Proceedings

Sixth Webinar

Expert Talk

(High Power Microwaves at 50 Years Encompassing Relativistic Backward Wave Oscillator)

Young Researchers' Talk Series

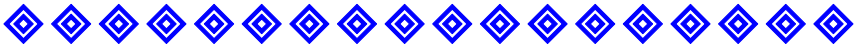
(Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source)

8 May 2021, Saturday

Editors:

Vishal Kesari

B N Basu



Thinkers in Vacuum Electron Devices Group

Contents

From Editorial Desk

This webinar was greatly marred by the Covid pandemic. For instance, leave aside the undersigned writing this editorial on behalf of the Editorial Board, the two active members of our Web management team were suffering from the disease. The sole speaker of session 1 of the webinar was discharged from the Covid hospital two days before the webinar. We guess many attendees had to suffer from this disease. Mr. Raj Singh, the Convener of the webinar, insisted that the show must go on. And we followed him.

After receiving the non-compliance of our request from several group members, we could find a host of this webinar in Dr. Srima Nandi, the then non-member of the group. She gladly agreed to host the programme with the support from her co-host Dr. Niraj Kumar. We made her a group member, and she hosted the programme from the Humanities Department of an engineering/ management college which she serves. Before the beginning of the programme, we had to satisfy her by answering her innocent questions such as: What are the full forms of ms, ns, ml, MHz, THz, mW, and MW? The post-webinar postings of the group members praising her hosting the programme are unprecedented. We have included in this webinar a response of Dr. Nandi to these praises.

In the beginning of the programme, Professor BN Basu said a few word of thanks for Dr. PC Panchariya for publishing his article on the contributions to the area of vacuum electron devices of the legendary made by Padma Bhusan Dr. Amarjit Singh, the erstwhile Director of CSIR-CEERI, Pilani. The article, which is dedicated to Dr. SSS Agarwala, another legendary in the area, is entitled as "Journey of Amarjit Singh from Phagwara to Pilani" and published in CSIR-CEERI NEWS, Vol. 60(1) (January 2021). However, under the emergent responsibility to handle the Covid situation at Pilani, Dr. Panchariya could not turn up and

sent an SOS: "Sorry sir, Due to the Covid cases in the colony and pressure to do some help for oxygen generation by working on converting nitrogen plant into oxygen plant, which can help for at least 10 beds in ICU, I completely missed. Regards". We thank him for his concern and congratulate him for doing his service to the society.

The Proceedings of the Webinar, divided in Sessions 1 and 2, have included the notes from the following members

(1) Mr. Raj Singh, Convener

(2) Dr. Srima Nandi, Host

(3) Dr. KS Bhat, Chairperson

(4) Professor Y Choyal, Coordinator of Session 1

(5) Mr. Mumtaz Ali, Coordinator of Session 2

(6) Dr. UN Pal, Vote of Thanks

alongwith

(7) Abstract of the talk in Session 1 by Professor KP Maheshwari

(8) Brief biography of Professor KP Maheshwari, the speaker in Session 1

(9) Abstract of the talk in Session 2 by Mr. Varun

(10) Biography of Mr. Varun, the speaker in Session 2

(11) Presentation slides of Professor KP Maheshwari, the speaker in Session 1

(12) Presentation slides of Mr. Varun, the speaker in Session 2

Vishal Kesari
On behalf of the Editorial Board

Professor BN Basu's words about an article of historical value on the contributions of Padma Bhusan Dr. Amarjit Singh

Thank you for giving me this opportunity to say a few words about an article of historical value written by me on the contributions of the legendary Padma Bhusan Dr. Amarjit Singh, the erstwhile Director of CEERI-Pilani, in the area of vacuum electron devices. The article is published in the January 2021 issue of the CSIR-CEERI News.

My article is dedicated to Dr. SSS Agarwala, another legendary in the area.

I express my profound gratitude to Professor SC Dutta Roy, the erstwhile Chairman of the Research Council of CEERI-Pilani, to provide me a lot of inputs. Professor Chandra Skekhar, the Chancellor of Academy of Scientific and Innovative Research (Ac-SIR) and the erstwhile Director of CEERI-Pilani, and Dr. SN Joshi, the erstwhile Head of Microwave Tube Area of CEERI-Pilani, critically examined the manuscript. Ms Sreelatha Menon, Editor of Universities Press, Hyderabad, has edited the manuscript of my article.

When I was trying to find a suitable medium in which to publish my article, I could reach Dr. PC Panchariya, the Director of CEERI-Pilani. It was made possible with the help of Dr. SA Akbar, Chief Scientist of CEERI-Pilani, for me to reach Dr. Panchariya.

Dr. Panchariya showed his gesture and requested me to contribute the article to the CSIR-CEERI News.

Therefore, I wish to use this platform of Thinkers in Vacuum Electron Devices Group to express my sincere gratefulness to Dr. PC Panchariya to help the article to see the light of day.

Convener's Words

Today (9 May 2021) in the morning I thought of writing a note of thanks to the speakers and audience of yesterday's webinar but when I saw my mobile I found a long line of note of thanks and thought that my work is over. But as a convener I am supposed to write a note of thanks.

Nice friends, it was really nice, yesterday's webinar. It was full of knowledge and contents. Talk by Prof. Maheshwari was as usual superb piece of science innovation and technological excellence. His way of presentation was with his full weight behind the talk. He has such a nice grip on the subject that the knowledge pour out automatically. Salute to you sir. Hope you will oblige us with your continuous association with this group.

Talk by Varun was really very detailed and every aspect of PS Discharg Based Plasma Cathod Electron Source was discussed. Thanks Varun for such a fabulous piece of scientific presentation.

But yesterday's webinar was special in more than one way. The session was not only scientifically marvelous but the way it was conducted by Dr. Srima Nandi was superb, beyond expectations. I am privileged to thank you Dr. Nandi on behalf of this group.

I would also like to thank Prof. Claudio Paoloni and Dr. Rosa to join this webinar and making it a truly global scientific event.

At the end, I would like to thank you all audience whose whole hearted involvement gives a real meaning to this event.

Thank you all.

Have a nice time.

Wish you all a hale and hearty time ahead.

Please follow COVID appropriate behavior.

Put on mask, avoid crowd, and keep isolation as much as possible.

Programme of the Webinar

Date: 8 May 2021, Saturday

Time: 05:00 – 06:30 pm

Convener: Mr. Raj Singh

Host: Dr. Srima Nandi

Session 1 - Expert Talk

Chair of the Session: Dr. KS Bhat

Coordinator of the Session: Professor Y Choyal

Duration	Topic of deliberation	Speaker
05:00 - 05:10 pm	Opening Remark	Dr. KS Bhat
05:10 - 05:55 pm	High Power Microwaves at 50 Years Encompassing Relativistic Backward Wave Oscillator	Professor KP Maheshwari
05:55 - 06:00 pm	Questions and Comments	Attendies

Session 2 – Young Researcher's Talk Series

Research Contributions of Younger Researchers in VEDs

Coordinator of the Session: Mr. MA Ansari

Duration	Topic of deliberation	Speaker
06:00 - 06:20 pm	Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source	Mr. Varun
06:20 - 06:30 pm	Vote of Thanks	Dr. UN Pal

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	Distinguished Adjunct Professor	Supreme Knowledge Foundation Group of Institutions, Mankundu Superanuated from Indian Institute of Technology, Banaras Hindu University, Varanasi	Advisor
Prof. Y Choyal	Professor	Devi Ahilyabai Vishwa Vidhyalaya, Indore	Coordinator Session 1
Dr. Vishal Kesari	Scientist E	Microwave Tube Research and Development Centre, Bangalore	Editor Proceedings
Dr. UN Pal	Senior Principal Scientist	CSIR-Central Electronics Engineering Research Institute, Pilani	Vote of Thanks
Dr. Srima Nandi	Associate Professor	University of Engineering and Management, Kolkata	Host
Dr. Vishant Gahlaut	Assistant Professor	Banasthali Vidyapith, Banasthali	Web-link Coordinator
Dr. Uttam Kumar Goswami	Post-Doctoral Fellow	Institute for Plasma Research, Gandhinagar	Web-link Coordinator
Mr. Mumtaz Ali Ansari	Research Scholar	Indian Institute of Technology, Banaras Hindu University, Varanasi	Coordinator Session 2

Dr. Srima Nandi

Associate Professor
Department of Basic Science and Humanities
University of Engineering and Management
Kolkata-700160, INDIA

Host's Words

First of all I apologise profusely for procrastinating.

Thanks to Mr. Raj Singh, the convener, for giving me this opportunity to host the program. I extend my gratitude to Dr. SN Joshi sir for introducing me. I was confident that if I did any mistake, my co-host, the great scientist, Dr. Niraj Kumar would correct me.

I had to learn the terminologies, which I had to know apriory from Professor Basu sir. He helped me a lot regarding this. I used to sit in his office when he was in SKFGI, Mankundu and see him guiding many research scholars. This gave me an opportunity to learn many technical terms from him. I would like to share an incident with you all. When he was lecturing before the faculty members of SKFGI regarding TWT (I was present during his lecture), he suddenly asked me "Srima, what is TWT?"

I was taken aback. But I knew the answer and told him the full form of TWT much to the surprise of the audience. This was how I learned many technical terms from him.

I am overwhelmed by the appreciation given for my work by the esteemed group members on this platform.

For me it was a great learning experience and being a part of this enriching webinar was a great honour for me.

With warm regards,

Srima

Session 1

Expert Talk

Topic of Deliberation

High Power Microwaves at 50 Years Encompassing Relativistic Backward Wave Oscillator

Speaker

Professor KP Maheshwari

Biography of Speaker in Session 1

Professor KP Maheshwari

Professor KP Maheshwari was Professor and Head and Dean of Faculty of Science, School of Physics, Devi Ahilya Vishwavidyalaya (DAVV), Indore. He was also Visiting Professor at Tokyo Institute of Technology, Tokyo, Japan.

Professor Maheshwari is internationally acclaimed for his outstanding theoretical as well as experimental contributions in the area of high power microwave generation. To him and his team goes the credit of developing the first ever relativistic backward-wave oscillator (BWO) in an Indian university at DAVV, Indore. For this purpose, a Marx generator was developed generating a 300-keV, 2-kA, 100-ns intensive relativistic electron beam (IREB). Thus, at DAVV, an IREB driven BWO experimentally yielded 5 MW, 8-11 GHz microwave output.

The areas of research of Professor Maheshwari include high power microwave generation/ Cherenkov radiation from the IREB interaction with a slow-wave structure; fast-wave devices (free electron lasers and gyrotrons); ultra-short, ultra-intense, laser-plasma interaction; high-harmonic generation; wake-field acceleration of charged particles; relativistic self-focusing of laser beams; laser induced underwater acoustics; and so on.

A good number of postgraduate and doctoral students were benefited for their dissertations by the mentorship of Professor Maheshwari.

Professor Maheshwari extended his expertise to national labs (BARC, Bombay; DRDO-MTRDC, Bangalore; CSIR-CEERI, Pilani; etc.).

Professor Maheshwari was recipient of the prestigious JSPS Fellowship of the Government of Japan.

Vacuum Electronic Devices & Applications Society, Bangalore, India (VEDA Society of India) felicitated Professor Maheshwari with the Life-time Achievement Award of 2012.

Dr. KS Bhat

DRDO Fellow and Ex-Scientist 'G'
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Bengaluru – 560013, India

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Chairman's Desk in Session 1

It was a pleasant privilege for me to chair a session in Webinar 6 where a very senior and eminent Professor K P Maheshwari, Prof. (Rtd) from Devi Ahilya Vishwa Vidyalaya, Indore, delivered his invited talk. The session went on excellently well. Prof. Maheshwari was on his elements when delivered his lecture on the design and development aspects of the first ever BWO built and demonstrated in the country. One must appreciate the fact that this work was done twenty years to now when the concept of High Power Microwave Devices for directed energy systems were just evolving. The work was done by Prof. Maheshwari and Dr. Choyal with a couple of research scholars working with them. Each and every piece parts used in the development was indigenous in nature. Help of BARC in developing the Pulse Power System, RRCAT for pulsed magnetic field and financial assistance from DRDO was also acknowledged. Since it was sponsored by DRDO I had the opportunity to interact with Prof. Maheshwari and Prof. Choyal of DAVV Indore in connection with this project. I must tell you that one has to see to believe the kind of good work done by the team led by him. He was as usual in his teaching best and all of us listened to him like dedicated students. It was a session worth remembering. Thank you Prof. KP Maheshwari.

Later in session 2, a young researcher Dr. Varun spoke excellently well on his work on Psuedo-spark Discharge Switches using plasma cathode sources and it was quite interesting and informative. My congratulations to him.

The other attraction was the young and dynamic host Dr. Srima Nandi, who very efficiently managed the whole show with her excellent skills of web hosting.

Once again, Congratulations to Prof. Maheshwari, Prof. BN Basu, Dr. Srima Nandi and and whole set of youngsters who made this webinar a grand success.

Professor KP Maheshwari

Visiting Faculty, Department of Physics
University of Kota
Kota, Rajasthan, India

Retired Professor and Head and Dean of Faculty of Science
School of Physics, Devi Ahilya Vishwavidyalaya (DAVV), Indore, India

Ex-Visiting Professor
Tokyo Institute of Technology, Tokyo, Japan.

High Power Microwaves at 50 Years Encompassing Relativistic Backward Wave Oscillator

Abstract of Talk in Session 1

Backward wave oscillator (BWO) is one of the device that efficiently convert energy of an electron beam into electromagnetic radiation at microwave frequencies. It essentially consists of a relativistic electron beam, confined radially by a strong magnetic field, propagating through a rippled wall metallic waveguide having radial profile specified by $R(z) = R_0 + h \cos (k_0 z)$ where R_0 is the mean radius, h is the corrugation depth and $z_0 = 2\pi /k_0$ is the spatial periodicity. It provides a set of structure modes having phase velocity less than the velocity of the beam electrons. These slow waves therefore can interact resonantly with the negative energy slow space charge wave supported by the beam leading to an instability that transfer the energy from the beam to the electromagnetic wave field. We report the results of an indigenous relativistic high power relativistic BWO experiment. In this experiment a 230 kV, 2 kA, 150 ns relativistic electron beam is generated using a Marx generator. The beam is then

injected into a hollow rippled wall metallic cylindrical waveguide forming a slow wave structure. The beam is guided using a half sine pulsed magnetic field having peak value 1 T and duration 1 ms. The field is generated by discharge of a capacitor bank into a solenoidal coil. A synchronization circuit ensures the generation of the electron beam at the instant when the peak magnetic field attains its peak value. The beam interacts with the slow wave structure (SWS) modes and generates microwaves at X-band frequency due to Cherenkov interaction. Estimated power of 2 MW in $TM_{0,1}$ mode is observed.

Joint Contributor:

Professor Yaduvendra Choyal

School of Physics
Devi Ahilya Vishwavidyalaya
Indore – 452001, India

Session 2

Young Researcher's Talk Series

Research contributions of younger researchers in VEDs

Topic of Deliberation

Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

Speaker

Mr. Varun

MA Ansari

Research Scholar
Department of Electronics Engineering
Indian Institute of Technology (BHU), Varanasi
Varanasi-221005, Uttar Pradesh, INDIA

Email: mumtazaa.rs.ece15@itbhu.ac.in

Coordinator's Words in Session 2

Dr. Srima Nandi introduced Mr. Varun for his research presentation on the topic "Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source". In his presentation, Mr. Varun gave an introduction of Pseudospark based cathodes and also highlighted the research background of Pseudospark Discharge based cathodes. He has also shown some simulation models that improve the working and also enhance the efficiency of the Pseudospark based cathodes. Mr. Varun also highlighted the future scope of this type of cathodes. In addition, Dr. Srima Nandi hosted the webinar enthusiastically.

I congratulate Mr. Varun for delivering an informative presentation on this platform of the Thinkers in VED Group and wish him all the best.

Thank You

Biographies of Speaker in Session 2

Mr. Varun completed his B.Tech. Degree in Electronics engineering from Dr. Ambedkar Institute of Technology for Handicapped (Dr. A.I.T.H.) Kanpur, India, in 2014 and M. Tech. degree in high power microwave devices and system engineering from the Academy of Scientific and Innovative Research (AcSIR), Ghaziabad at CSIR-CEERI, Pilani in 2017. Since 2017, he is pursuing his Ph.D in Engineering Sciences from AcSIR, Ghaziabad at CSIR-CEERI, Pilani. His research area includes the generation of high density and energetic electron beam from the pseudospark discharge based plasma cathode electron (PD-PCE) source.

Mr. Varun was recipient of IEEE student travel grant and International Travel Support (ITS) by Science and Engineering Research Board (SERB), GOI, for attending and presenting the papers at 2019 IEEE Pulsed Power and Plasma Science Conference (IEEE PPPS-2019), Orlando, Florida, USA, June 2019.

He has authored four journal papers in IEEE Transactions on Electron Devices, one in IEEE Transaction on Plasma Sciences, and co-authored one paper each in IEEE Transactions on Electron Devices and Physics of Plasmas.

He is graduate student member of IEEE including NPSS society and Electron Devices Society, Associate Member of VEDAS and Member of VIBHA.

Mr. Varun

Research Scholar
Academy of Scientific and Innovative Research
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Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

Abstract of Talk in Session 2

Pseudospark discharge based plasma cathode electron (PD-PCE) gun and sources can generate self-focused intense electron beam that can propagate without using any external magnetic field. The electron beams of pulse duration 10's of ns, current density (≥ 102 A/cm^2), brightness (upto 1012 A/m^2 rad^2) and emittance of 10's of mm × mrad with fast current rise (upto 1012 A/s) can be generated from the PD-PCE sources. In fact, PD-PCE sources differ by the use of a cold cathode from the other thermionic electron beam sources, which makes it to have a longer life and is more reliable and compact. Its unique characteristics open the door in various potential and growing applications in the areas of microwave radiation generation, extreme ultraviolet (EUV) sources, intense X-ray sources, electron beam lithography, and surface modification of the polymers and materials.

The work is being carried out for the discharge analysis and generation of high density and energetic electron beams from the PD-PCE source that can be used for the generation of extreme ultraviolet (EUV) radiation sources in a wavelength range between 124 and 10 nm having photons with energies between 10 eV up to 124 eV and X-ray sources with photon energies of 124 eV up to tens of keV. The proposed multi-gap PD-PCE source mainly consists of hollow cathode,

trigger unit, multi-gap floating electrodes, anode and multi-ring annular collector. The generated focused electron beam has been propagated tens of mm in the ion focused regime without using any external magnetic field. The radial and axial profile of generated electron beams using plasma simulation and experimental study have been analyzed for different operating and circuit conditions. The electron beam of ~30 kV energy and ~103 A/cm^2 current density have been generated and investigated.

Topic of Deliberation

Vote of Thanks

Proposed by

Dr. UN Pal

Dr. UN Pal

Senior Principal Scientist
CSIR-Central Electronics Engineering Research Institute
Pilani, INDIA

Professor
Academy of Scientific and Innovative Research
Gaziabad-201002, INDIA

Email: udit@ceeri.res.in, paludit@gmail.com

Vote of Thanks

It is my pleasant duty to propose a vote of thanks for the sixth Webinar of Vacuum Electron Devices –VED, having two sessions: 1. Expert Talk and 2. Young Research Talk

First of all, we thank the speaker Professor KP Maheshwari, Ex. Professor and Head and Dean of Faculty of Science, School of Physics, Devi Ahilya Vishwavidyalaya (DAVV), Indore, for very informative and impressive presentation on "High Power Microwaves at 50 Years Encompassing Relativistic Backward Wave Oscillator". Prof. Maheshwari is a very well-known and renowned personality among the VED community.

Prof. Maheshwari has presented the review of the HPM devices and state of the art in this field. He has presented the design, fabrication and development of the first ever relativistic backward-wave oscillator (BWO) in an Indian university at DAVV, Indore, an IREB driven BWO experimentally yielded 5 MW, 8-11 GHz microwave output.

We thank the Chairman of the webinar, Dr. KS Bhat, for very nicely conducting the session, and also for his valuable comments.

Thanks are due to Prof. Y Choyal, DAVV, Indore, for nicely coordinating the Session-I.

We thank the speaker for young researcher talk, Mr. Varun for talking on "Analysis of Pseudospark Discharge based Plasma Cathode

Electron Source". He has nicely presented the interesting results of pseudospark discharge devices for high density and energetic electron beam generation.

We thank Mr. Mumtaz Ali for nicely coordinating the second session.

We thank the host of the webinar, Dr. Srima Nandi, University of Engineering and Management, Kolkata and Dr. Niraj Kumar, CSIR-CEERI, Pilani, for efficiently managed the entire webinar.

Thanks are also due to Dr. Vishant Gahlaut, Dr. Uttam Goswami, and their team for very effectively web management of the webinar.

We sincerely thank the Convener, Mr. Raj Singh for his untiring effort to make this even successful.

We sincerely thank Prof. Claudio Paoloni and Prof. Roza Letizia from Lancaster University, U.K. for their presence and valuable technical suggestions.

Thanks are also due to Dr. Lalit Kumar, Dr. SN Joshi, Dr. RS Raju, Dr. LM Joshi, and others for providing their guidance and valuable technical inputs.

Finally, we sincerely thank the Stalwarts in the VED area, Prof. B. N. Basu, for his untiring efforts and guidance to make the "Thinkers in VED", a real platform for the discussion and guidance.

Last but not the least, we sincerely thank all the participants to make this webinar successful.

Thank you all.

Namaste!!

Annexure I:
Expert Talk Slides

High power microwaves at 50 years encompassing relativistic backward wave oscillator (BWO)

K. P. Maheshwari * and Y. Choyal
* Formerly Professor
Professor of Physics

Devi Ahilya Vishwavidyalaya, Indore.

Thankfully acknowledging the valuable contributions of my colleagues

- Group Members:
- Y. Choyal
- Lalit Gupta
- V Rajput
- N. Parmar
- Prasad Deshpande
- K. P. Maheshwari

What does the term HPM mean ?

Conventionally high power microwaves or (HPM), are coherent electromagnetic radiation (1 GHz – over 100 GHz) with pulse power of at least 100 MW.

High-Power Microwaves

Benford – Swegle

Plan of lecture

- Basic physics of HPM generation
- Beam-waveguide interaction
- Negative energy space-charge waves
- Dispersion relation of beam-waveguide coupled system
- Preparation of BWO experiment
- Fabrication of MARX
- Relativistic electron beam generation
- Fabrication of SWS
- Development of axial magnetic guide magnetic field
- Successful demonstration of HPM signal
- Power ~ couple of megawatts in X-band

Relativistic High Frequency Electronics.

- **The term HPM is interpreted in two ways :**

  High average-power microwaves which implies long-pulse duration, high repetition rate or continuous wave (cw) source.

- **Another interpretation is high –peak power microwaves which implies short-pulse duration, a low repetition rate,**

  or ‘single-shot’ sources.

Why HPM ?

- for plasma heating; tokamak plasma heating
- Communication
- Industrial applications
- Increasing interest in developing directed energy weapons (DEW)

history

- This year is the **50th anniversary** of the publication of the first three papers providing experimental results for a true , high power microwave source:

1. J. A. Nation , Appl. Phys. Lett. **17**, 491, (1970)
2. N. F. Kovalev et al , JETP Lett , **18**, 138, (1973)
3. Y. Carmel et al, Phys. Rev. Lett., **33**, 1278, (1974)

first plasma microwave generator

- The first plasma microwave generator based on the stimulated Cherenkov emission of a relativistic electron beam in a plasma waveguide appeared in 1982.
- **(Kuzelev MV et al Sov. Phys. JETP 56 , 780, 1982)**

Variety of HPM Sources:

- Three types of sources are becoming increasingly popular:
- High Power BWOs, TWTs, Relativistic Magnetrons, Pasotrons etc.
- Gyrotrons
- Vircators
- Free electron lasers

source classification

- oscillators vs amplifiers
- whether high/ low- current regimes of operation?

