPL stopped further work in that area.

Over the years GPL has actively collaborated with MTRDC & CEERI by providing engineering services in this field for them to fabricate Dispenser Cathodes for research activities.

In the past GPL also worked with ISRO on their project to develop indigenous Ion Thrusters used in Satellite positioning.

At the present time GPL continues to design, develop and supply Dispenser Electrodes used in Flash Lamps and other scientific applications to customers in India, USA, UK, Korea, Japan and China.

To get an overview of GPL product range, interested could visit the website www.glowtronics.com

I will be glad to interact with anybody having further queries.

Dr. Alok Gupta Ph.D. (gupta.alok@glowtronics.com)

08/03/2021, 10:34 - Raj Singh IPR:

WEBINAR#5

Date: 13th March, 2021

Time: 4:00 to 6:00 PM

Total Two Sessions

Host of Webinar: Dr N. Purushothaman

Web Management: Dr Vishant Gahlaut, Dr Uttam K Goswami and their team

Session 1: Expert Talk

Duration: 1 hr 10 min

Chair: Dr K S Bhat

Coordinator: Dr. Ranjan Barik / Mr. Sushil Shukla

Speaker: Professor R S Raju

Topic: Some Aspects of Development of Cathodes for Microwave Tubes

Duration of talk plus discussion: 55 min + 15 min

Session 2: Research Contributions of Younger Researchers in VEDS

Two Talks

Total Duration: 50 minutes

Chair: Dr Hasina Khatun

Coordinator: Dr Richards Joe Stanislaus / Dr S Yuvaraj

Speakers

First Talk. Dr. Vikram Kumar

Topic: Sectoral Waveguide HPM Mode Converters

Duration of talk plus discussion: 20 min + 5 min

Second Talk: Dr. Ajith Kumar M M

Topic: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillators

Duration of talk plus discussion: 20 min + 5 min

Vote of Thanks: Professor KP Ray

Convener: Mr. Raj Singh

All are cordially invited

08/03/2021, 12:45 - Dr. Lalit Kumar: Nice that Dr Gupta has highlighted his involvement in early work on cathode and pioneering efforts in setting up oxide cathode and dispenser cathode and heater business in India.

Another Indian who did pioneering work on dispenser Cathodes was Dr. Arvind Scroff at Thales France. He also spent a few visits at MTRDC as a consultant.

We at MTRDC have tried to involve GLOWTRONICS to produce a few batches of Cathodes as per MTRDC tech dev by Dr Bhat.

Considering the cathode tech base MTRDC CEERI GLOWTRONICS and BEL there is a good potential for its commercial exploitation. The need is to evolve a robust business model keeping the sight on Global market.

08/03/2021, 22:34 - BNBasu Prof: I attach the January 2021 issue of CSIR CEERI News (Vol. 60(1)). It is so nice of Dr. PC Panchariya, the Director, CEERI to publish my modest effort in an article on the life of Dr. Amarjit Singh, the erstwhile CEERI Director, who significantly contributed to the area of vacuum electron devices (VEDs), besides other various areas of electronics engineering. The article is dedicated to Dr. SSS Agarwal, another great scientist in the area of VEDs. I have written this article from the information received from Professor SC Dutta Roy; Dr. Chandra Shekhar, the erstwhile CEERI Director and presently Chancellor of CSIR-Academy of Scientific and Innovative Research; and Dr. SN Joshi, the erstwhile Head of Microwave Tube Area of CEERI. Ms. Sreelatha Menon edited the manuscript. Mr. Rohit Singh of CEERI Library helped me in proofreading the manuscript.

10/03/2021, 15:40 - KSBhat MTRDC: For a change a piece of poetry on cathodes.

Cathode calling…

Hello hello microwaves,

Don't run with the speed of light

I would like to be with you in your flight

Together we will reach the goal tonight

Please don't run, Wait, please wait!

I am 'electron', my mother is Cathode

Was playing In a space charge in her heavenly abode..

Suddenly A high voltage swing came from nowhere

and caught me unaware and drove me to where you are!.

There I saw you in a sprinting speed

I wondered where you were going indeed

Why don't you try to take me with you and lead

We can be friends, from now and in deed!

May we go together in thick and flow
I have the energy to lend you to grow
Together we reach the heights of the sky
With power and energy sufficiently high!
And finally, you grow and I get spent
That's what life is, to a large extent…!

Written by K S Bhat

10/03/2021, 15:49 - SNJoshi CEERI: Very nice description of call of Cathode. Thanks Dr Bhat for your this imagination and creativity.