- An amplifier produces an output signal that is a larger version of some input signal; in the absence of an input signal, there is usually no output signal other than low-level amplified noise.

What is BWO ?

- **A backward-wave-oscillator (BWO) is a slow wave structure in the form of a sinusoidal rippled wall waveguide driven by relativistic electron beam.**

- **BWO converts efficiently the kinetic energy of beam electrons into electromagnetic radiations to generate high power microwaves.**

Start-oscillation current

- Backward-wave device is an oscillator. For an oscillator one requires (1) feedback and (2) sufficient gain to overcome the net losses per cycle, so that an output signal can be generated spontaneously, even in the absence of an input signal.
- Since gain typically increases with beam current, the requirement is usually translated on the threshold condition on the beam current , called *start-oscillation-current* for oscillations.

The start current is a function of system parameters

- Below this critical value, the system will not oscillate spontaneously, while above it , spontaneous signals will result.
- The start current is a function of system parameters, including the length of the interaction region.

Why the name backward wave oscillator?

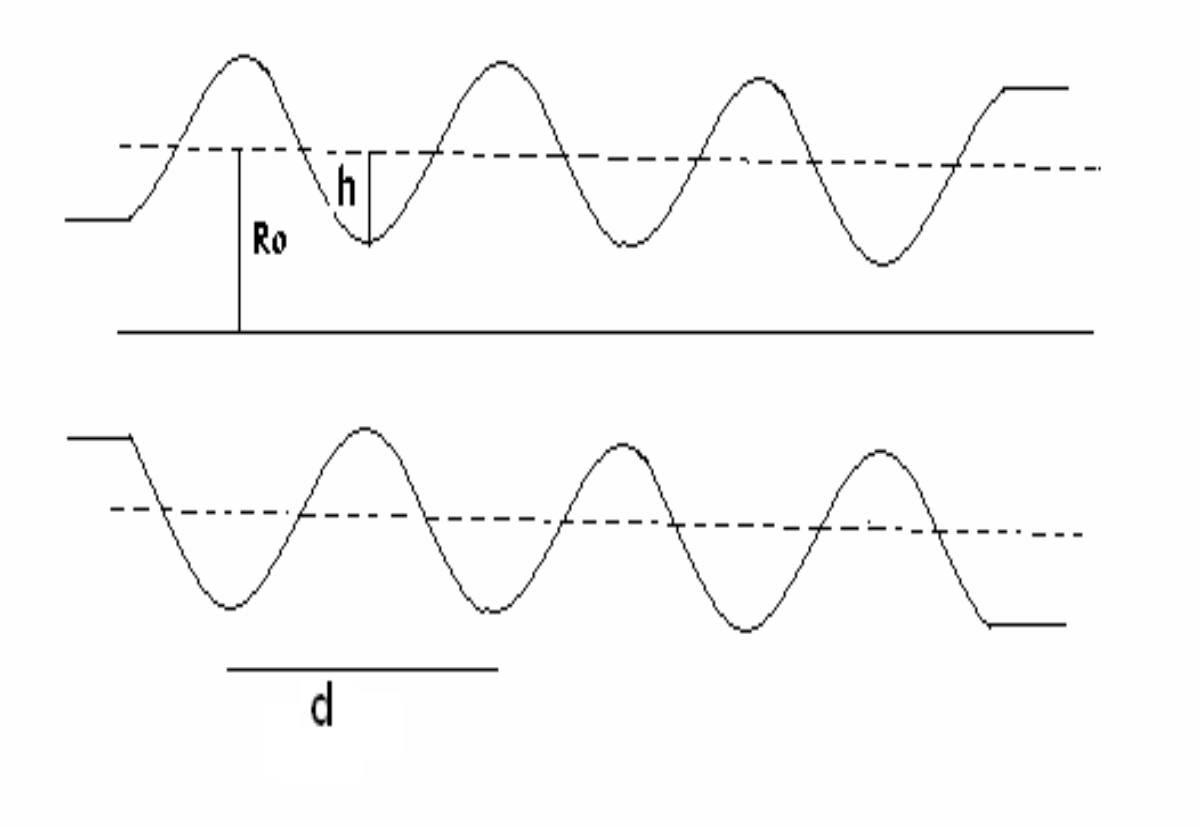
- The BWO is so named because the slow wave structure mode involved in the resonance has a negative group velocity, accordingly the wave energy transfer is backward along the beam, with the Poynting vector anti-parallel to the beam velocity.

- This process typically occurs in a waveguide or cavity, the role of which is to tailor the frequency and spatial structure of the fields in a way that optimizes the energy extraction from certain natural modes of oscillation of the electrons.

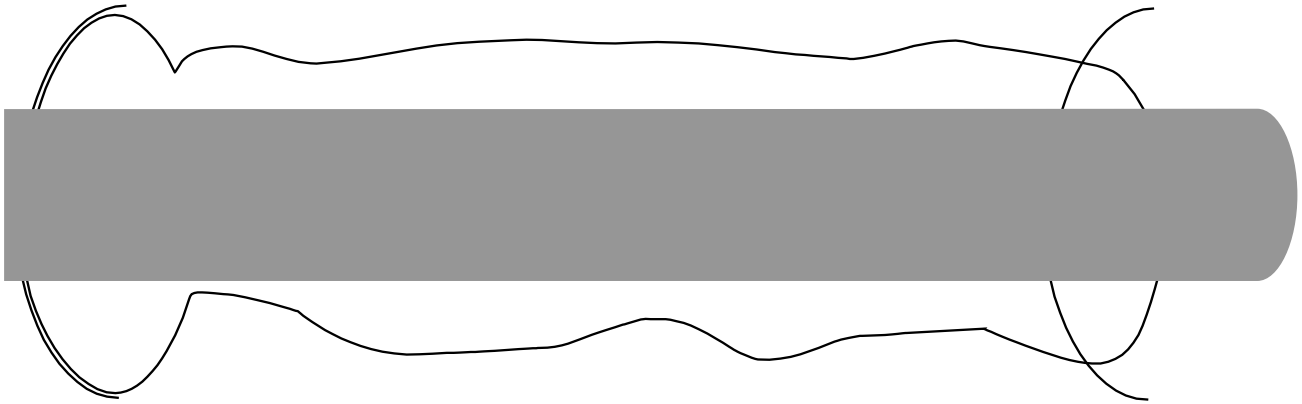
Schematic of BWO

$$R(z) = R_0 + h\cos(k_0 z)$$

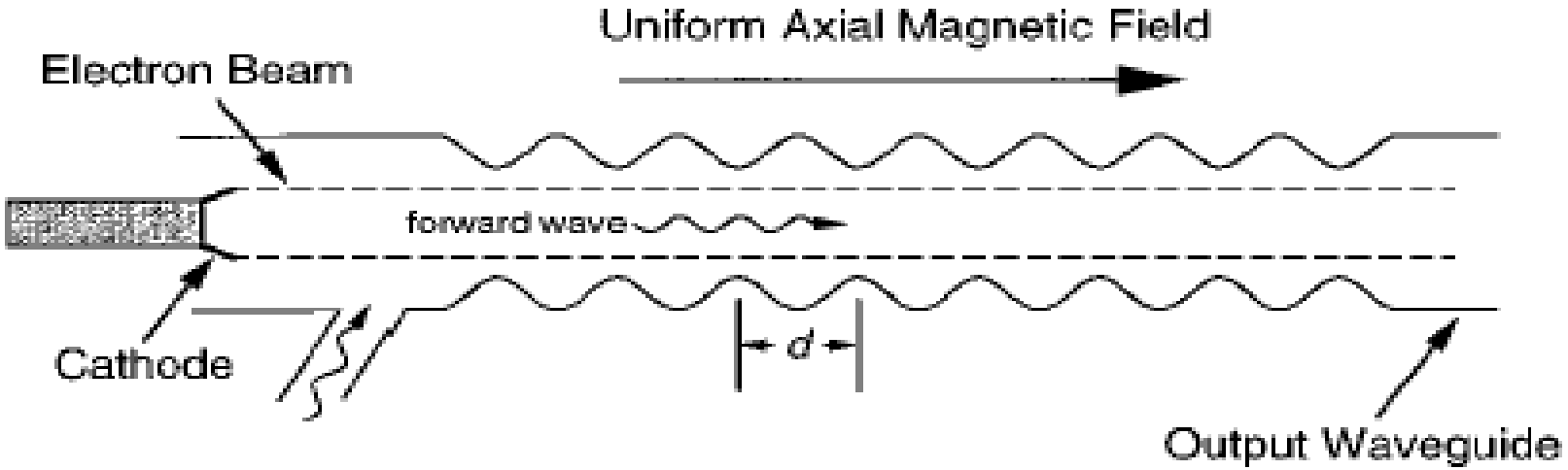
$$k_0 = 2\pi / d$$

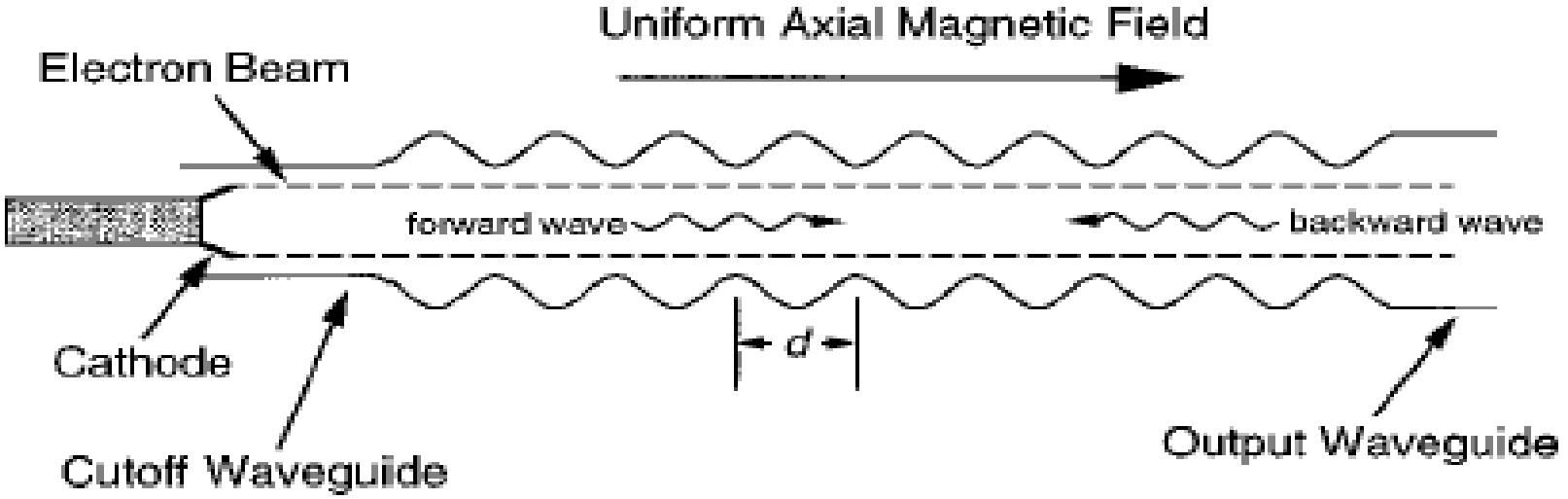


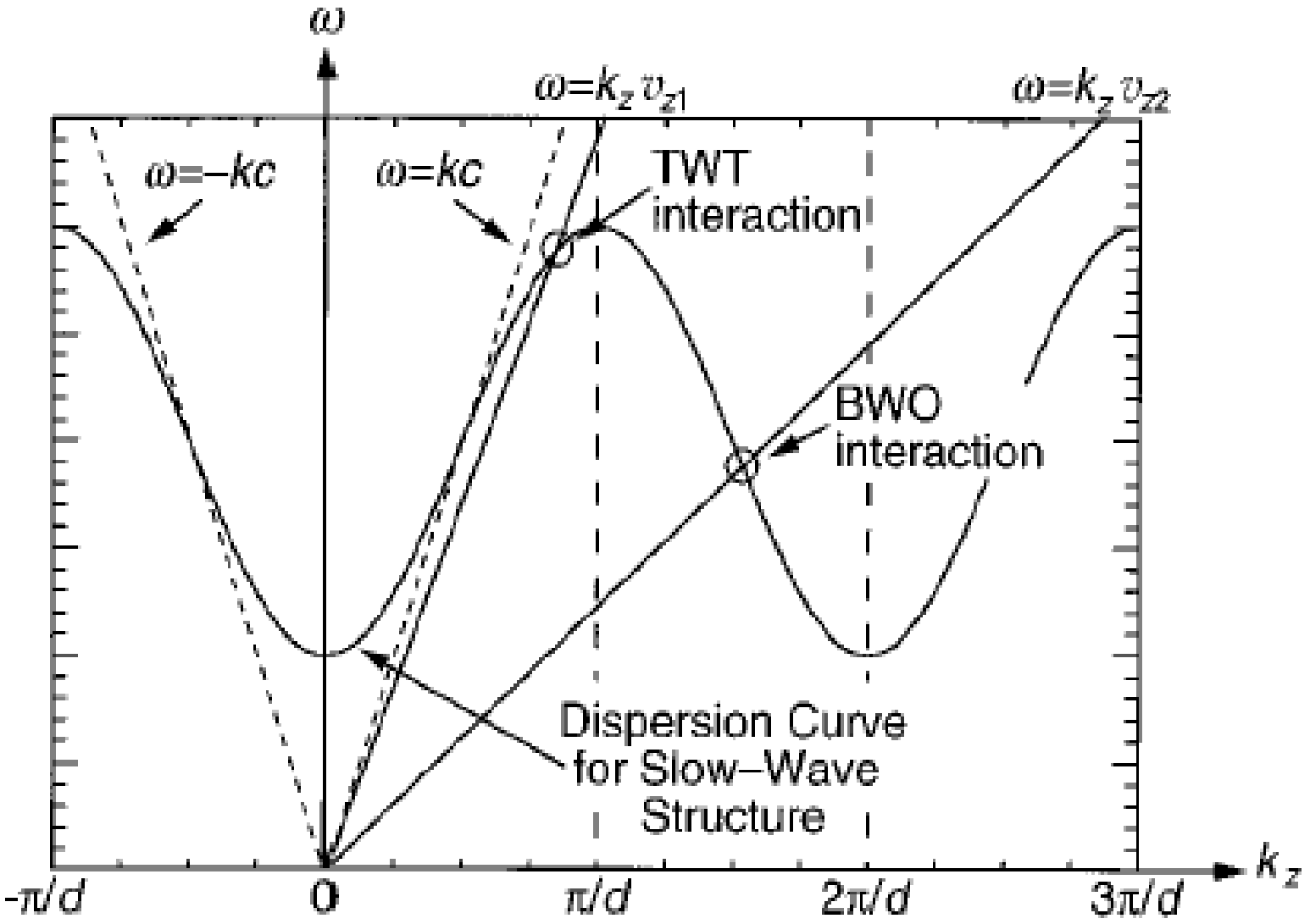
BWO is a device designed to efficiently convert the directed energy of electron beam into microwave radiation



- Waveguides act as ducts for propagating Microwave radiation, and under certain circumstances , also as cavities within which microwaves are generated.


Uniform Axial Magnetic Field
Electron Beam
forward wave
Cathode
d
Output Waveguide


Uniform Axial Magnetic Field
Electron Beam
forward wave
backward wave
Cathode
d
Cutoff Waveguide
Output Waveguide


ω
ω=k_z v_z1
ω=k_z v_z2
ω=−kc
ω=kc
TWT
interaction
BWO
interaction
Dispersion Curve
for Slow−Wave
Structure
k_z
-π/d
0
π/d
2π/d
3π/d

- In analyzing this process, we deal with the interactions between two conceptual entities: the normal electromagnetic modes of the waveguides and cavities, and natural modes of oscillation of electron beams and layers.
- The dispersion relation of rippled wall slow-wave structure is

$$\omega^2 = \left(k_{z0} + nh_0\right)^2 c^2 + \omega_{co}^2$$

Physics of microwave generation

- The microwave generation process in HPM sources can be understood in terms of resonant interactions between the normal modes of a cavity or waveguide and the natural modes of oscillation in a beam or layer of electrons

Positive and negative energy space-charge waves

- The electron oscillation participating in the resonance is said to be a negative energy wave in the following sense: **“the total energy of the coupled system, including the electromagnetic energy of the normal mode and summed energy of electrons is positive; however, the total energy is higher in the initial equilibrium state with no electron oscillations than it is in the presence of the unstable electron oscillations”.**

- The electron oscillation has therefore reduced the total energy of the system, and has a negative energy in the incremental sense.

- This energy reduction does not occur for some electron oscillations, which are said to be positive-energy waves; these will not interact with the electromagnetic normal modes, which always have a positive energy.

Saturation of wave-growth

- Of course, the process of wavegrowth and bunching cannot proceed indefinitely

, eventually , if given enough time, the instability will proceed to saturation and wave-growth ceases.

Coherence of electromagnetic waves

- In a uniform beam of electrons , the phases of the waves emitted by the individual electrons are completely random , so that the sum total of the radiation emitted by all the electrons cancels.
- Due to action of the waves back onto the beam , however, the beam forms into bunches, the phases of the waves from each electron are no longer random, and the net sum of the emitted waves become nonzero.

The microwave output power

- The microwave output power P is proportional to the number of bunches

, N_b , and the square of the number density of electrons within the bunches, n_b :

$$P \propto N_b \, n_b^2$$

Fast wave / slow wave device

- A fast-wave interaction involves a waveguide mode with a phase velocity greater than the velocity of light, as in the smooth walled waveguide.
- Slow-wave interaction involves a waveguide mode with a phase velocity less than the speed of light.

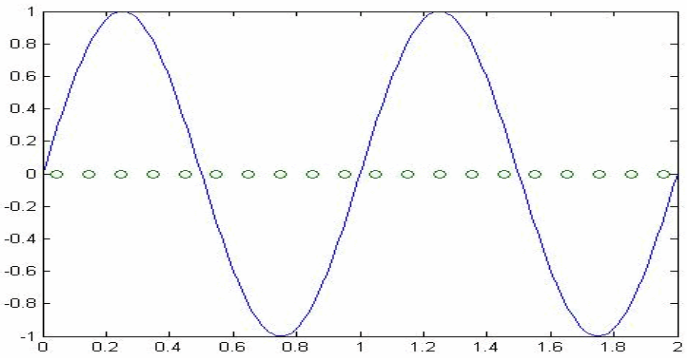
Why do we need slow wave structure?

- The beam is usually confined by a strong magnetic field .
- The slow wave structure reduces the phase velocity of EM waves below the vacuum speed of wave, so that the electron in the relativistic beam can give up the energy directly to one of the eigenmodes of the structure.

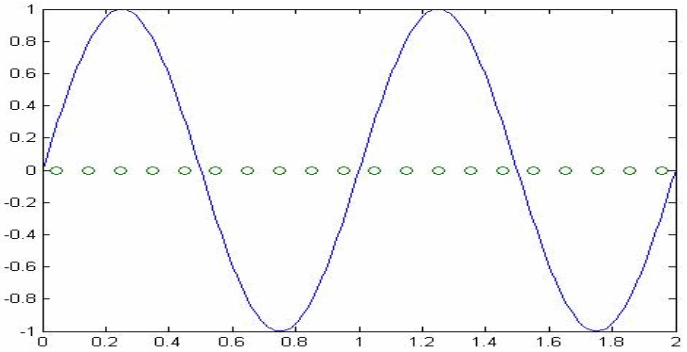
Cerenkov Interaction, $\omega - k_z V_z \approx 0$

Coherent electromagnetic radiation is produced when electrons that are initially uncorrelated, and produce spontaneous emission with random phases, are gathered into microbunches that radiates in phase.

$v_e \leq \omega / k$



$v_e \geq \omega / k$



Space-charge limited current

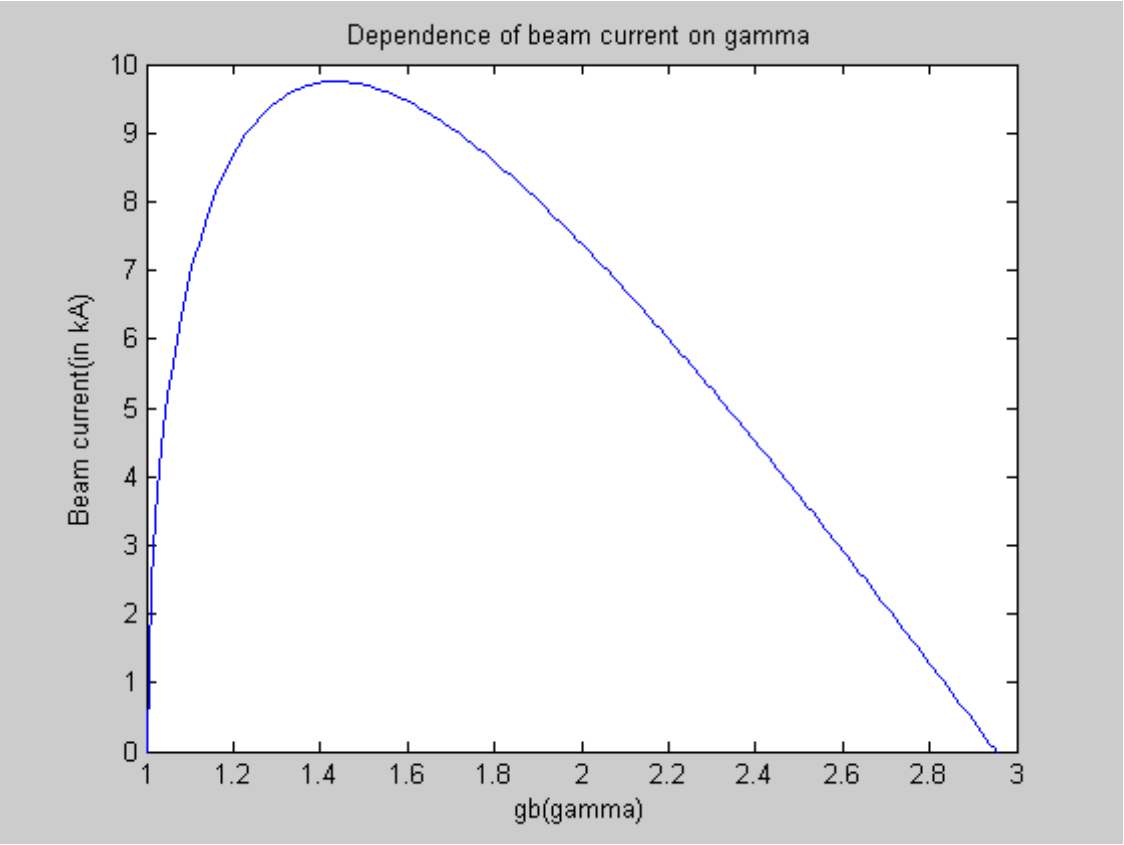
- The maximum steady-state current that the waveguide will allow and is referred as the space-charge –limited current

$$I_b = \frac{I_A}{2\ln\left(r_o / r_b\right)}\left(\gamma_b^2 - 1\right)^{1/2}\ \frac{\gamma_c - \gamma_b}{\gamma_b}$$

- Where

$$I_A = \frac{4\pi\varepsilon_0 mc^3}{e} = 17.1\,kA$$

$$\gamma_c = 1 + \frac{|e\phi_c|}{mc^2} \qquad \gamma_b = \left(1 - \frac{v_b^2}{c^2}\right)^{-1/2}$$


Dependence of beam current on gamma
Beam current(in kA)
gb(gamma)
0
1
2
3
4
5
6
7
8
9
10
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3

Need for a full dispersion relation for a coupled system of electromagnetic waves and electrons.

- The issue of which intersections lead to resonant microwave generation can be resolved by deriving and solving the full dispersion relation for a coupled system of electromagnetic waves and electrons.

BWO Publications from our group

1 Dispersion relation of a REB driven plasma filled rippled wall waveguide Y. Choyal and K. P. Maheshwari :

Phys. Plasmas, 1, 171-175, 1994.

2. Excitation of electromagnetic waves in a relativistic BWO with end reflectors: Y. Choyal and K. P. Maheshwari :

Phys. Of plasmas **2,** 319, (1995).

3. Linear dispersion relation of BWOwith finite strength axial magnetic field: K. Minami et al IEEE Trans on plasma science **30,** 1134, 2002.

4. Slow cyclotron instability in a high-power BWO: Y, Choyal, K. Minami, V. L. Granstein: IEEE Trans on plasma science **32, 2157,** 2004.

5. Saddle point analysis of a high – power BWO near cyclotron absorption: : IEEE Trans on plasma science **32, 1100,** 2004.

Dispersion relation of a relativistic electron beam driven backward wave oscillator

dispersion relation of a REB driven BWO is in a matrix form: D. A = 0, where A is a vector with elements A_n, .

and D is a matrix with elements :

- **We choose the transverse magnetic modes because their axial electric field component drives the axial bunching of the electron beam. In the common case of cylindrical geometry, modes with no azimuthal variation take the form:**

$$E_z = \left(\sum_{n=-\infty}^{n=+\infty} A_n J_0\left(k_{\perp n} r\right) e^{inh_0 z} \right) e^{i\left(k_{z0} z - \omega t\right)}$$

$$D_{mn} = \left(\frac{\omega^2 - k_m k_n c^2}{\Gamma_n^2 c^2} \right) \left[I_{mn}^J - \alpha \left(\frac{\Gamma_n c}{\omega - k_n v_b} \right)^2 . J_0(\Gamma_n r_b) \left(I_{mn}^J N_0(\Gamma_n r_b) \right) \right.$$

where

$$I_{mn}^J = \frac{1}{\pi} \int \frac{P_{mn}(v)}{(1 - v^2)^{1/2}} J_0(\Gamma_n r_0 (1 + \varepsilon v)) dv$$

$$v = \sin(h_0 z), \qquad \alpha = \frac{\pi I_b}{\beta \gamma_b^3 I_A}, \quad I_b = \int n_b e v_b 2\pi r dr$$

and $P_{mn}(v) = 1 \qquad n - m = 0$

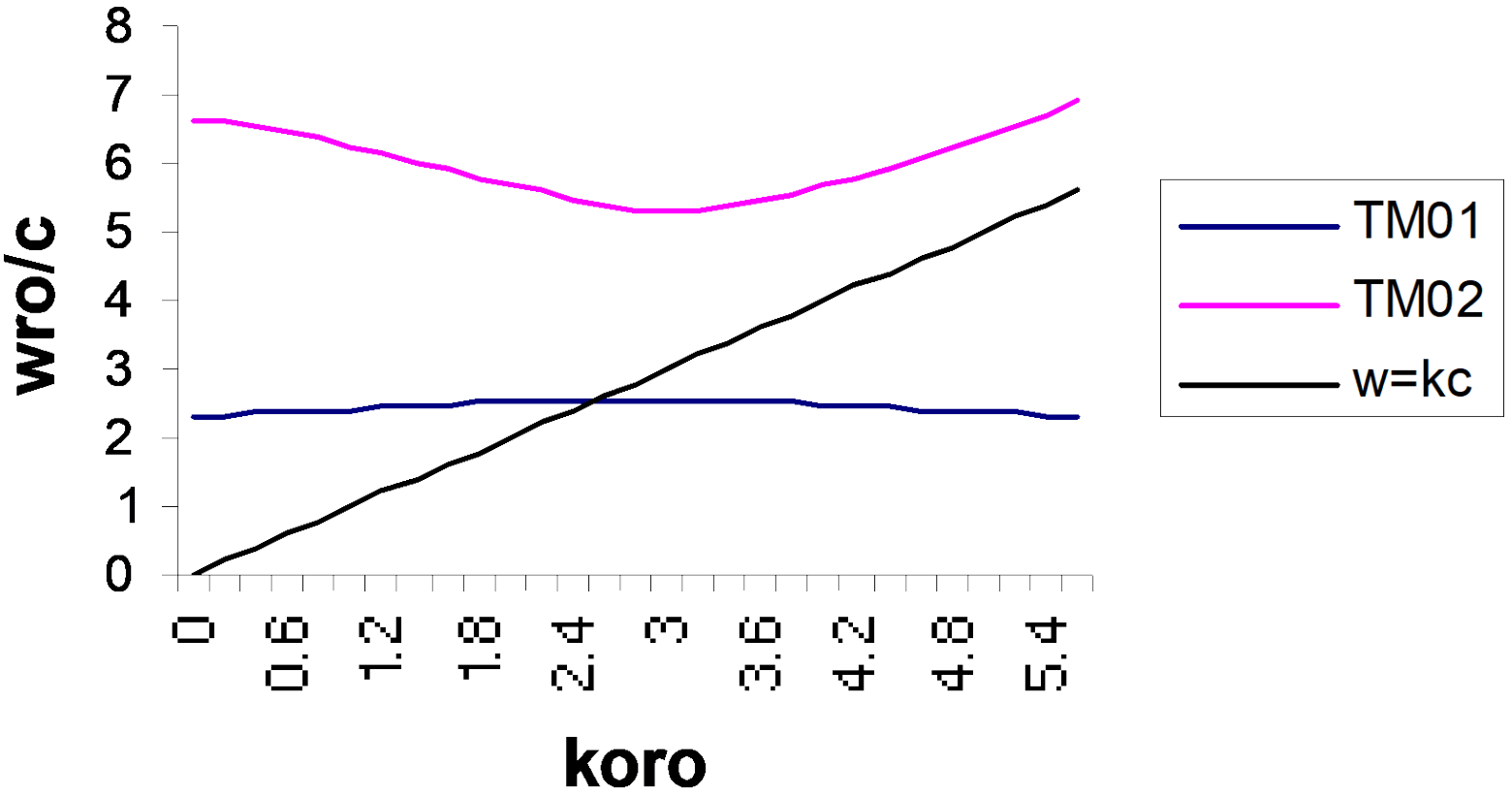
$= \pm iv \qquad n - m = \pm 1$

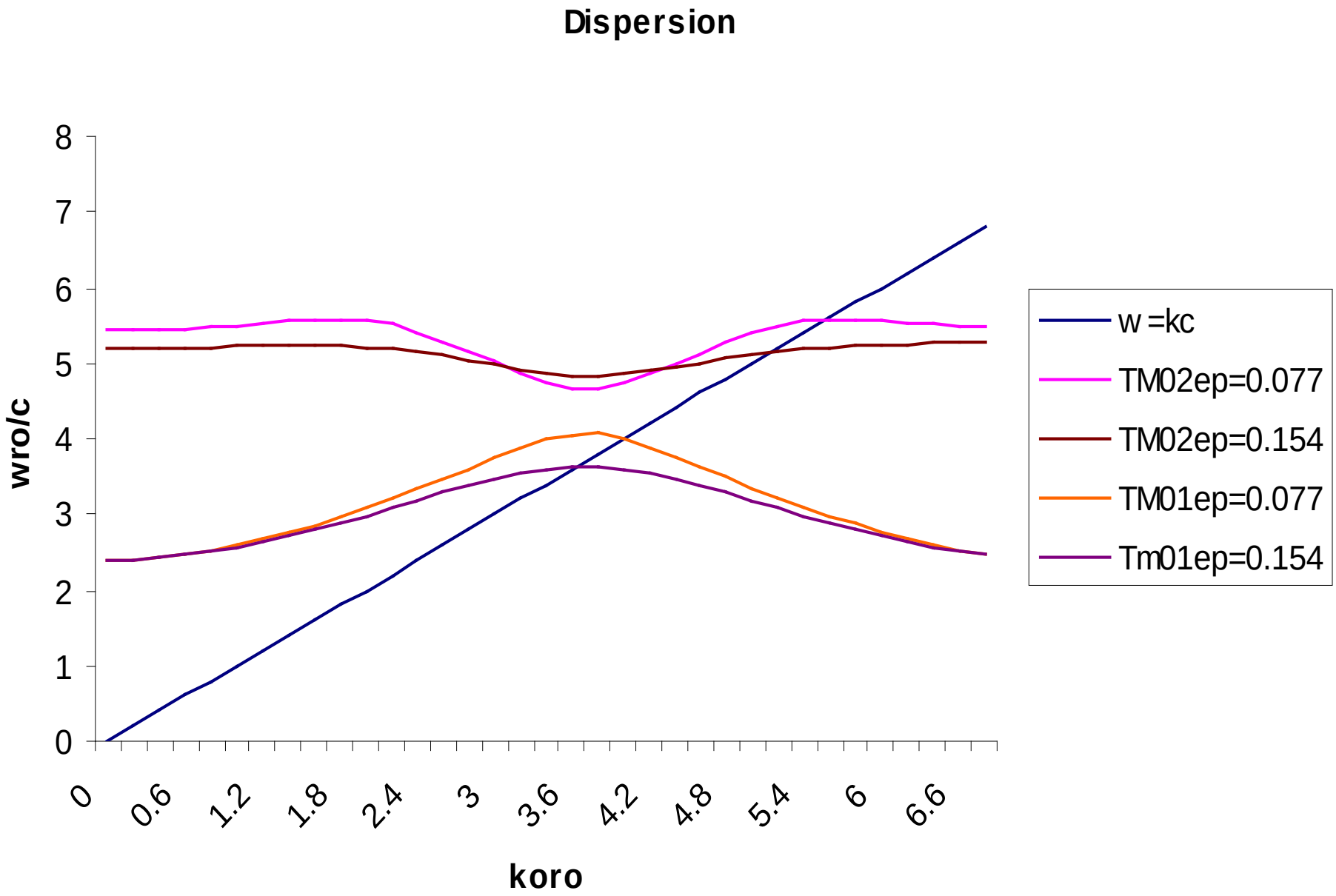
$= 1 - 2v^2 \qquad n - m = \pm 2$

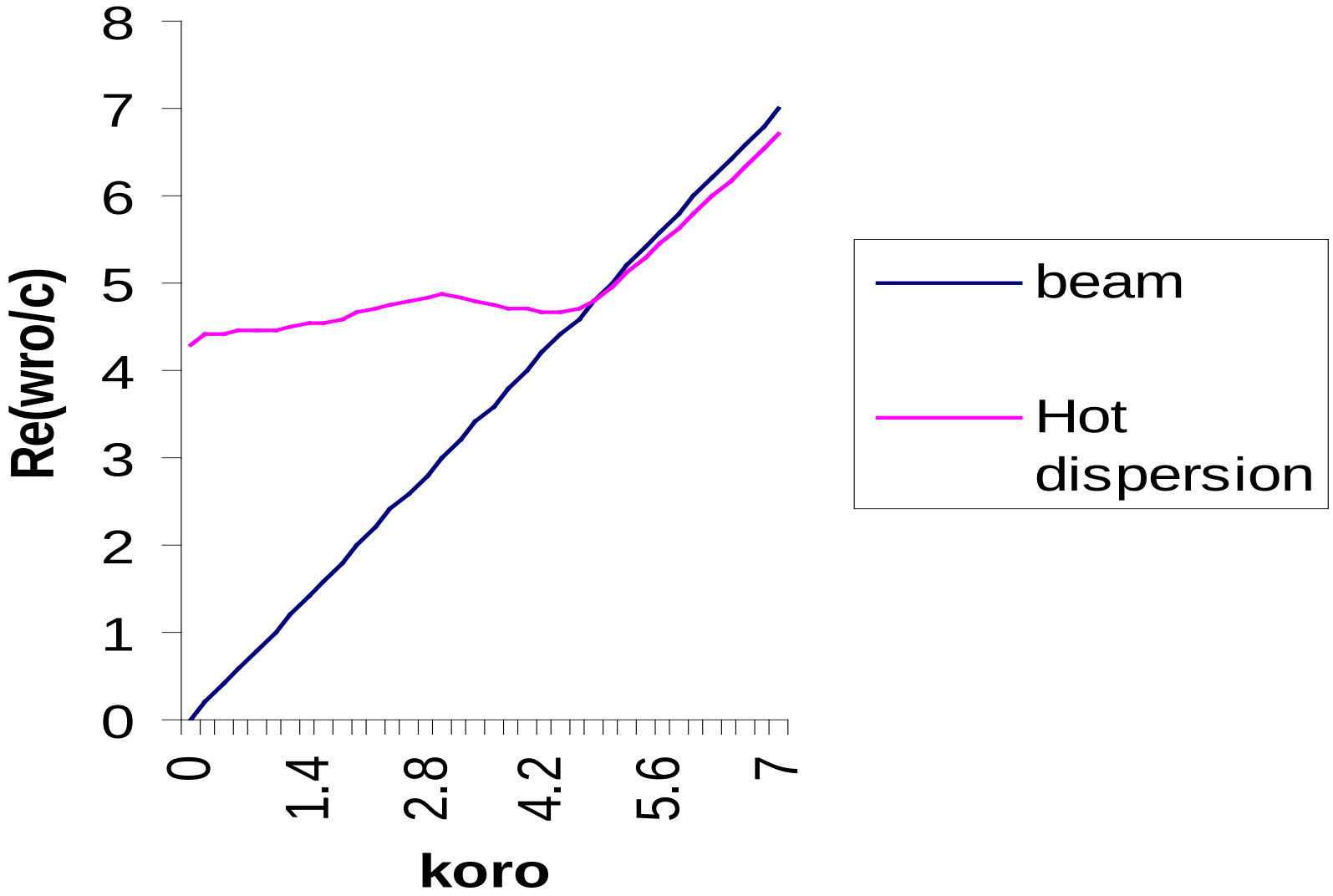
$= \pm i(3v - 4v^2) \qquad n - m = \pm 3$

$= 1 - 8v^2 + 8v^4 \qquad n - m = \pm 4$

- Results of calculations are displayed below




Dispersion
wro/c
koro
0
1
2
3
4
5
6
7
8
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
5.4
6
6.6
w =kc
TM02ep=0.077
TM02ep=0.154
TM01ep=0.077
Tm01ep=0.154


Re(wro/c)
8
7
6
5
4
3
2
1
0
0
1.4
2.8
4.2
5.6
7
koro
beam
Hot dispersion

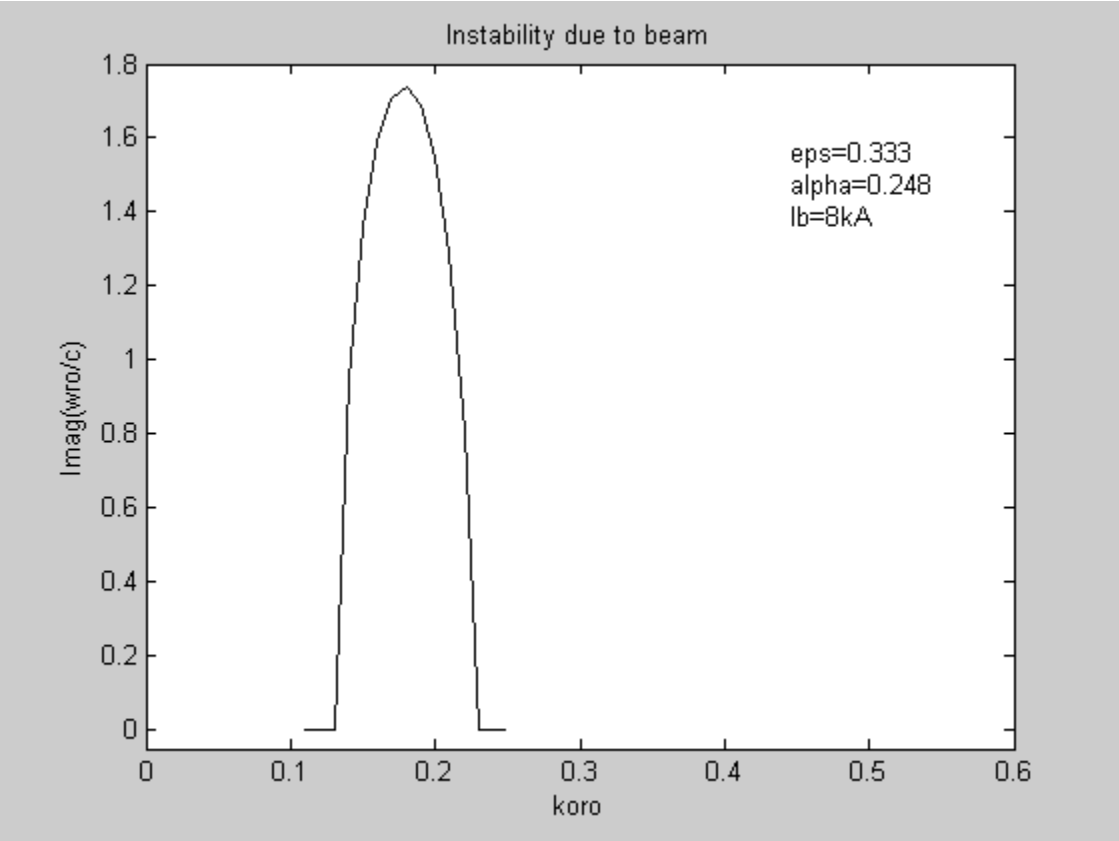
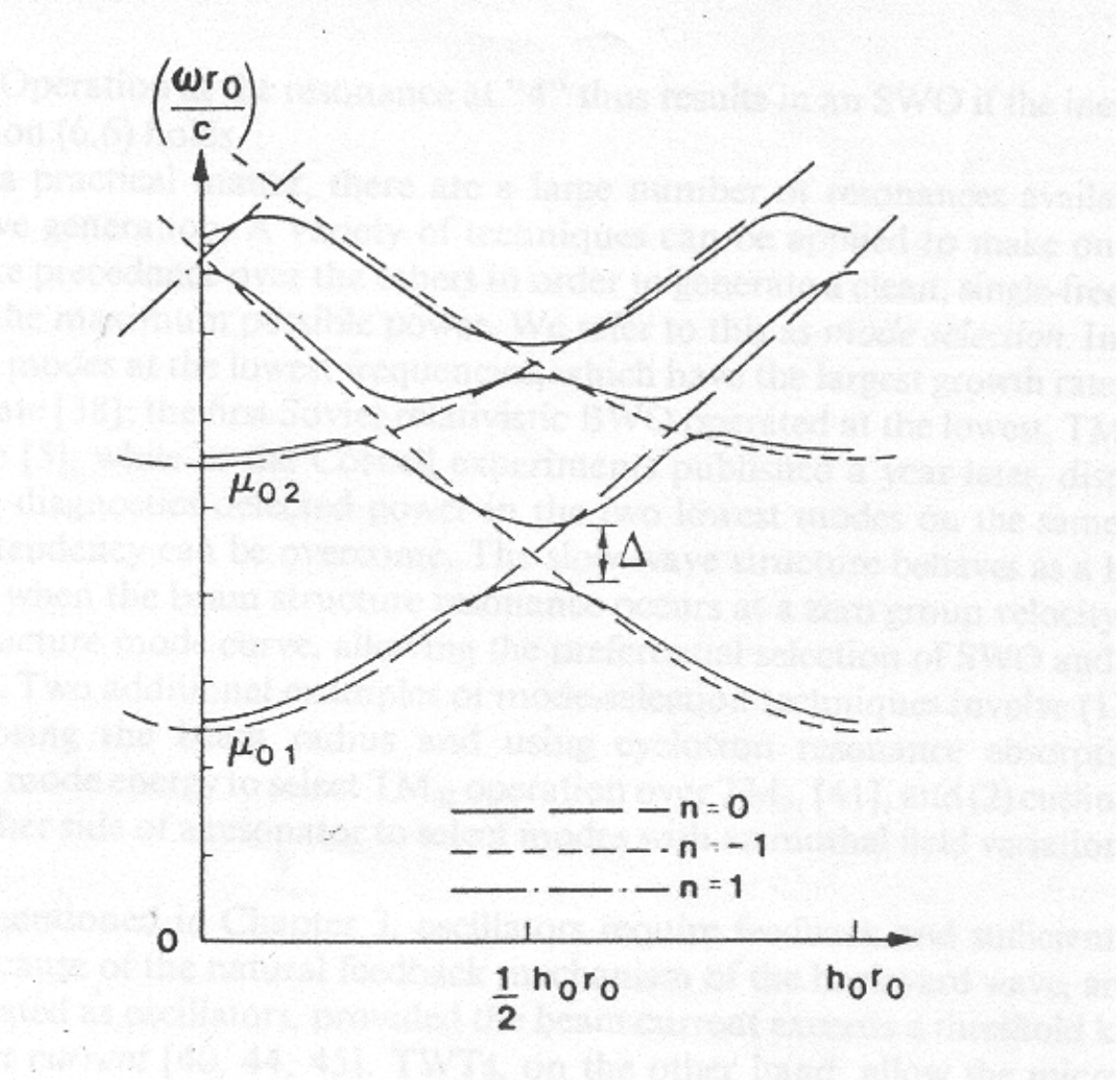

Instability due to beam
eps=0.333
alpha=0.248
Ib=8kA
Imag(wro/c)
koro
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6

Table depicting space charge and beam parameters as well as the maximumTM01 growth rate and the frequency at which greatest growth occurs .For these calculations we choose r0=1.5cm,r1=0.5cm, rb=0.5cm, z0=1.5cm,and Vc=1.0MV.