Good evening and best wishes to you all.

10/03/2021, 15:55 - BNBasu Prof: This is from the Chairman of the first session on CATHODES of the webinar on 13th March convened by Mr. Raj Singh. This is a welcome message to the group. Thank you, Dr. Bhat!

10/03/2021, 18:46 - BNBasu Prof: Togetherness is so much necessary. You have to keep me close to your structure. Or else I would depress your potential and limit my current and your power. I am your heart.

10/03/2021, 19:15 - KSBhat MTRDC: All the elderly in this group are like the electron beam, always energetic and glowing, ready to impart their energy and knowledge to the youngsters. we need to keep them always close to our hearts. Thanks Dr Joshi, Prof Basu and all others.

10/03/2021, 20:30 - BNBasu Prof: WEBINAR#5

Final Program

Date: 13th March, 2021

Time: 4:00 to 6:00 PM

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Duration of talk plus discussion: 20 min + 5 min

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Duration of talk plus discussion: 20 min + 5 min

Vote of Thanks: Professor KP Ray

Convener: Mr. Raj Singh

11/03/2021, 06:23 - Dr. Vishal Kesari: If you're interested learning how to model multiphysics phenomena involving

fluid flow, join us for this interactive online workshop on Tuesday, 23 March

2021, at 3 p.m. IST.

During this session, you will:

- Explore the capabilities of the COMSOL ® software for modeling fluid flow along with other physical phenomena

- Understand how fluid flow interacts with solid objects and learn how to model fluid-structure interaction and aeroacoustics

- See how you can couple fluid flow with heat transfer, chemical reactions, and electromagnetic fields to study various multiphysics phenomena including conjugate heat transfer, electrokinetic flow, and magnetohydrodynamics.

Register for this event here: https://www.comsol.co.in/c/bjyh

11/03/2021, 06:36 - Dr. Vishal Kesari: Upcoming Ansys Webinars

https://www.ansys.com/about-ansys/events

11/03/2021, 12:37 - Uttam Goswami CEERI: Dear VED Thinkers,

I request all the eminent members of VED consortium to join the Google meet cloud well before 4:00 PM on March 13 in order to commence the webinar at scheduled time. I hope that we will keep the video mode off and mute audio for smooth functioning of the webinar.

The web link is as follows:

https://meet google.com/evz-jwow-xda

Uttam Goswami

11/03/2021, 15:50 - BNBasu Prof: The link that you give is for the 5th Webinar of the group, which has two sessions. The cathode is included in the first session.

11/03/2021, 15:55 - BNBasu Prof: WEBINAR#5

Final Program

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Duration of talk plus discussion: 20 min + 5 min

Vote of Thanks: Professor KP Ray

Convener: Mr. Raj Singh

12/03/2021, 10:40 - BNBasu Prof: Dr. Hasina Khatun of CEERI, Pilani will chair the second session of the webinar on 13th March 2021. I wish to share the abstract of one of her papers which was published in 2011.

12/03/2021, 10:40 - BNBasu Prof: Hasina Khatun, Reddy R Rao, A K Sinha, and Sri Niwas Joshi, “Accurate estimation of start oscillation current for maximum output power in 42-GHz, 200-kW gyrotron,” Indian J. Pure & Appl. Phys., Vol. 49, November, pp. 776-781 (2011).

Abstract:

Design of a 42 GHz, 200 kW gyrotron operating at TE03 involves optimization of a guiding magnetic field across the tapered cavity. The start oscillation current (SOC) or starting current is one of the most important parameter to estimate the guiding magnetic field to excite the desired operating mode irrespective of large numbers of competitive modes. This paper presents an accurate method to estimate SOC, based on the linear theory, yielding the guiding magnetic field at which the maximum desired power level is also achieved through the beam-wave interaction simulation using 3D MAGIC-PIC code. The method involves interpretation of the beam wave interaction length as 1/e times of the normalized axial Gaussian electric field profile. This method is successfully applied to low order symmetric operating mode gyrotron. The minimum SOC from the linear theory for the operating mode TE03 and the maximum power from the non-linear theory/code are obtained at the same guiding magnetic field 1.607 T with an error of 0.12% only. The paper also reports the effect of noise on SOC and output power, simultaneously.

12/03/2021, 11:07 - BNBasu Prof: The host of the webinar to be held on 13th March 2021 is Dr. N Purushothaman of CEERI, Pilani. To the best of my knowledge, he has the credit of writing the first ever PhD thesis in the area of metamaterial assisted VEDs titled as “Design of metamaterial-based interaction structures for microwave tubes.”