S.No.	**I_b(kA)**	**α**	**γ_b**	**β_b**	**$(\omega_i)_{max}$(nsec)$^{-1}$**	**f(GHz)**
1	8.0	0.248	1.91	0.852	0.348	14.1
2	6.0	0.121	2.18	0.888	0.746	14.0
3	4.0	5.35×10^{-2}	2.47	0.914	1.03	14.0
4	3.0	3.42×10^{-2}	2.59	0.923	1.028	13.9

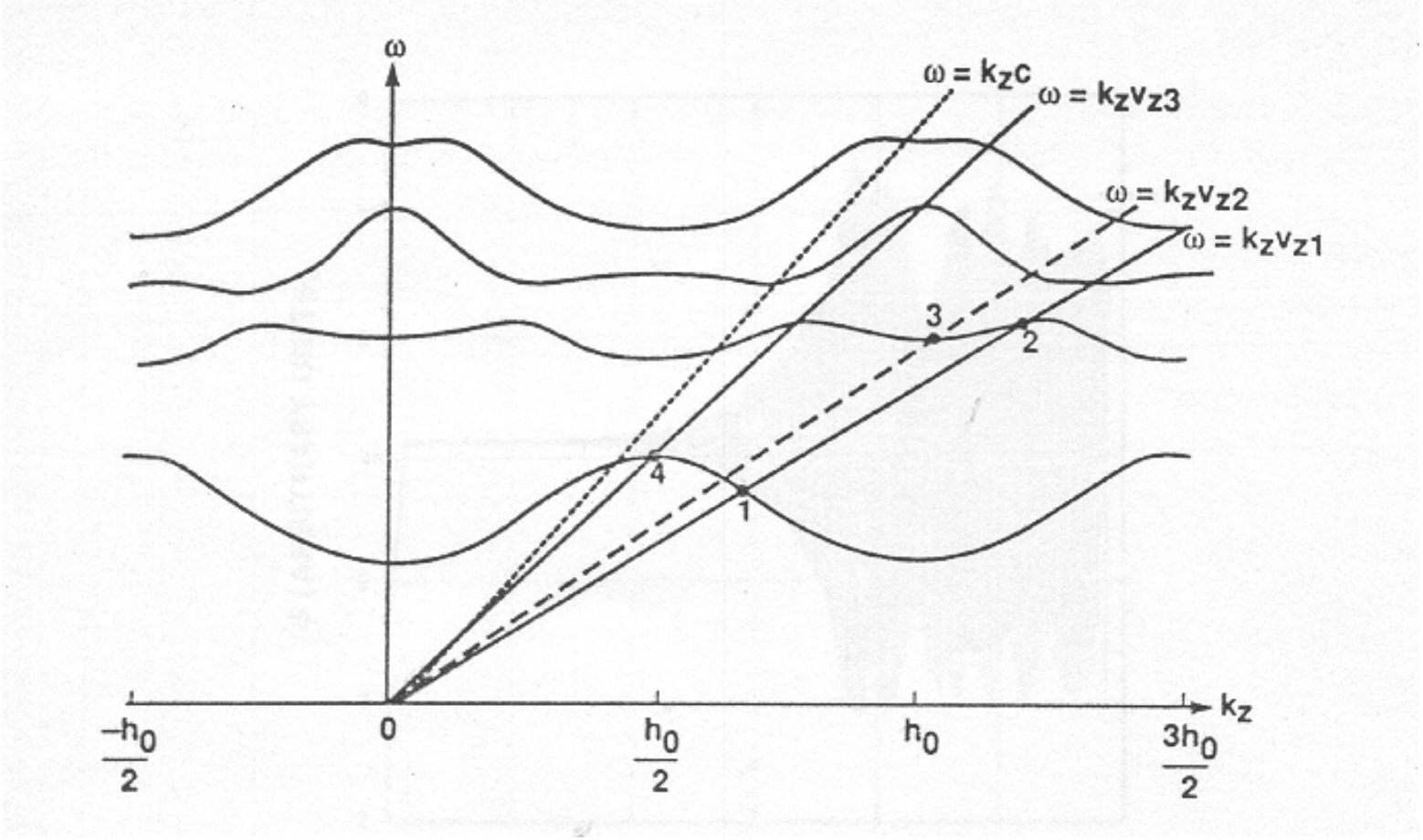
Dispersion characteristics of BWO



- The slow space-charge waves have a dispersion curve given by:

$$\omega = k_z v_z - \frac{\omega_b}{\gamma_0}$$

Beam-waveguide dispersion diagram



Advantages of Plasma filled systems

- The main advantages of the relativistic Cherenkov plasma microwave sources over the traditional vacuum sources like travelling and backward wave tubes lies in:
- Possibility to adjust the frequency of radiation easily by adjusting the plasma density to construct narrowband (almost monochromatic) and broad-band (noise like) microwave sources.

Pasotron

- The word pasotron is an acronym for “ plasma assisted slow wave oscillator”.
- These devices can be configured as both a backward-wave oscillator (BWO) and a traveling wave (TWT) amplifier.
- Absence of guide external magnetic field,
- Beam dynamics is 2-D in pasotron
- Highly efficient.

BWO experiment involves the following:

- High voltage source for electron Beam Generation
- Slow wave structure
- Need of axial guide magnetic field
- Microwave Detection

Relativistic Electron Beam Generation

- The DAVV- Marx generator is capable of delivering a maximum of 300 kV on a matched load for 30 kV DC charging. The generator is used to produce REB. The beam is capable to drive a backward wave oscillator (BWO) for generating high power microwaves in the power range of couples of MWs and can be used in various experiments like Vircator, Free electron lasers (FEL), etc.

100 % Indigenous BWO Experiment

- Fabrication of 300 keV Marx
- Relativistic electron beam generation
- Fabrication of rippled wall SWS
- Fabrication of guide magnetic field
- Successful transportation relativistic electron beam through SWS
- Successful demonstration HPM signal

Specifications of the DAVV- Marx generator

Charging voltage	**0-30 kV DC**
Number of capacitors used in Marx (N)	**20**
Capacitance of each capacitors	**21-nF**
Diameter of spark gap (SG)	**15 mm**
Resistance (of each tail resistors R)	**50 Ω**
Total energy stored in Marx	**180 Joules**
Output voltage on matched load	**~ 300 kV**
Pulse duration	**~150 ns**

- An indigenous development of pulsed power supply capable of generating magnetic field upto 1 T has been demonstrated. The pulsed magnetic field (0–1 T), and duration ~260 ms can be used for the propagation of an unneutralized 300 keV, 150 ns, electron beam. This magnetic field pulse can be used to guide the relativistic electron beam in high power microwave generation experiment from a backward wave oscillator.

Development pulsed power supply for generating 1-T pulsed magnetic field of duration ~ 300 microsecond.

The used components are :

- Transformer :Input 220 V, Output 2.0 kV
- Resistors :Charging resistor 50 k Ohm,
- Diodes :IN4007
- Capacitors :12 capacitors each of value 15 F
- Switch :SCR- HF120TB12 – 4 in series

- The circuit diagram of the assembly is given in Figure.

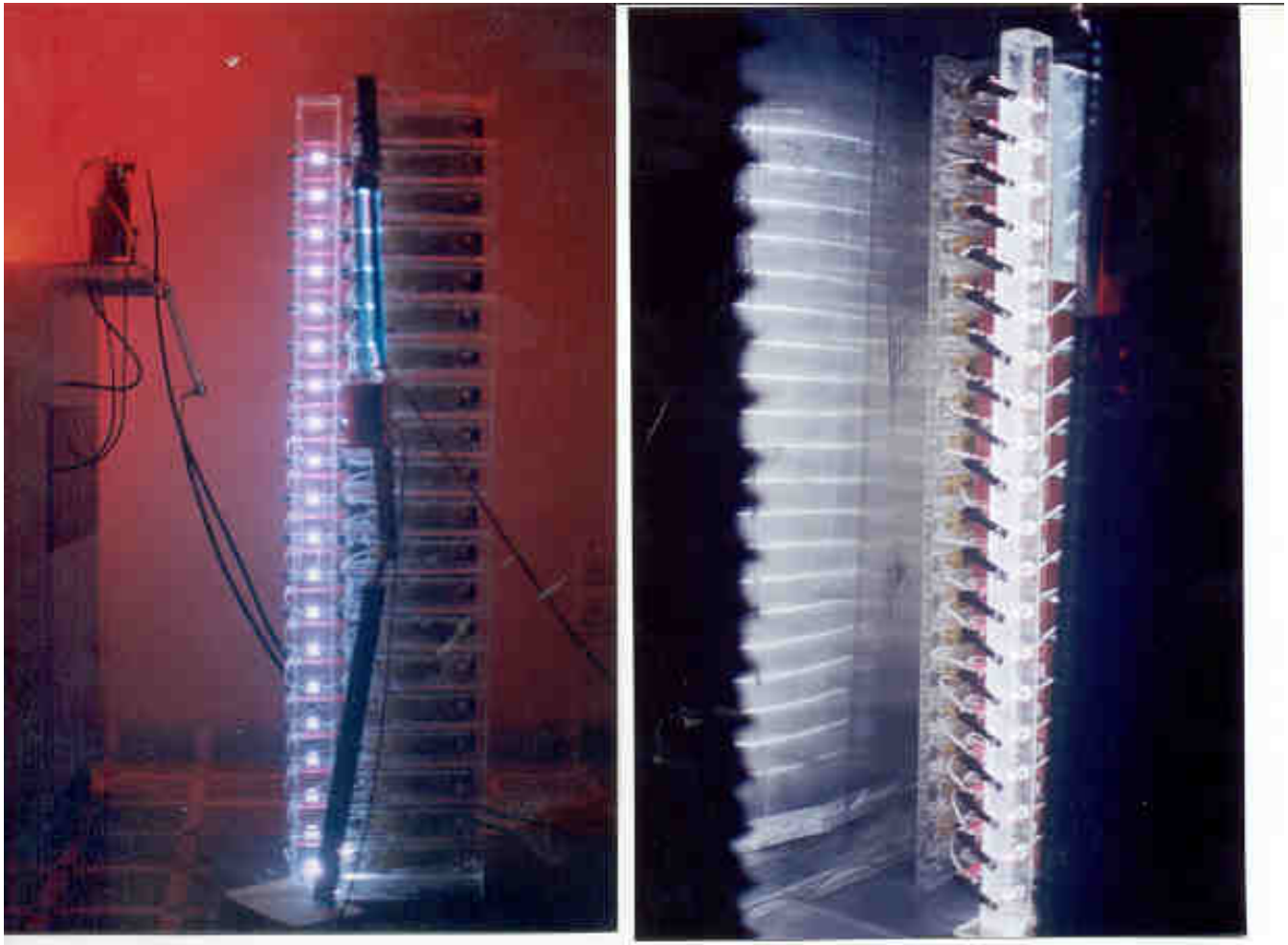
iv) Development diagnostics for beam characterization:

- To measure the beam current we have fabricated the Rogowski coil.
- The specifications of the fabricated Rogowski coil are:
- Major radius of the elliptical winding

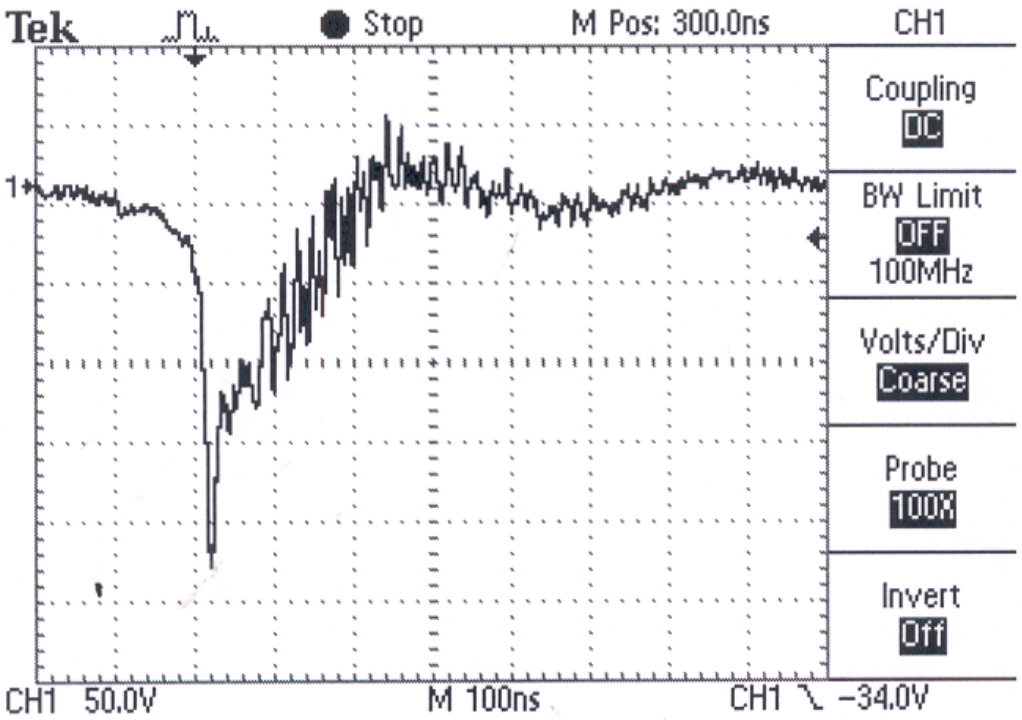
a = 20 mm

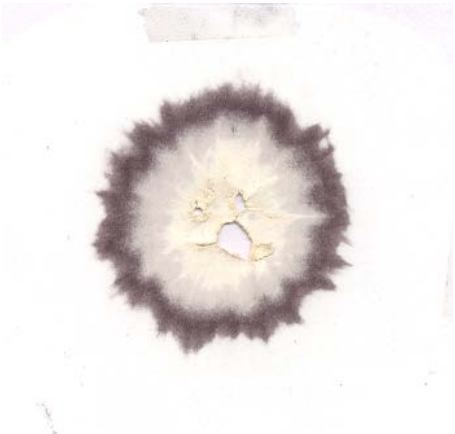
- Minor radius : b = 5 mm
- Number of turns N= 60.

Erected Marx Generator

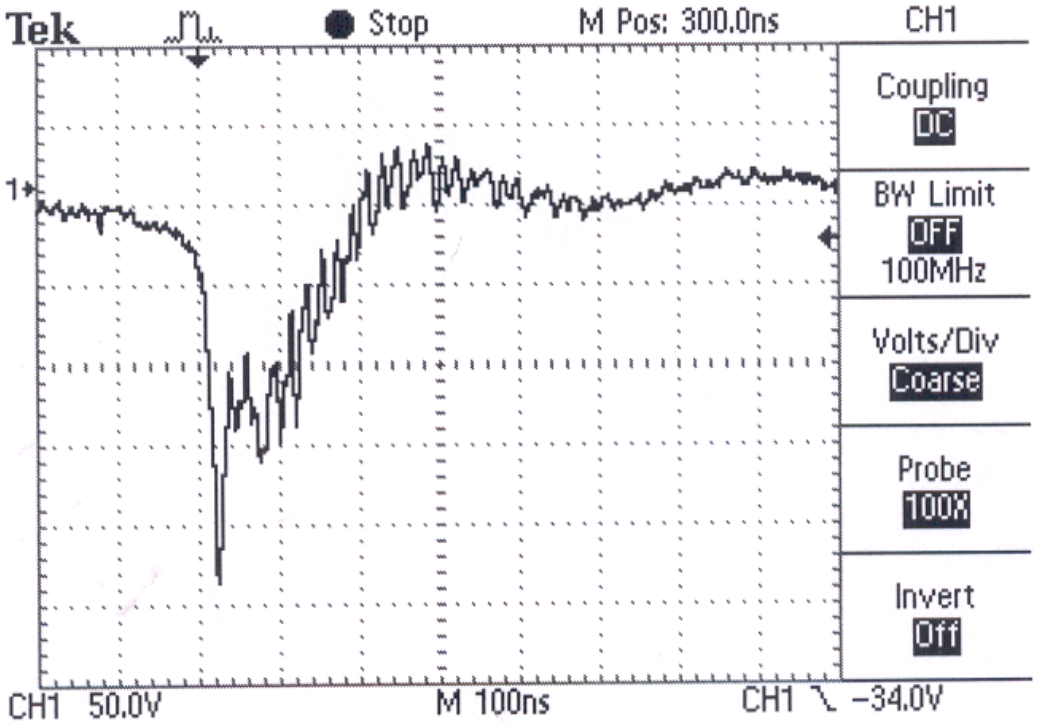


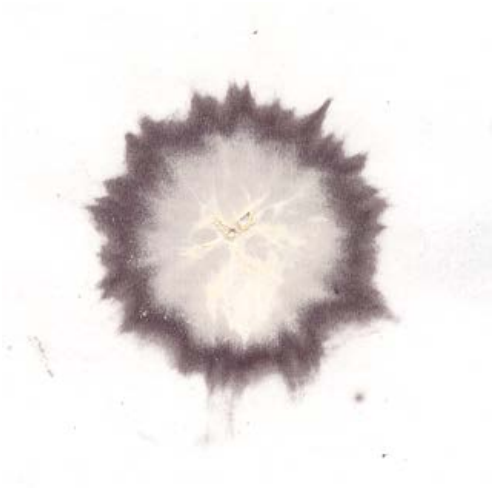
Beam Voltage Profile and Size



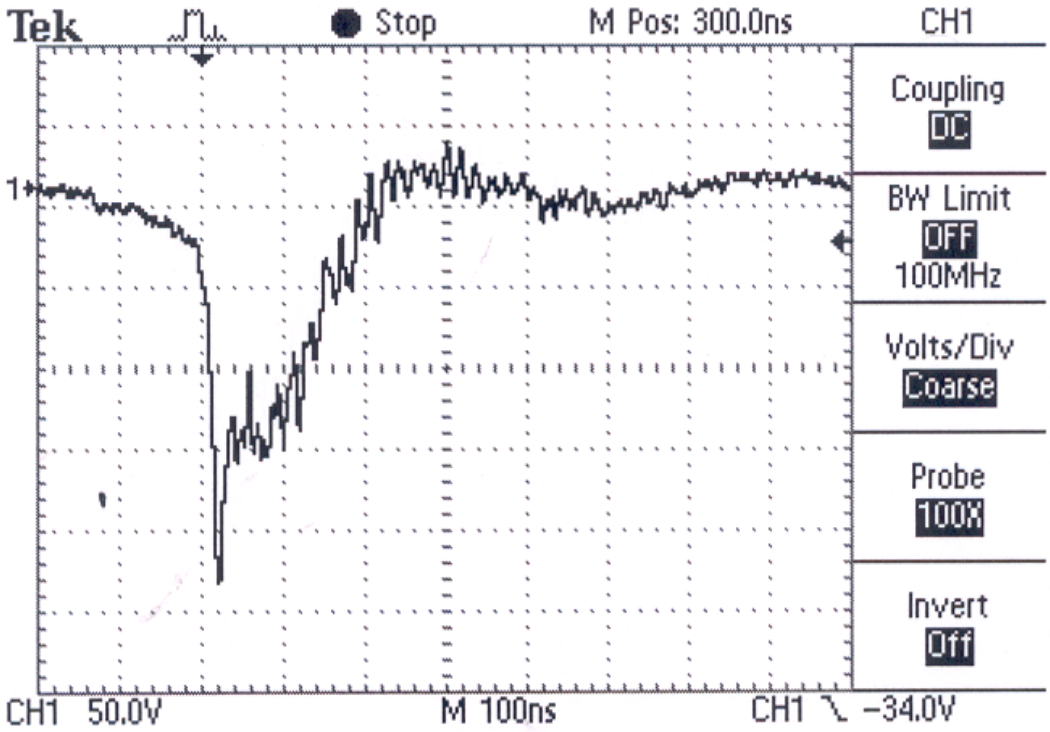


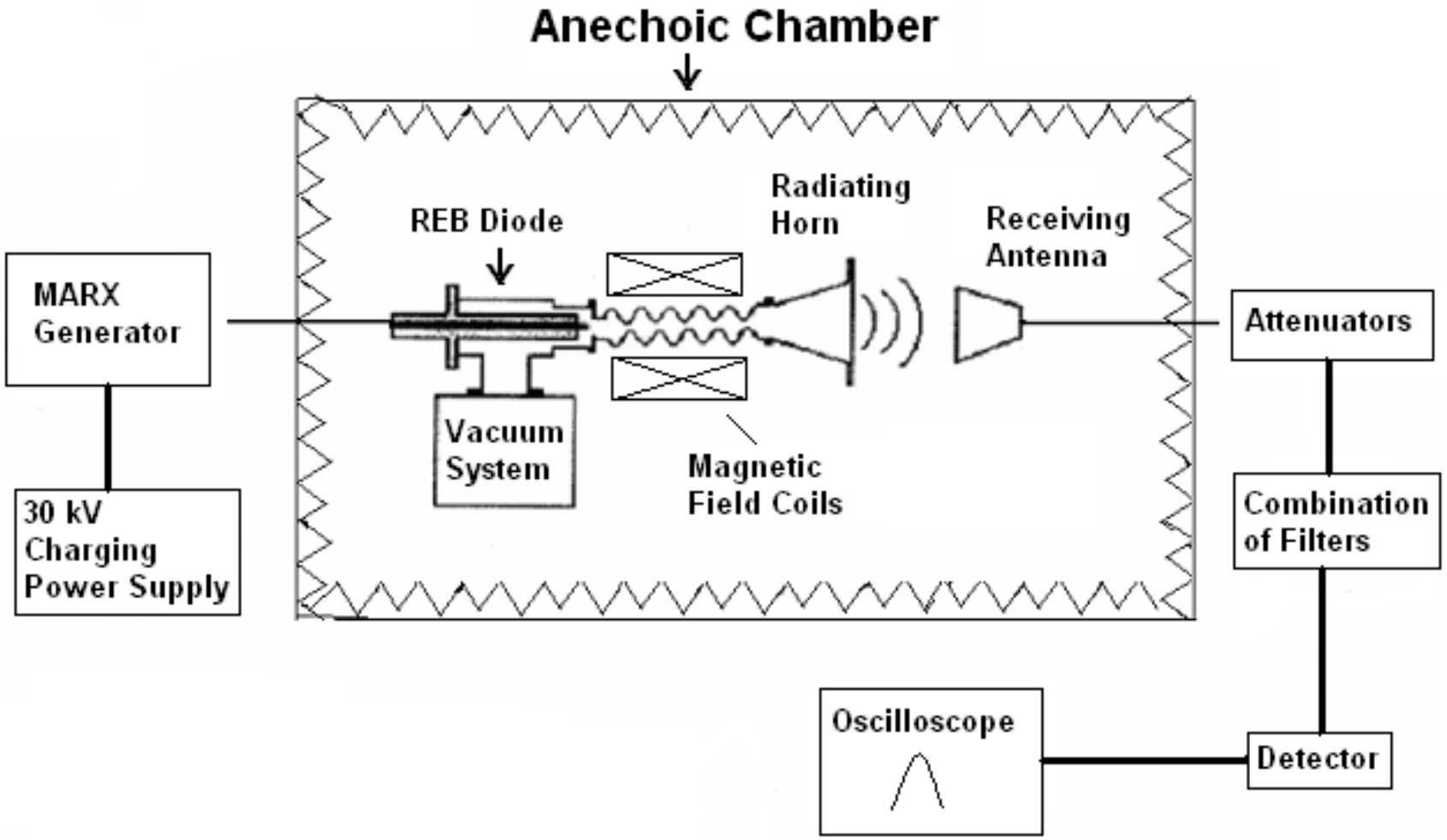
Beam Voltage Profile and Size



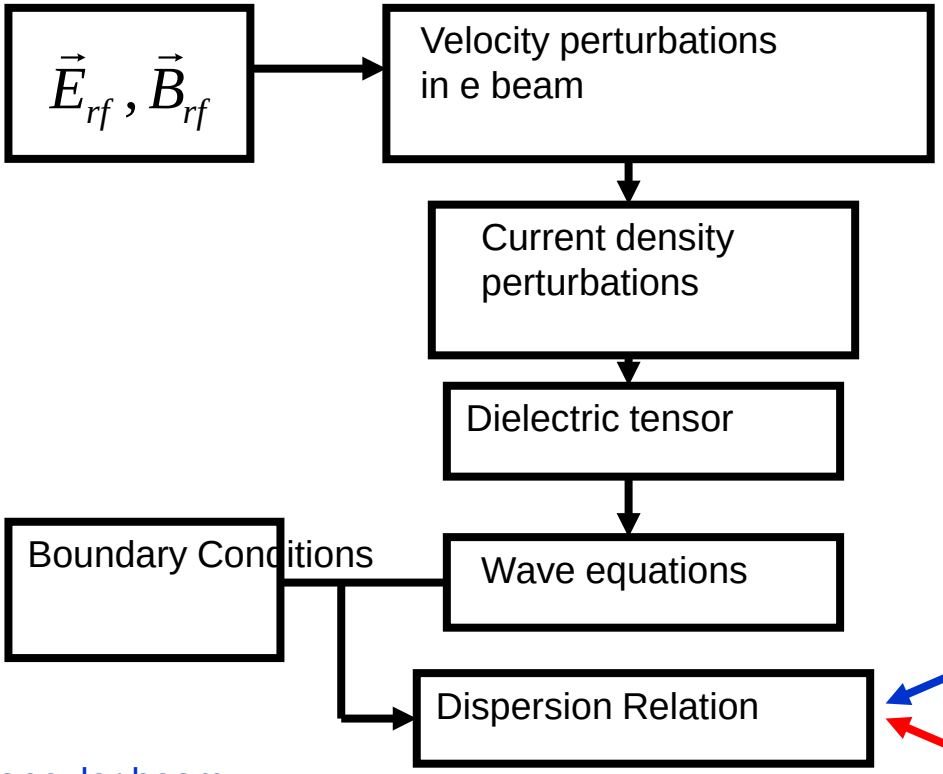


Beam Voltage Profile and Size





Full Experimental Set-up



Equilibrium velocity of electrons $\vec{V} = V_0 \hat{z}$

Guide Field $\vec{B}_0 = \infty \hat{z}$

$\vec{B}_0$ is finite

$\vec{B}_0 \neq \infty \hat{z}$

Negative energy SCM and positive energy FCM

annular beam

solid beam

High Power Microwave Lab (DAVV, Indore)
MARX Generator Parameters

- Charging voltage : 30 kV, 20 mA DC
- Number of stage : 20
- Capacitance per stage : 21 nF
- Resistance : 50 Ohm (each)
- Inductance per stage : ~ 84 nH
- Total energy stored in Marx : 130 Joules
- Output voltage (matched load) : ~ 230 kV
- Pulse Duration : ~ 130 ns

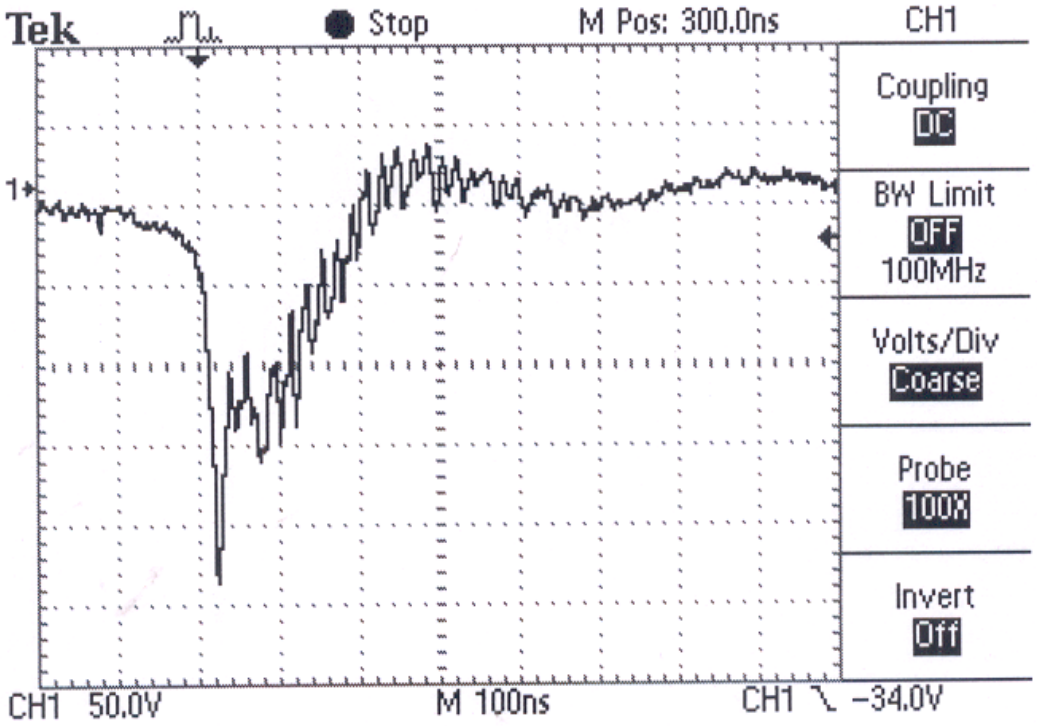
Relativistic Electron Beam Parameters

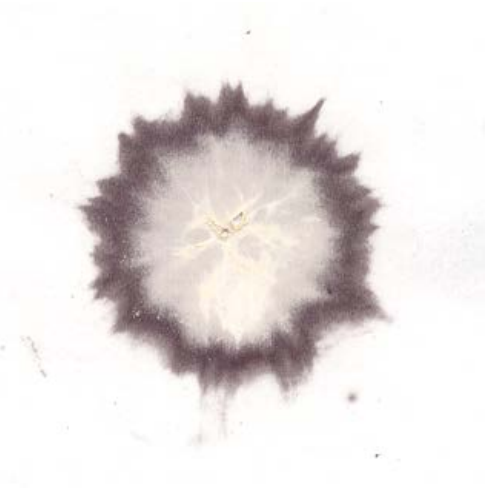
- Electron Beam Energy : ~ 230 keV
- Beam Current : ~ 1.0-2.0 kA
- Beam Current Density : ~ 0.2 – 0.8 kA/cm^2
- Beam Radius : ~ 0.7-0.9 cm
- Energy : ~ 130 J
- Impedance of beam diode : ~ 90 ohm
- Vacuum : ~10^{-5} Torr
- Guide Magnetic field : 1 T, 260 micro sec

- An indigenous development of pulsed power supply capable of generating magnetic field upto 1 T has been demonstrated. The pulsed magnetic field (0–1 T), and duration ~260 ms can be used for the propagation of an unneutralized 300 keV, 150 ns, electron beam. This magnetic field pulse can be used to guide the relativistic electron beam in high power microwave generation experiment from a backward wave oscillator.

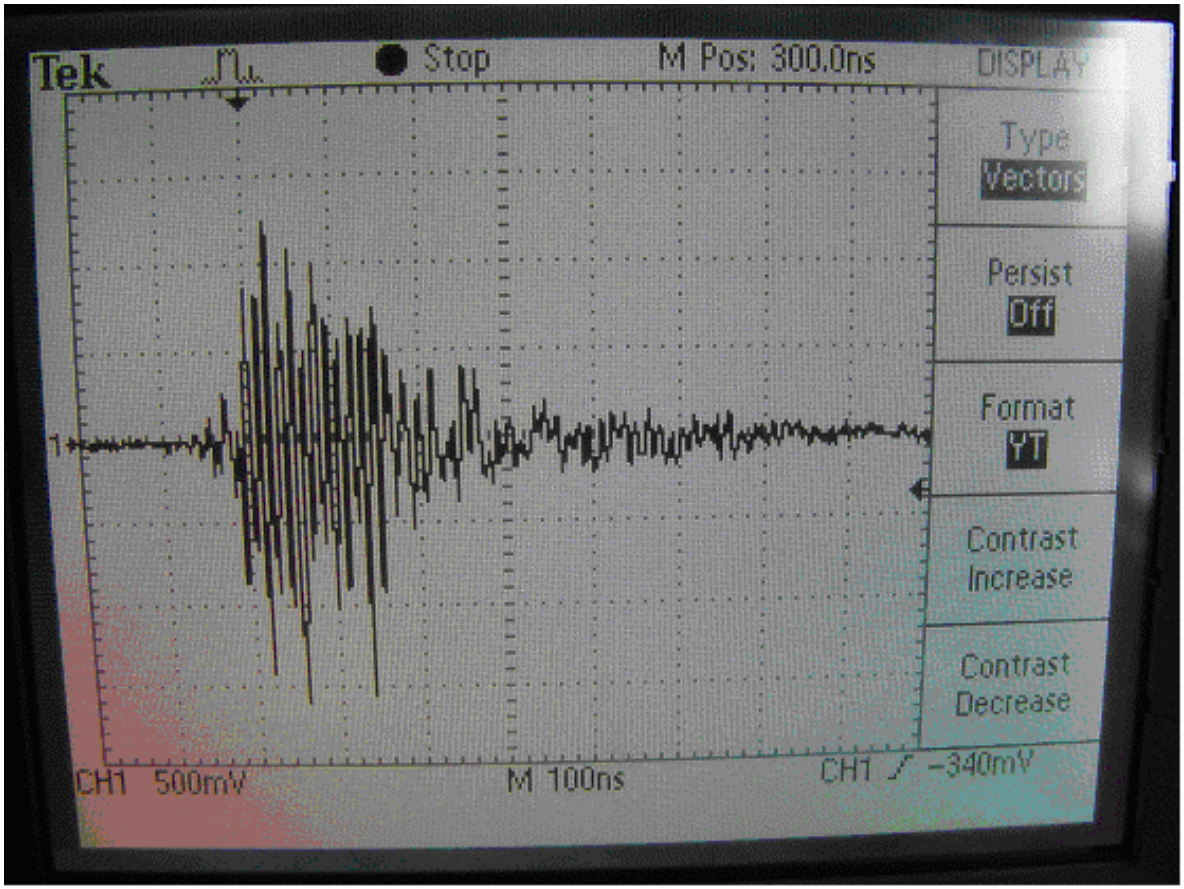
- Presently upgradation of this is in progress so that B goes upto 1.5 T, pulse duration 1.5 ms

Beam Voltage Profile and Size

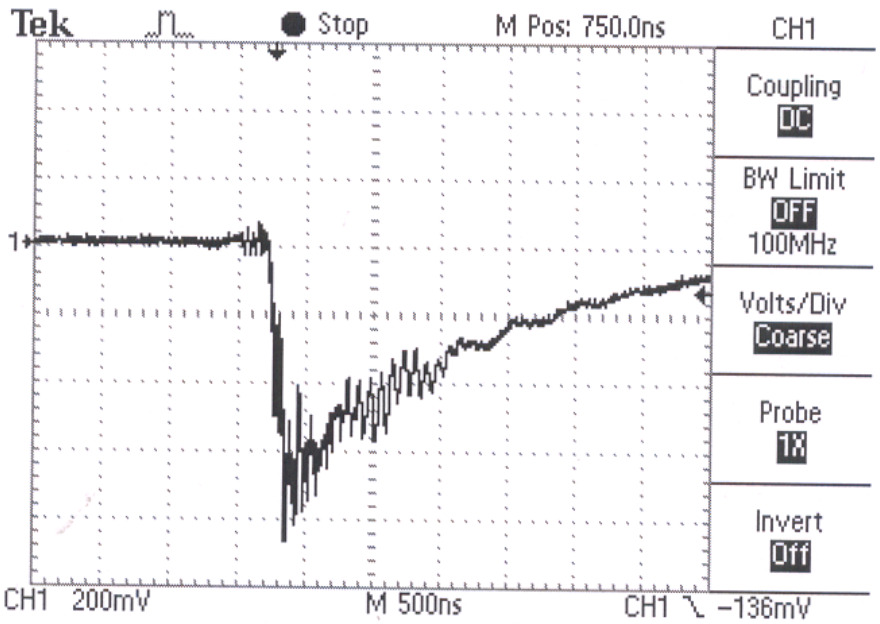




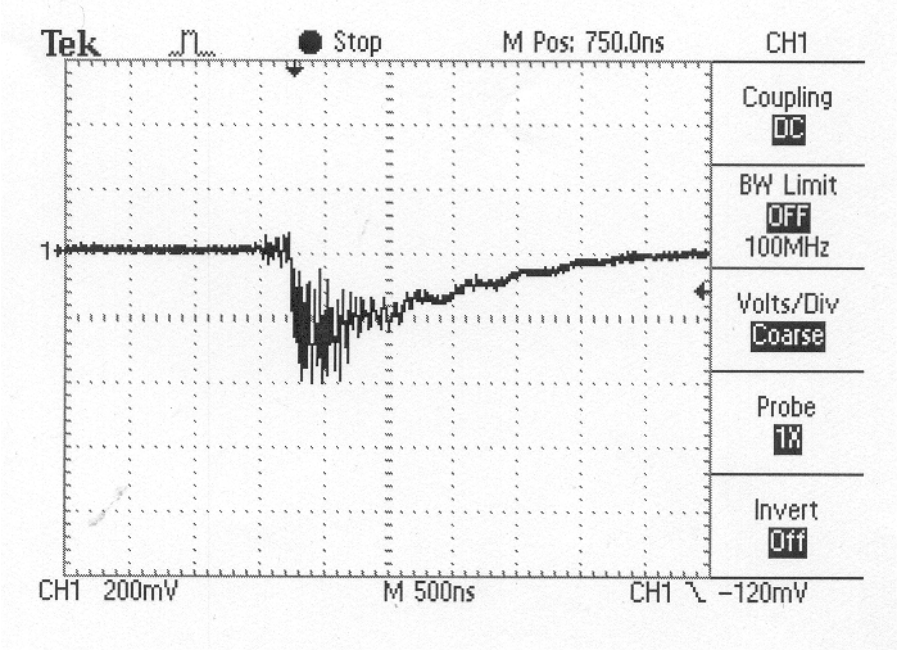
BWO Signal (in absence of guide magnetic field)



BWO Signal

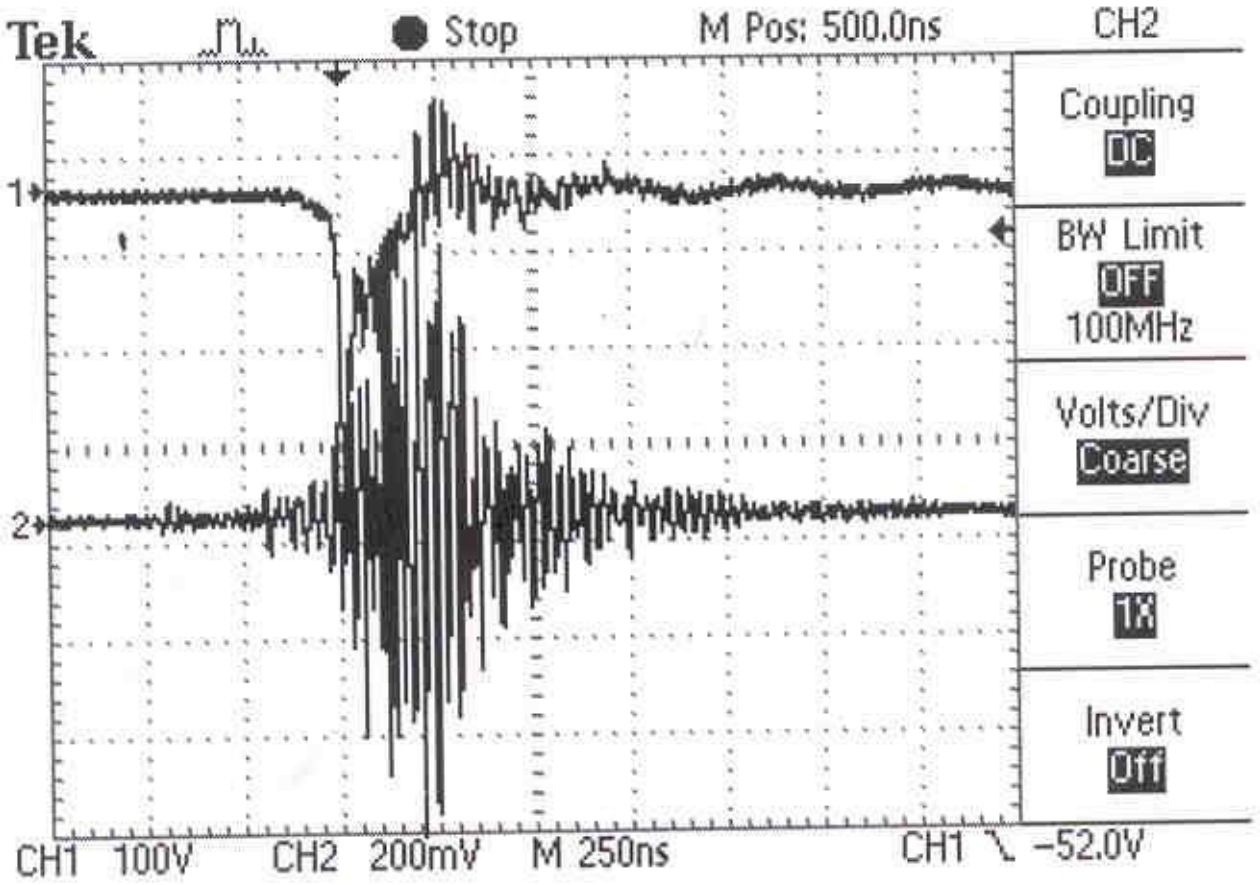


Without Attenuation



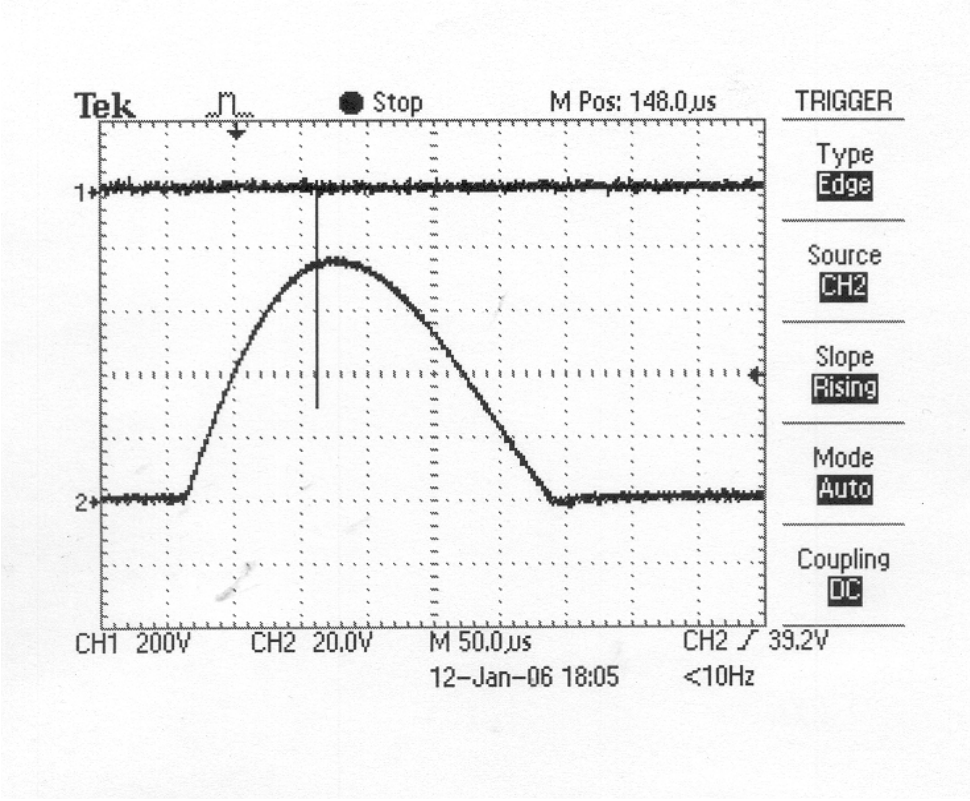
With 30 dB Attenuation

BWO Signal with Beam



Synchronization of pulsed magnetic field and electron beam generation from Marx

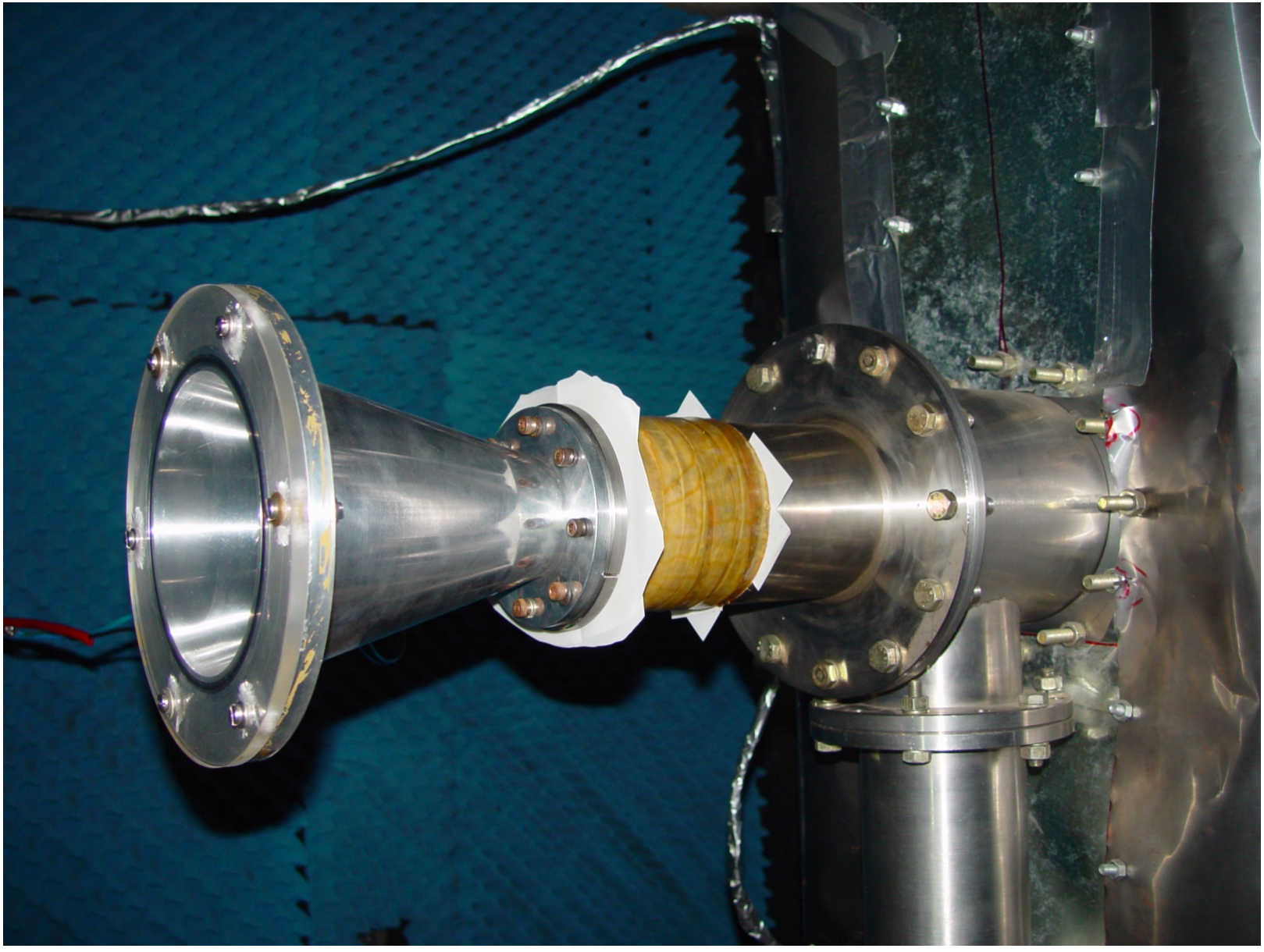
The electron beam sees the quasi steady magnetic field over its characteristic time scale of ~ 100 ns.