12/03/2021, 11:44 - BNBasu Prof: The chairman of the first session of the webinar to be held on 13 March 2921 is Dr. KS Bhat. You may choose to have a glimpse of him by visiting the Website:

https://ieeexplore.ieee.org/author/37413634000

12/03/2021, 12:09 - Dr. Lalit Kumar: Very thoughtful and witty composition.Keep it up.

12/03/2021, 12:29 - Vishant Gahlaut Bansthali:

Dear VED Thinkers,

I request all the eminent members of VED consortium to join the Google meet cloud well before 4:00 PM on March 13, 2021 in order to commence the webinar at scheduled time. Also, request that we will keep the video mode off and mute audio for smooth functioning of the webinar or broadband issues.

The web link is as follows:

https://meet.google.com/evz-jwow-xda

Thankyou!

Team Webinar Coordinator

Please let us know if you have any issues regarding the meeting link given above.

12/03/2021, 21:20 - LMJoshi CEERI: Lovely poetic personalization of Cathode. It can emit only from a heart and soul of a person who dedicated himself to it's nurturing. Wonderful Bhatt sahib 👌👌👌👌🙏🙏🙏

Looking forward to virtually meet tomorrow.

13/03/2021, 20:36 - KSBhat MTRDC: It was a well organized webinar. Thanks to Dr Raj Singh, Uttam and others. Thanks to Prof Basu for his ever continued support.🙏🙏

14/03/2021, 03:14 - Ajesh Palliwar:
https://spectrum.ieee.org/energy/nuclear/5-big-ideas-for-making-fusion-power-a-reality

14/03/2021, 09:15 - Raj Singh IPR: A team is working behind the seen inspite of their very tight schedule to convert this series of very useful science event into a beautiful science festival, where people enjoy the learning and interaction in a fabulous scientific way and that team has very hard working people - working behind the seen, taking all the pain so that we are relieved and relaxed to discuss the science. The team is of Vishant, Uttam, Vishal and others. Let's give them a big hand. 🙏🙏🙏

14/03/2021, 09:18 - BNBasu Prof: Indeed so!

14/03/2021, 15:52 - Dr. Vishal Kesari: Feedback form for the Webinar#5:

It is requested to all the group member to provide your feedback for the Webinar#5 using the link:

https://forms.gle/zahV7d98rz842K2D8

16/03/2021, 16:00 - BNBasu Prof:

(i) We get together for the webinar lectures of our group on Google Meet platform. Recently, Professor Gun-Sik Park (who is acclaimed for his contribution in the area of VEDs and their applications) of South Korea (Seoul National University) as well as his students and Professor PK Datta of IIT-Kharagpur of India as well as his students presented their research papers through ppts on Google Meet platform. I attended that interaction which was jointly convened by Professors Park and Datta, on their invitation. The objective was to identify the common areas of interest and accordingly select the appropriate postdoctoral students. According to me, the approach is worth taking up for all of us to meet such an objective.

(ii) I am happy to inform you that Professor Gun-Sik Park has recently selected one of our younger group members in his doctoral programme of Seoul National University.

(iii) Following the lecture of Professor Claudio Paoloni of Lancaster University, UK on our fourth webinar, some of younger group members became interested in working with him. Subsequently, following a virtual interview, Professor Paoloni selected one of them in his postdoctoral programme.

(iv) In the fifth webinar, there was a consensus on holding a brainstorming session on the different aspects of bottlenecks on manufacturing microwave tubes and their components including cathodes. I request Dr. SN Joshi, Dr. Alok Gupta, Mr. TRK Janardan, Dr. LM Joshi, Dr. KS Bhat, Mr. RR Patnaik, Professor KP Ray, Dr. Shivendra Maurya, Mr. Guriqbal Sidhu (C/o Dr. GS Sidhu), and our members from industrial sector to kindly organize such a session. I believe Mr. Raj Singh would kindly support the group by convening such a session under the guidance of Dr. Lalit Kumar, who has agreed to gladly lead such a discussion, while expressing his feeling that such a discussion has to be driven by people from CEERI-Pilani, MTRDC-Bangalore, SAC-Ahmedabad, SAMEER-Bombay, SAMEER-Guwahati, BEL-Bangalore, Pilani Electron Tubes and Devices-Sangrur, and Panacea Medical Pvt. Ltd.-Bangalore, and VEM Technologies Pvt. Ltd.-Hyderabad, and so on.

Participant's Feedback Analyses