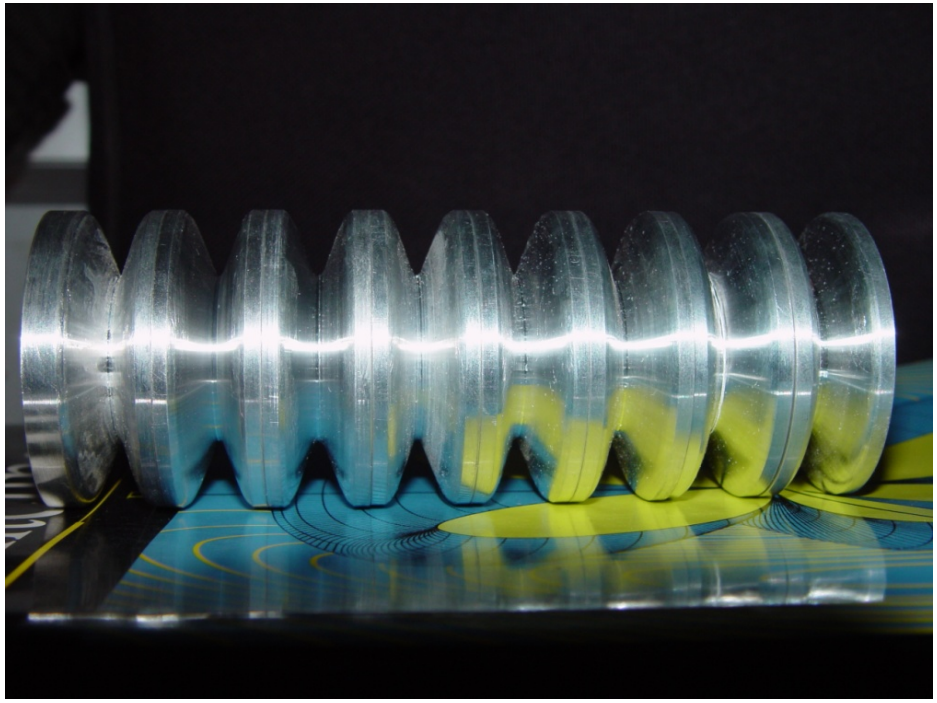
Optimized parameters for our sinusoidal structure

- R_0 = 1.5 cm
- d =1.5 cm
- h = 0.5 cm
- No. of periods = 8
- Length of the tube = 12 cm

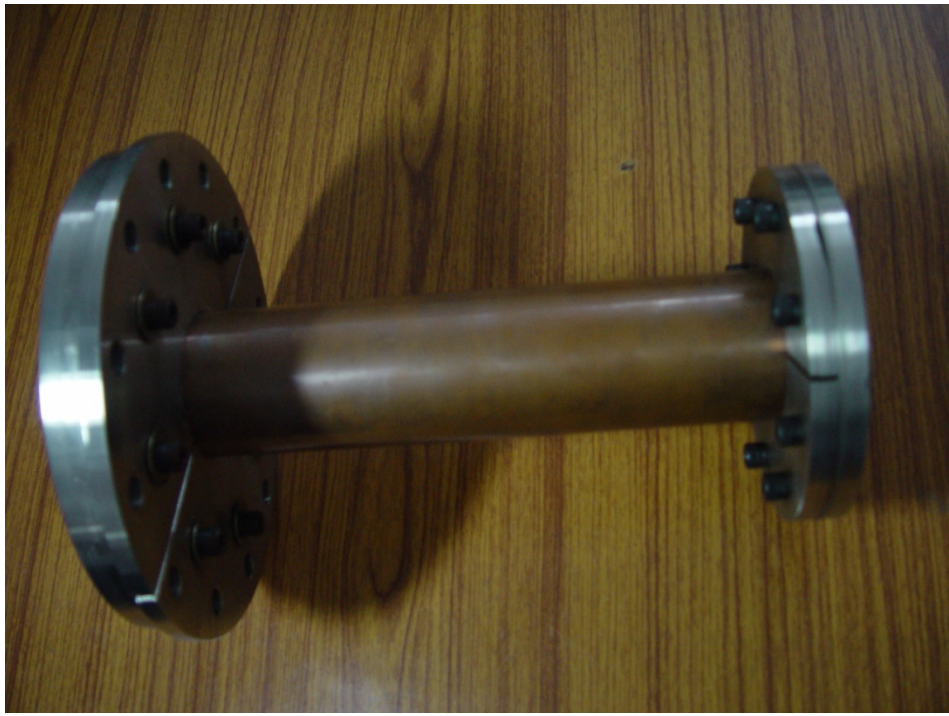
Experimental Set-up



Photographs of BWO tubes

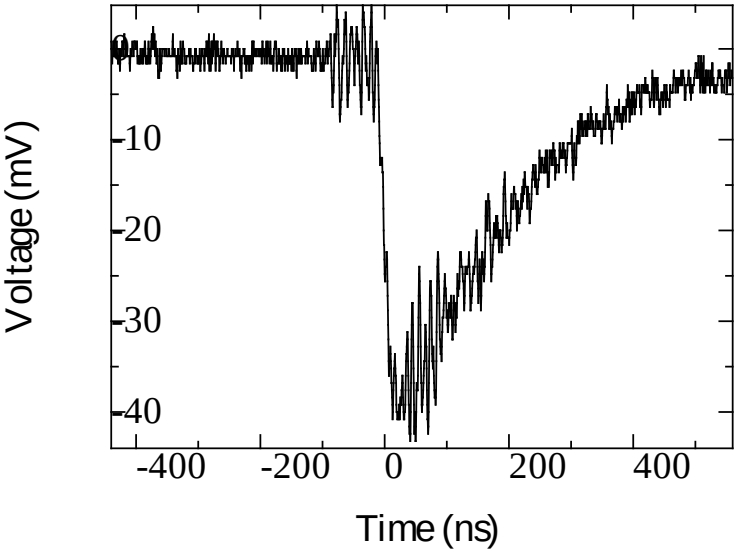


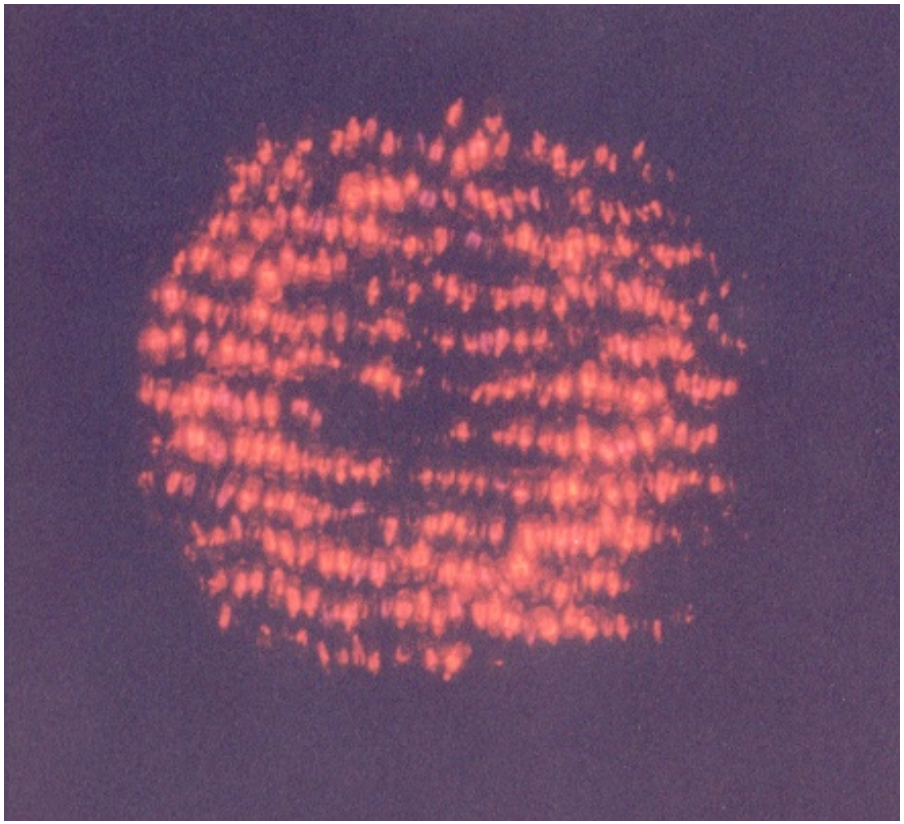
Al SWS



Cu SWS

Results





conclusion

- We have demonstrated experimentally BWO experiment to generate HPM signal in X-band in a university laboratory.
- All parts of the experiment developed/fabricated indigenously.
- Further work in this field of strategic importance , both in theory and experiment needs to be supported.

Thanks to the collaborators

- Dr. P. H. Ron , Head –APPD, BARC
- Dr. K.C. Mittal and his colleagues, APPD, BARC
- Dr. Lalit Kumar and his group, MTRDC, Bangalore
- Dr. S.C. Baphna, DC-ACC Lab, RRCAT
- Late Professor K. Minami, Niigata University, Japan
- Professor Emeritus T.Watanabe, NIFS, Japan

Acknowledgements

Thanks are due to Defence Research & Development Organization (DRDO), New Delhi for financial support for this work.

Thanks to the Thinkers in VED group for the opportunity and support given to us for sharing our research work.

Thanks for your kind attention

Annexure II:
Young Researcher's Talk Slides

Analysis of Pseudospark Discharge Based Plasma Cathode Electron Source

Presented by:

Varun

Ph.D. Student, CSIR-NET, SRF

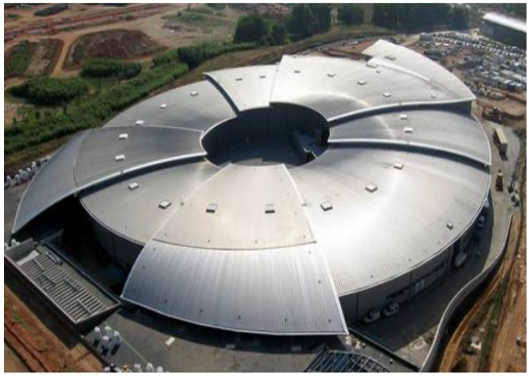
CSIR-CEERI, Pilani, Raj.

Organization of Presentation

- **Motivation:** PS discharge e-beam based EUV/Soft X-ray, Microwave, and Material Science Applications
- **Effect of Plasma for enhancing space charge limiting current:** Performance enhancement of Microwave Tubes
- **PS Discharge Fundamentals:** A technique for short pulse high density electron beam generation
- **PS discharge based plasma cathode electron beam source (PD-PCE Source)**
- **Analysis of geometrical, operating and circuit parameters**: Generation of PS discharge based short pulse electron beams
- **Results and Discussions**
- **Conclusion**

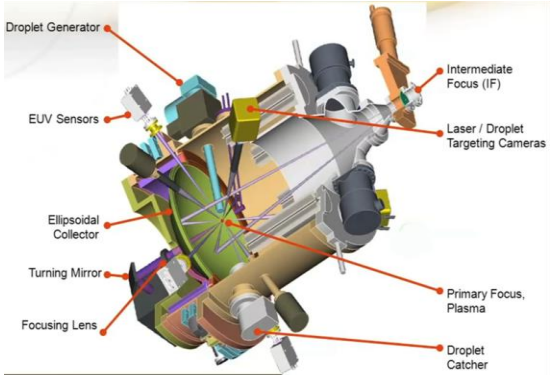
Motivation

- EUV/soft X-ray sources are of high importance in the immerging areas of growing surface modification of polymers for biocompatibility improvements, radiography of small objects for potential biological applications, X-ray Crystal Spectroscopy (XRCS) calibration applications, etc.



Synchrotron radiation facility

Journal of synchrotron radiation, ISSN 1600-5775, 2014.



Cymer LPP EUV source

Proc. of SPIE, Vol. 6151, 61513M, 2006

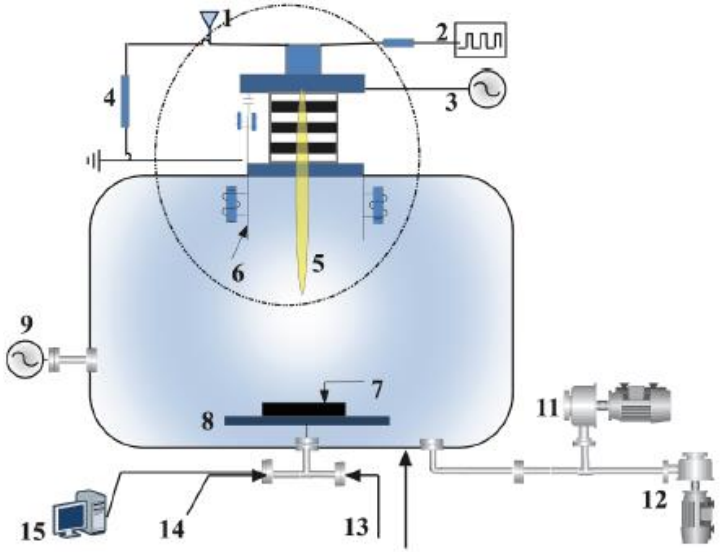
Capillary discharge EUV source

Sadhana, Vol. 36, Part 3, pp. 349–355, 2011

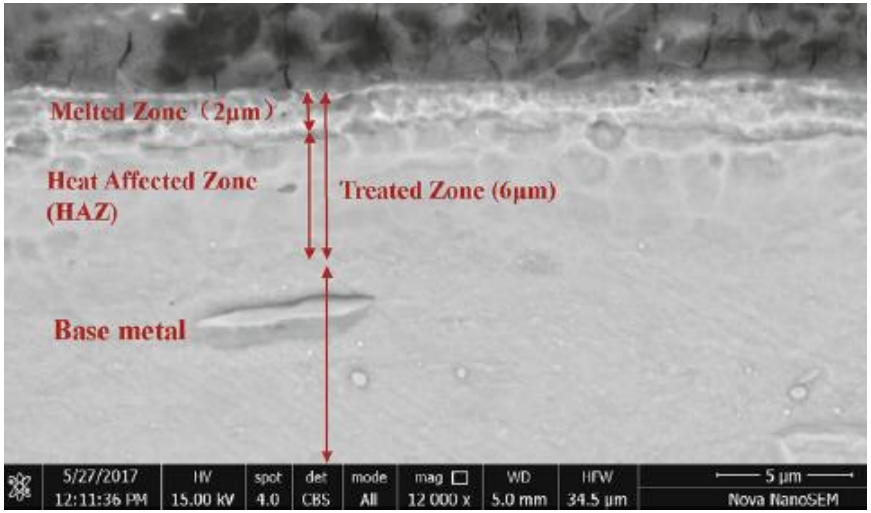
- **One of the latest approach:**
  - To use ferroelectric triggered pseudospark (PS) discharge based EUV/X-ray source which can be operated at higher repetition rate (up to 2.5 kHz) and will require less cooling
  - Such sources would be simple, tunable, compact and low cost.

Motivation

- PS Discharge Based e-beam applications:
  - Surface modification of Materials



Material processing chamber



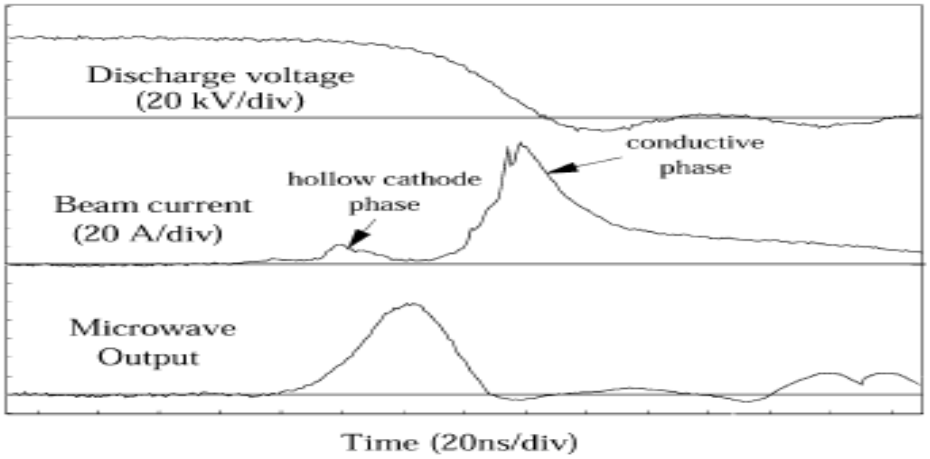
Y. Fu, et al., Nuclear Inst, and Method in Physics Research, B 434, pp. 88-92, 2018.

	T-ebeam	PD-ebeam	HCPEB	IPEB	GESA	Pseudospark
Accelerating voltage(U)	30~100 kV	30~40 kV	10~35 kV	20 kV	50~150 kV	5~15 kV
Discharge current(I)	30~300 mA	20~100 mA	up to 10 kA	~	100 mA	0.5–1.5 kA
Irradiation area (Radius)	3~5 mm	5~20 mm	2~3 cm	~	4~10 cm	1~3 mm
Pulse duration	*Continuos*	*Continous*	1~5 μs	100~200 μs	20~50 μm	around 100 ns
Repetition	~	~	0.5 Hz	0.3 Hz	~	50~5*k* Hz
energy density	~	~	1~10 J/cm^2	10~80 J/cm^2	20~80 J/cm^2	1~10 J/cm^2
melted thickness	≫ 10 μm	≫ 10 μm	1~10 μm	>10 μm	>10 μm	1~10 μm

Y. Fu, et al., Nuclear Inst, and Method in Physics Research, B 469, pp. 10-18, 2020.

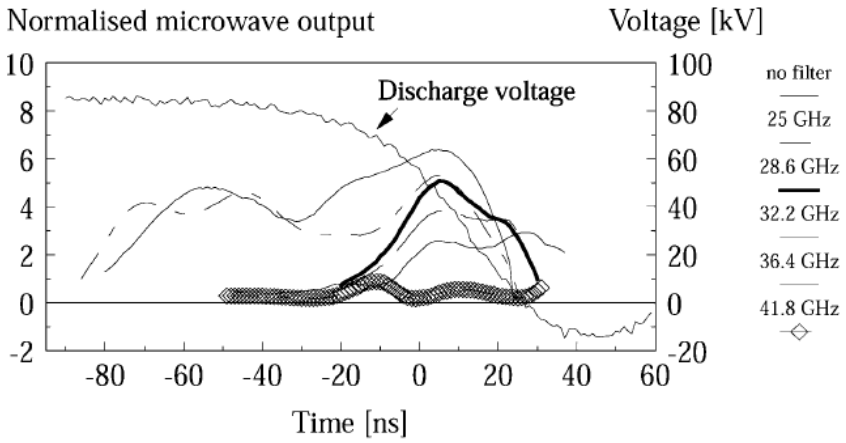
Motivation

- PS Discharge Based e-beam applications :
  - Microwave / THz radiation

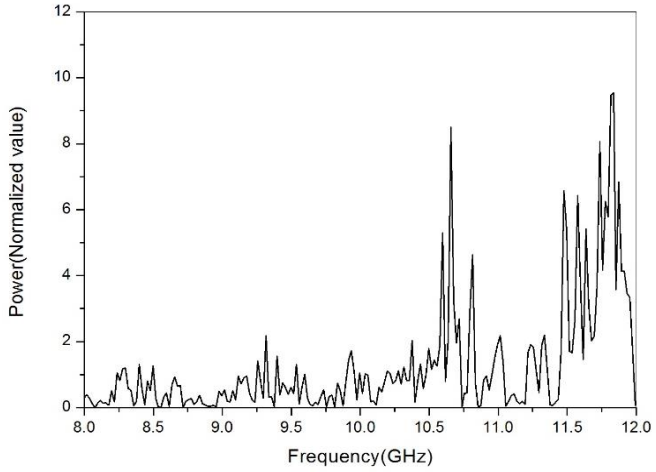


N. Kumar et al, Applied Physics Letters, 111, 213502, 2017.

G. X. Shu, et al., IEEE Electron Device Letters, vol. 39, no. 3, pp. 432-435, 2018



YIN et al, IEEE Trans. Plasma Science, vol. 32, no. 1, 2004



N. Kumar et al, Applied Physics Letters, 111, 213502, 2017.

Advantage of Plasma Filling of MW Sources

- Increased beam current (50 - 1000 A/cm^2)
- Low or zero magnetic field requirement
- Increased Power and Efficiency (>70%)
- Increased in gain
- Increased bandwidth (~30%)
- Compact and light weight
- Long pulse operation (~120 μs)
- Capable of high pulse repetition rate

D. M. Goebel, Phys. of plasmas, vol. 6, pp. 2225-32, 1999.
D. M. Goebel, et al, IEEE Trans. Plasma Sci., vol. 22, pp. 547–553, 1994.

Discharge Characteristics in Plane Electrodes

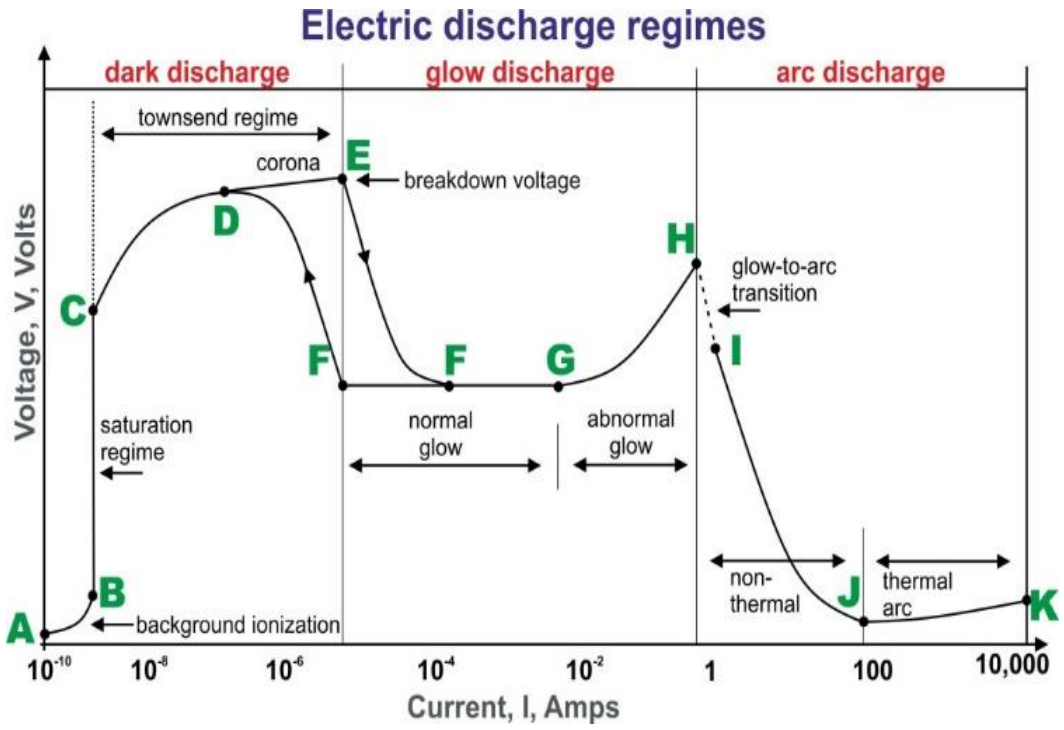
Townsend Breakdown criterion

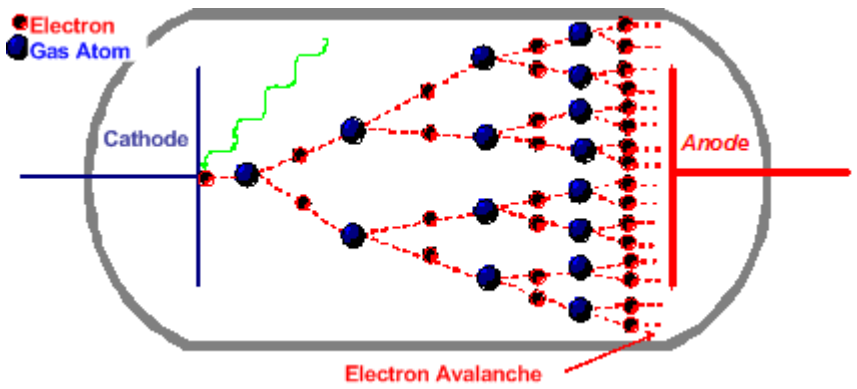
In order to maintain a self-sustained discharge it is necessary to create for each primary electron at least one secondary electron by γ-process. This process can be described by the following mechanisms:

Primary electron starts at the cathode→avalanche→anode

Photons from the volume→cathode →photoionization

← Ion avalanche

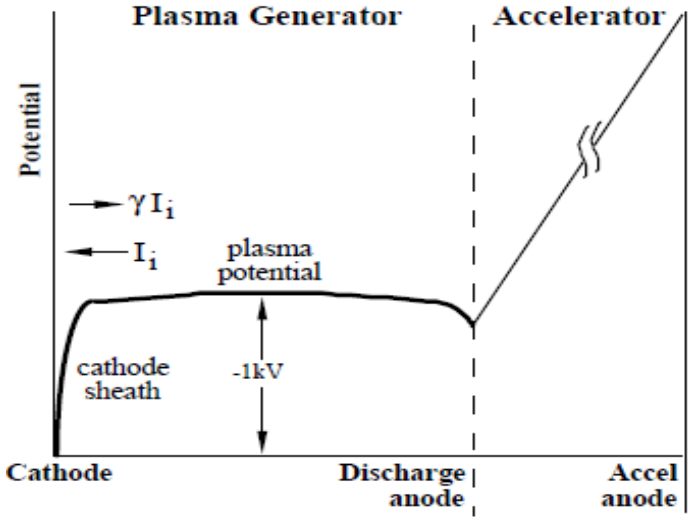


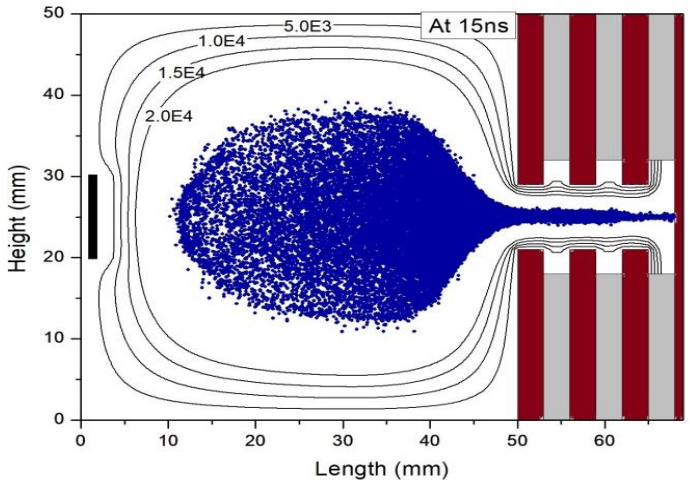


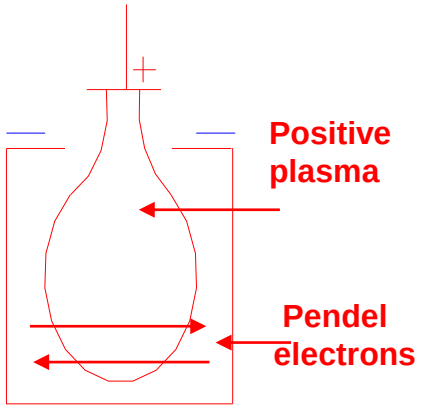
Principle of Hollow Cathode Discharge

- A characteristic feature of hollow cathode discharge is the oscillation of fast electrons emitted from the inner walls of the cathode cavity and accelerated into the cathode sheath.
- There is a fast growth in the ionization of neutrals. The pendel effect causes the emitted electrons to stay for a longer in the +ve plasma.

- **Radial geometry increases the cathode surface (plane-cylinder)**
- **Higher current density within the cathode fall**
- **Higher ionisation rate**
- **Higher ion density**
- **Higher secondary electron emission**

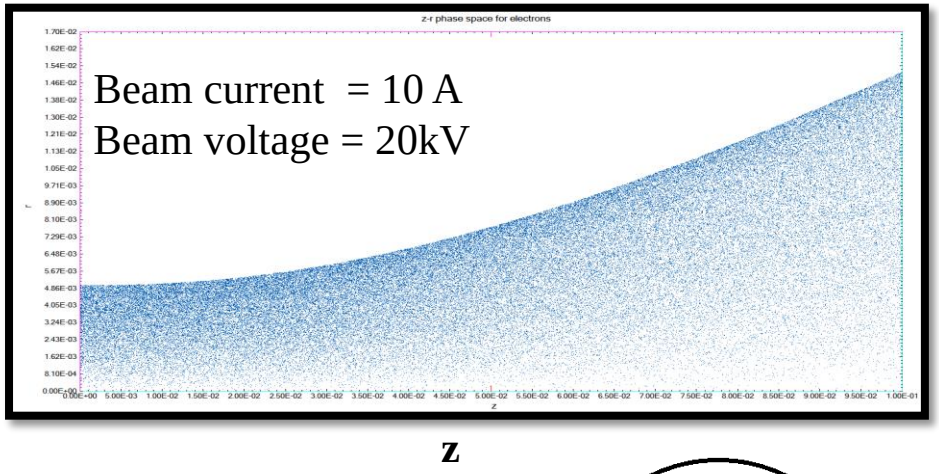


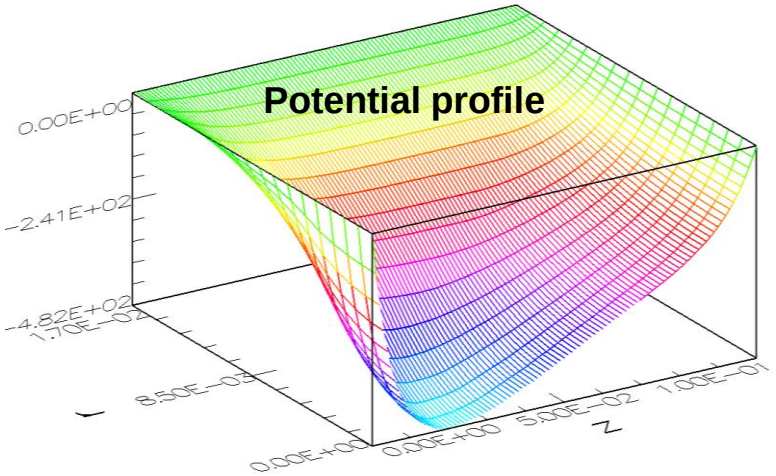


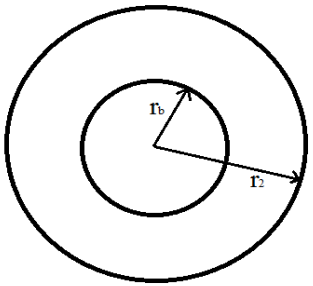


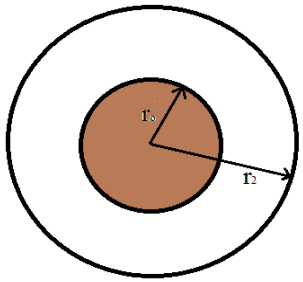
Limited Beam Current in Vacuum MW Devices

- In vacuum MW devices, the virtual cathode forms on beam due to space charge effects. The excess electrons are reflected back to electron gun due to formation of virtual cathode.
- Space-charge limiting current (I_{scl}) depends on the dimensions of the structure.



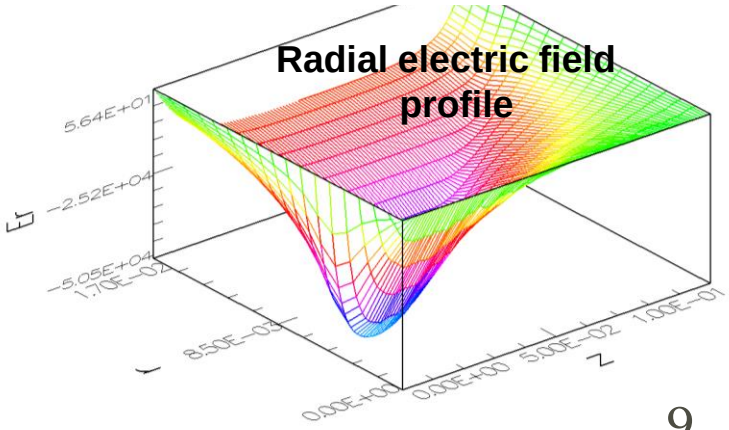




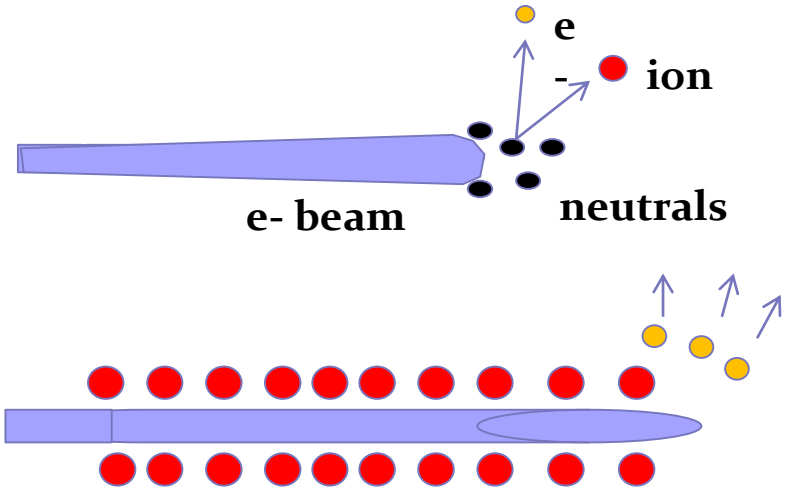


$$I_{scl} = \frac{I_A}{2}\frac{\left(\gamma_0^{2/3} - 1\right)^{3/2}}{ln(r_2/r_b)}$$

$$I_{scl} = \frac{I_A\left(\gamma_0^{2/3} - 1\right)^{3/2}}{1 - 2ln\left(r_0/r_2\right)}$$



Higher Beam Current in Plasma Filled MW Devices



$$F_r = \frac{4\pi e^2}{r}\int (1 - f_e - \beta^2) n_e r dr$$

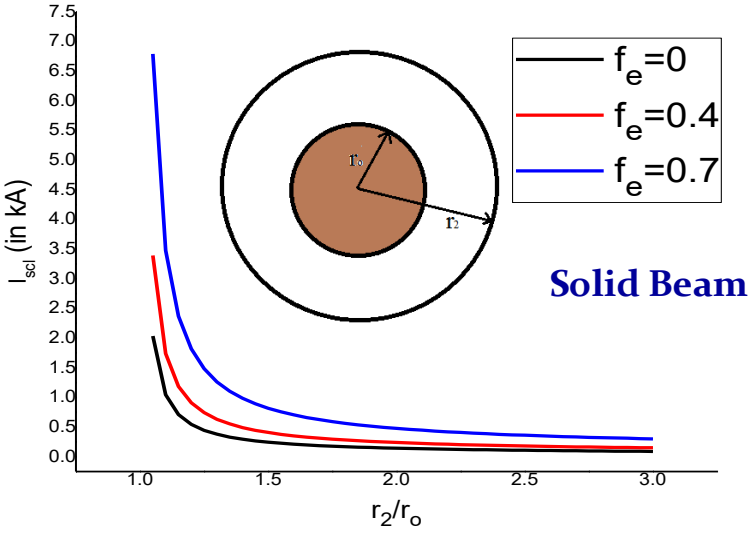
Beam is un-neutralized, $1-\beta^2 \rangle 0$

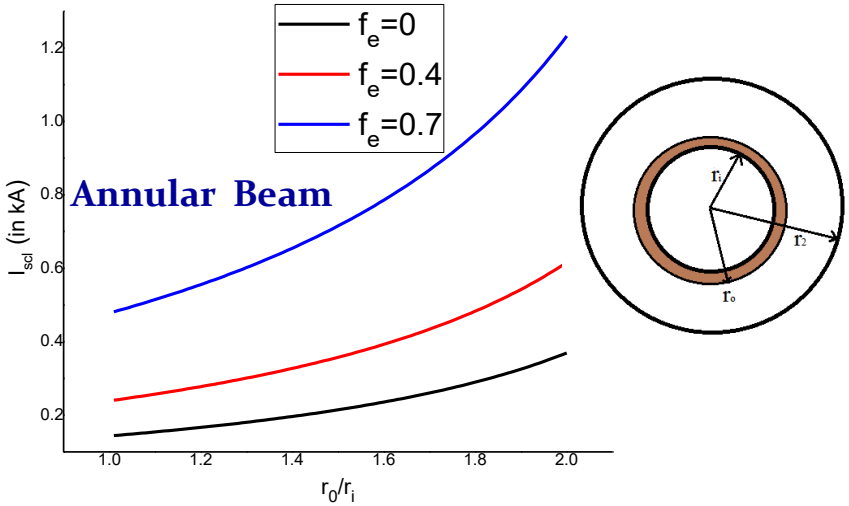
Condition for neutralization of beam, $f_e \geq 1-\beta^2$

where, f_e is the neutralization factor $f_e = \frac{n_i}{n_{eb}}$ and $\beta = \frac{v_z}{c}$

SCL (kA) of a thin, hollow beam with a mean radius *a* in a drift tube of radius *b* is

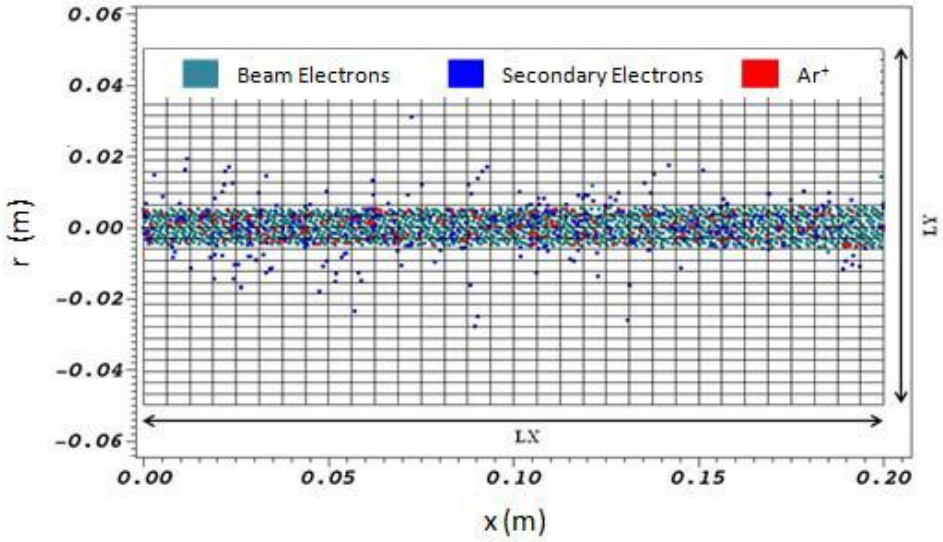
$$I = \frac{17[\gamma_0^{2/3} - 1]^{3/2}}{[2\ln(b/a)][1 - f_e]}$$

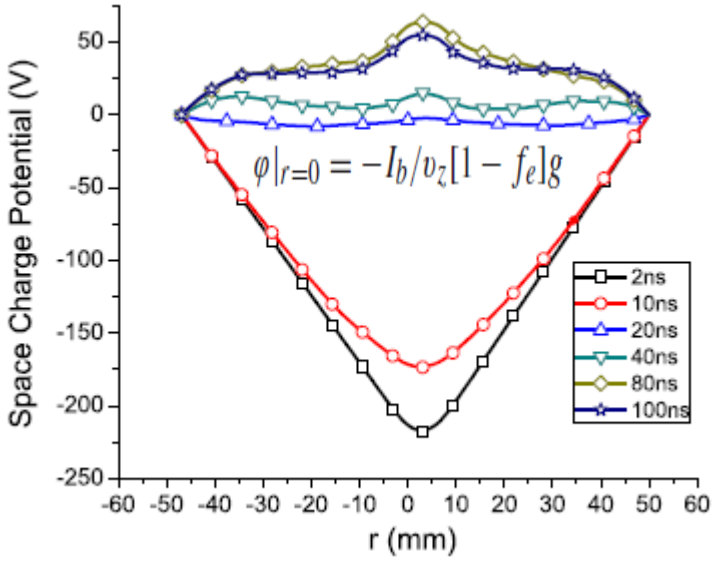




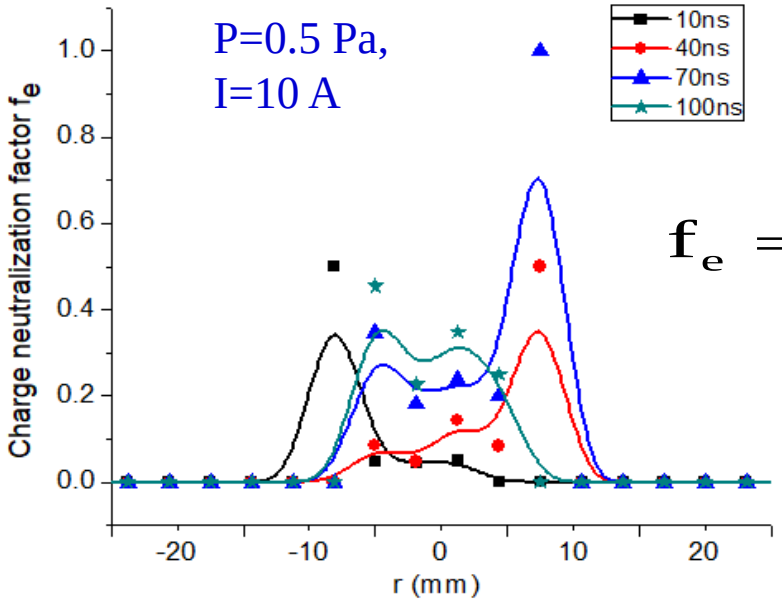
R. B. Miller, *An Introduction to the Physics of Intense Charged Particle Beams* (Plenum, New York, 1982.)

Beam Transport in Drift Space Region

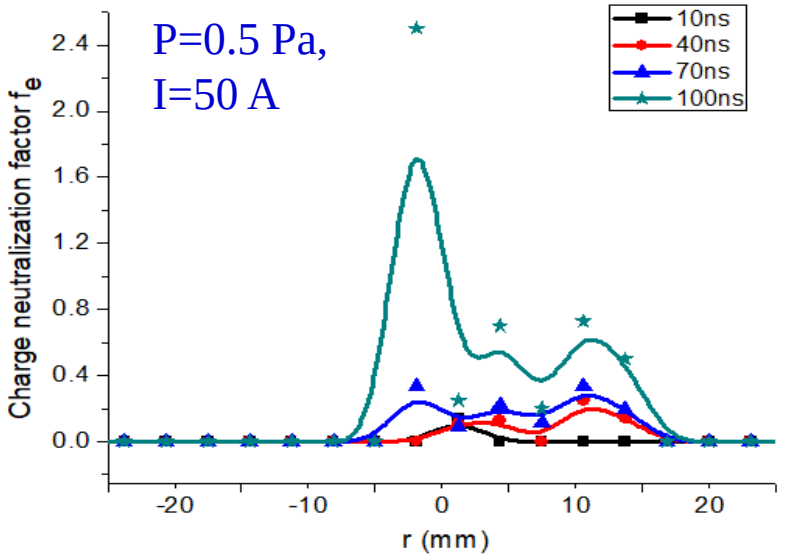




5-50 Pa, 10-100 A Beam current at 10 ns.



$$f_e = \frac{n_i}{n_{eb}}$$



U. N. Pal, et al., IEEE Trans. on Plasma Sci., vol. 45, no. 12, pp. 3195-3201, 2017

Plasma Cathode Electron (PCE) Gun

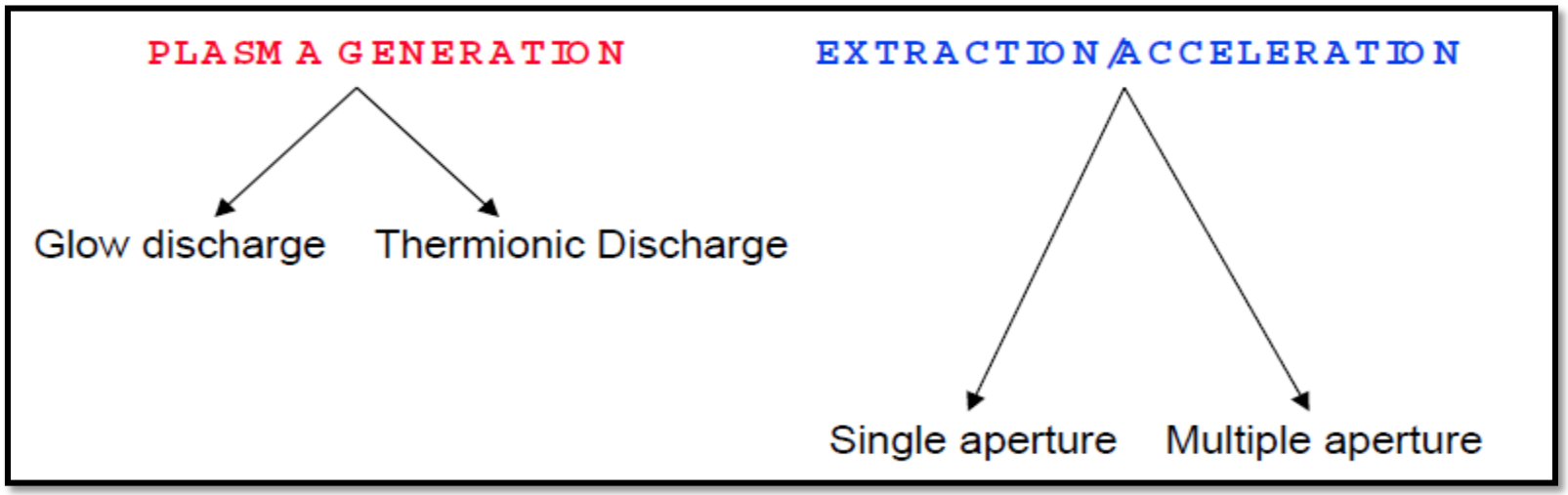
Plasma cathode electron gun: a system provide well-defined electron beam that is formed by extraction from the Hollow Cathode Plasma discharge.

To create a plasma one needs a discharge.

There are two main parts to the plasma cathode electron gun:

1. ***A plasma generator based on some kind of electrical discharge***

For instance, one of the discharges (the main discharge) is used to produce the emissive plasma and the other (the auxiliary discharge) is employed to initiate and sustain the main discharge.



Plasma Cathode Electron (PCE) Gun

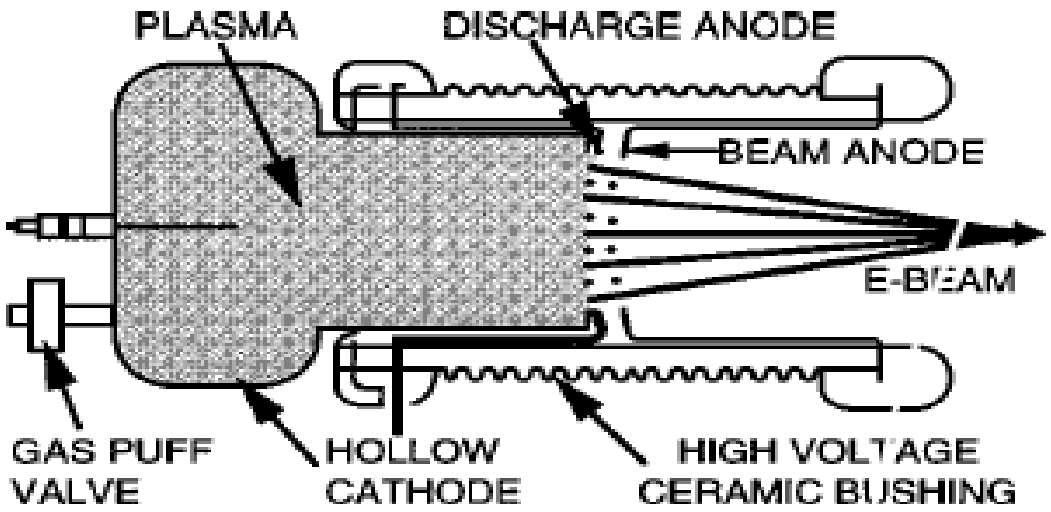
- In normal vacuum tubes, ions from the plasma drift toward the gun at high energy. This high energy ion bombardment will normally damage the cathode. To mitigate this issue is to replace the material cathode with a plasma cathode.

1. Differential pressure based PCE-Gun:

high current, long pulse electron beam generation used in Pasotron, TWT, BWO experiments, etc.

A. Gas-puff plasma-cathode electron (PCE) gun

For low (PRF) or single pulse operation, the gas puff PCE gun was developed

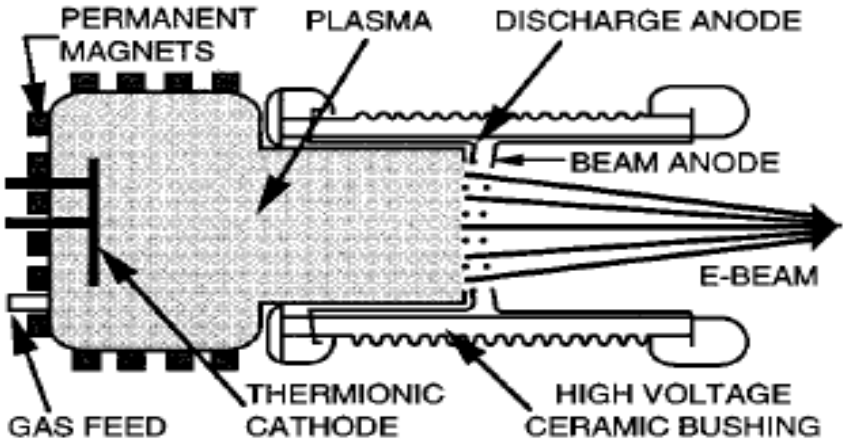


G. S. Nusinovich, et. al., IEEE Trans. Plasma Sciemce, vol. 26, no. 3, June 1998

Plasma Cathode Electron (PCE) Gun

B. Thermionic plasma-cathode electron (PCE) gun:

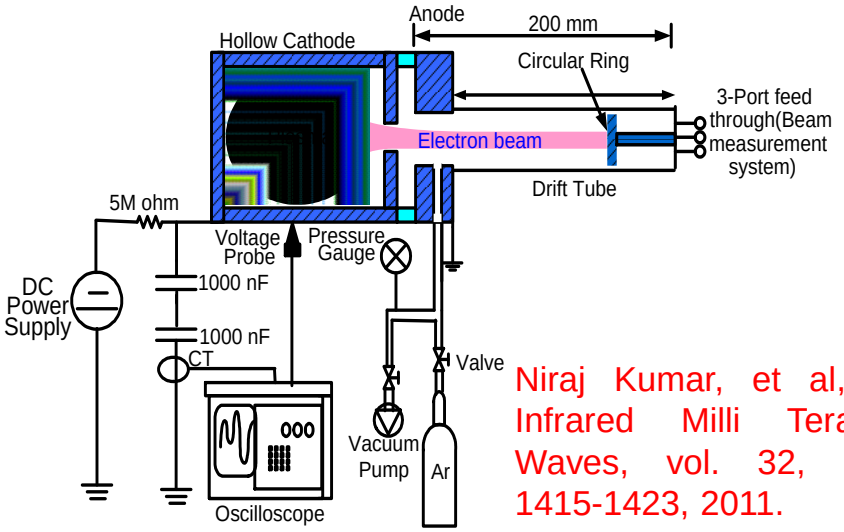
- For high PRF operation in excess of 10-50 Hz, it is very difficult to pump the neutral gas out of the microwave tube's vacuum system in time to set up a sufficient pressure differential for the next pulse
- The plasma generation enclosure is surrounded by a permanent magnet array to provide confinement of the primary electrons emitted by the thermionic cathode in order to increase the ionization efficiency
- To generate an adequate plasma density at these pressures, a thermionic discharge can be used (or possibly a differential pumping system)



G. S. Nusinovich, et. al., IEEE Trans. Plasma Sciemce, vol. 26, no. 3, June 1998

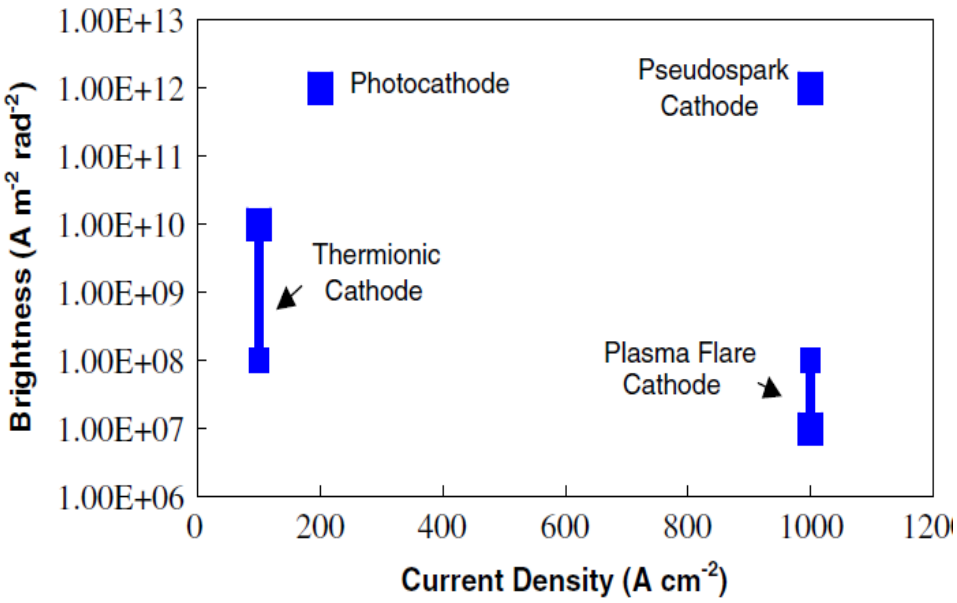
Plasma Cathode Electron (PCE) Gun

2. **Pseudospark based PCE-Gun:** high current, short pulse electron beam and used in Experiments of FEM, THz sources, Pasotron, surface modification, etc.



Niraj Kumar, et al, J Infrared Milli Terahz Waves, vol. 32, pp. 1415-1423, 2011.

- The PS discharge offers the possibility of fast and high repetition rate electron beam sources of high current density (10^4 Acm^{-2}), high brightness (up to 10^{12} A m^{-2} rad^{-2}), small beam diameter (<4 mm), and variable duration (tens of nanoseconds to hundreds of nanoseconds).



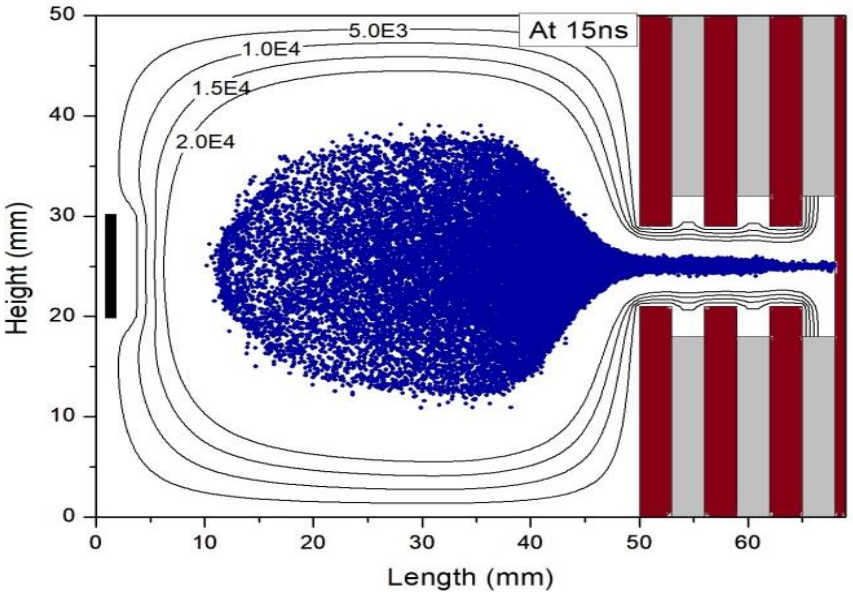
A. W. Cross, J. Phys. D: Appl. Phys. **40,** 1953–1956, 2007.

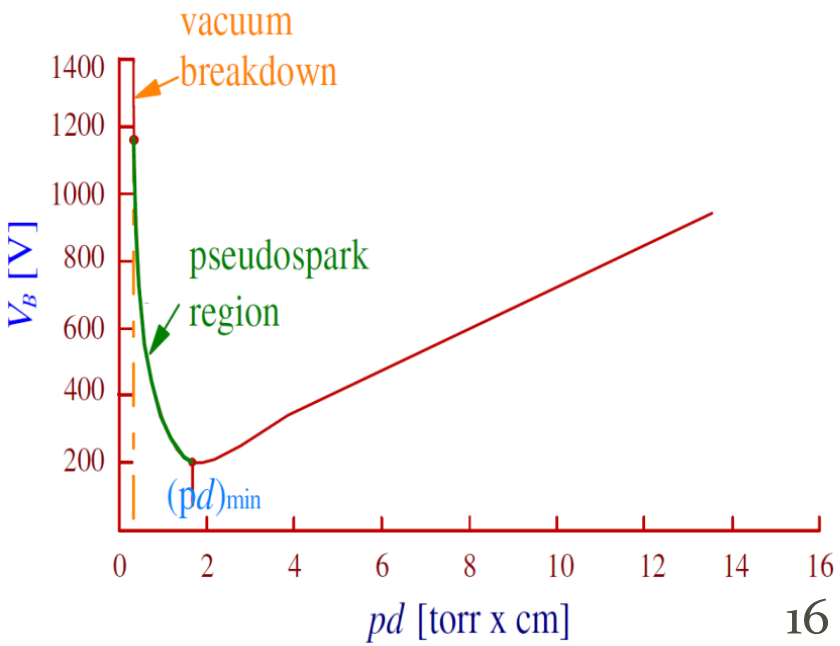
PS Discharge Fundamental

- The pseudospark (PS) discharge is an axially symmetric, self-sustained, transient, low pressure gas discharge in a hollow cathode with a planar/hollow anode configuration

- The PS is the complex discharge development with different discharge phases.

- Operates on the left-hand side (with respect to the minimum) of Paschen's curve.





PS Discharge Characteristics

Discharge geometry:

-electrode distance: 2 – 5 mm

-bore hole diameter: 2 – 5 mm

Pressure: 5 – 80 Pa

Peak current: 100A – multi kA

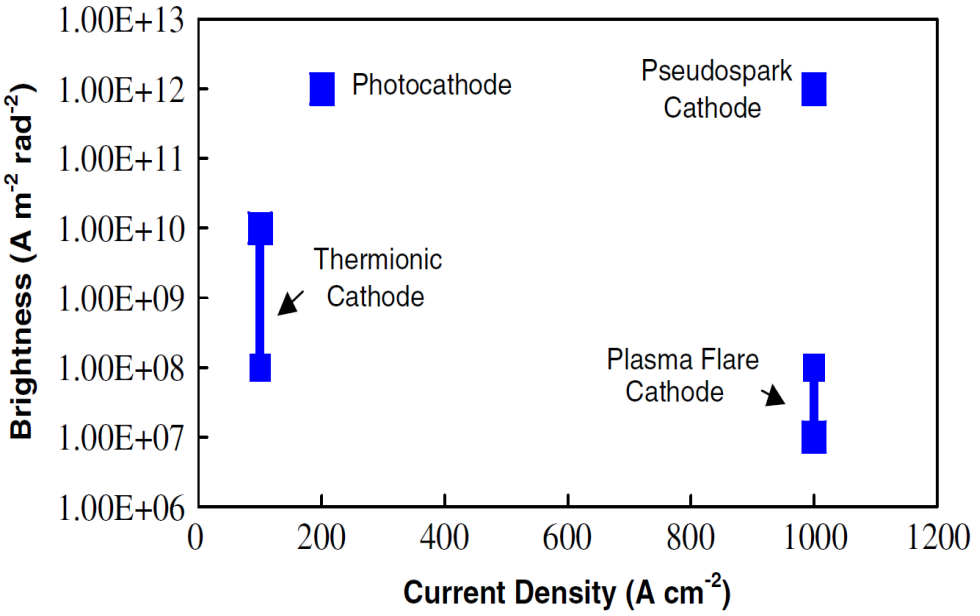
Current density: upto 10^4 Acm^{-2}

Rate of current rise: up to 10^{12} A/s

Plasma parameters:

- electron density:10^{12}– 10^{15}/ cm^3

- electron temperature: 2–10 eV

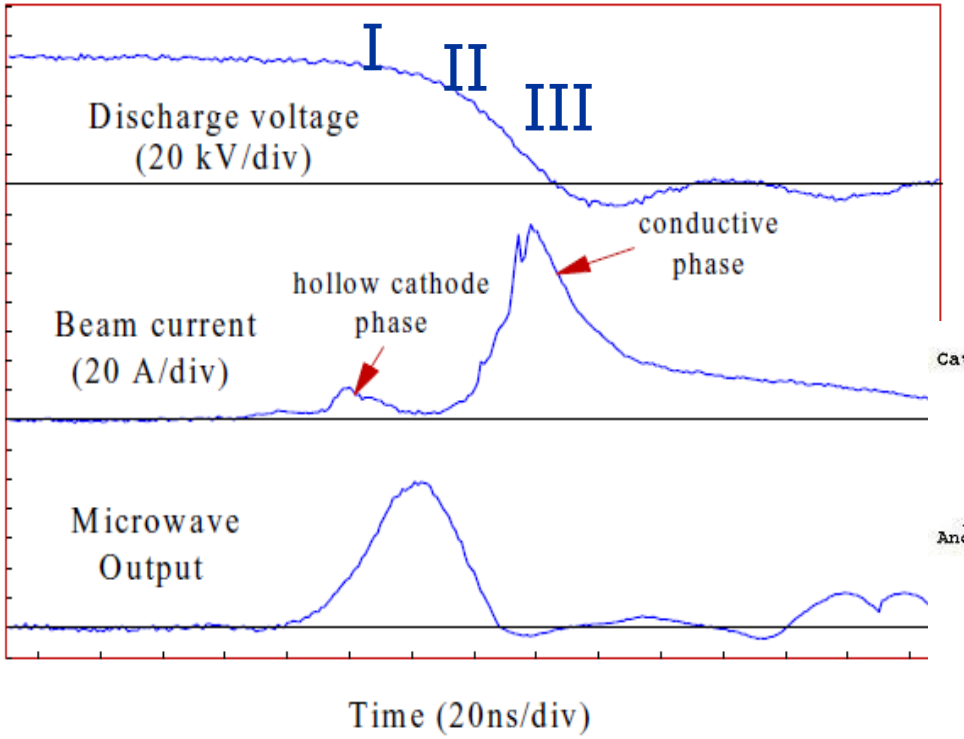


⇒hollow cathode effect
⇒pendulum electrons
⇒easily triggered from the back of the hollow cathode

K. Frank and J. Christiansen, IEEE Trans. Plasma Sci., 17, 748, 1989

A. W. Cross, et. al., J. Phys. D: Appl. Phys, 40, 1953-1956, 2007

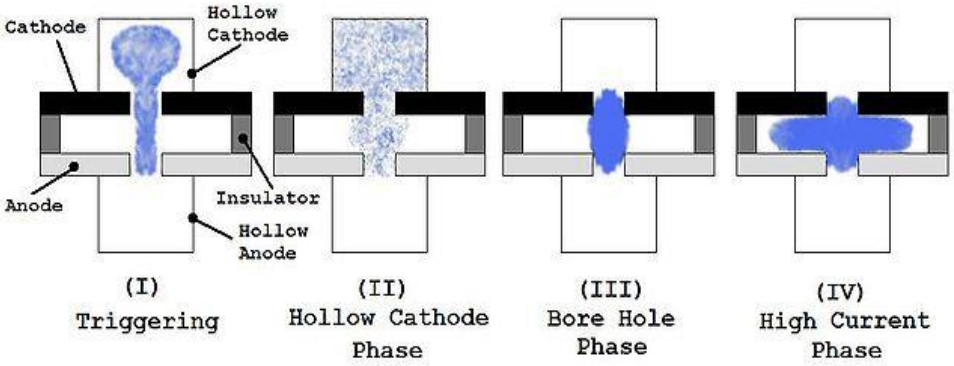
Phases during Pseudospark Discharge



Objective:

- High current density and high energy electron beam

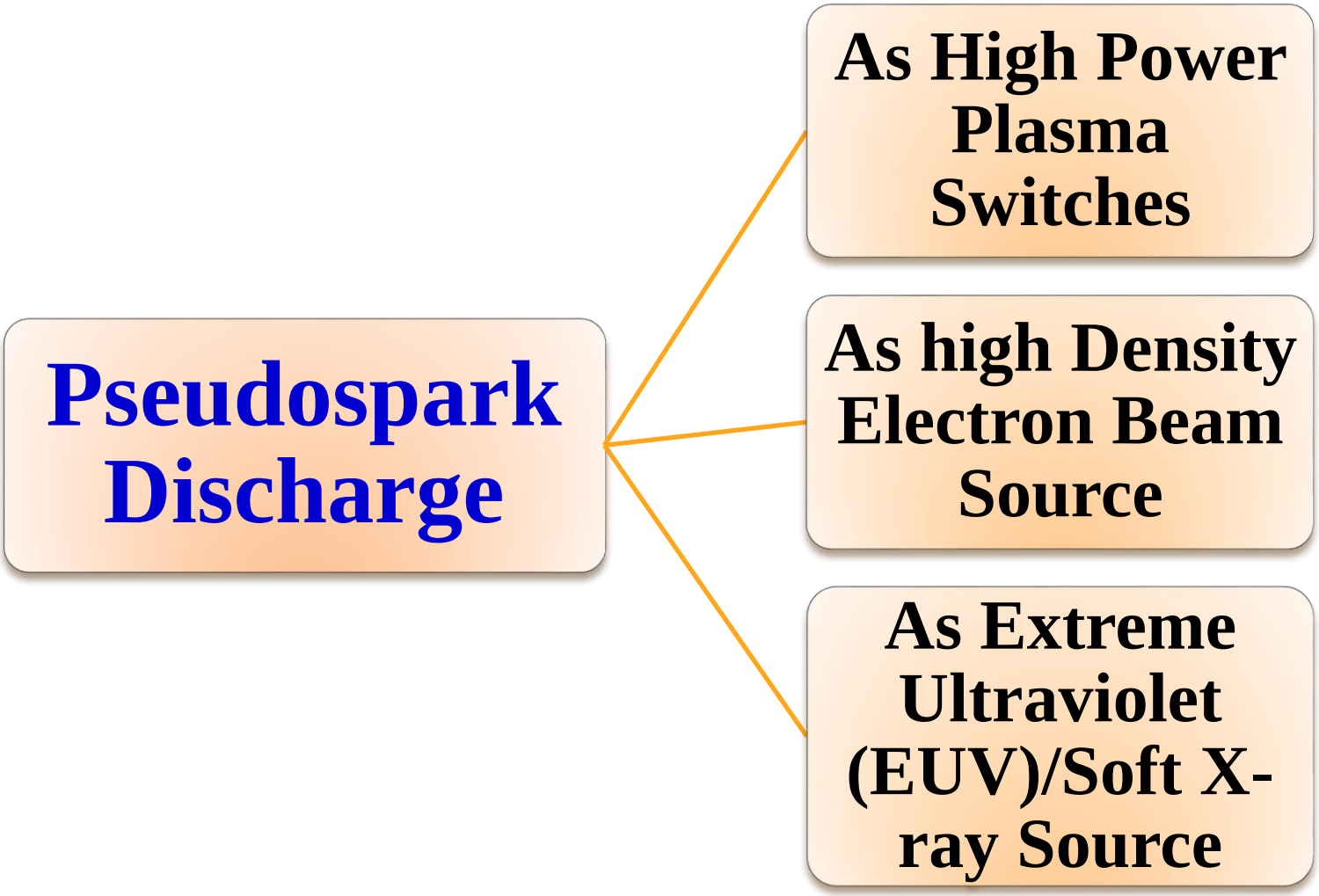
J. Phys. D:Appl. Phys. 40 , 1953-1956, 2007.



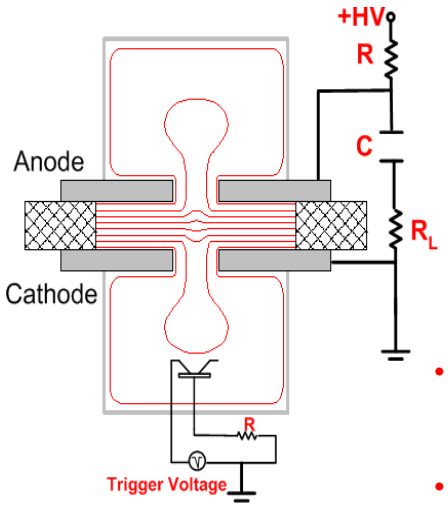
Region I: High voltage, low current, long (~50 nsec) pulse-near off state/immediately before breakdown

Region II: Reduced voltage, high current, short (1-20 nsec) pulse-during the commutation phase

Region III: Low voltage (1-1000V), very high current, very long pulse-during the conduction phase

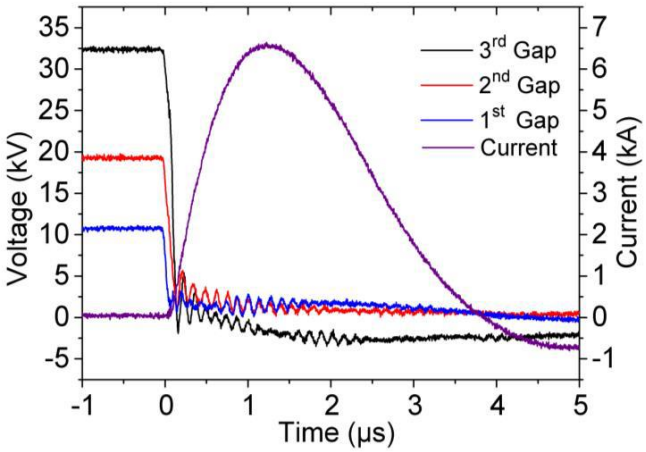

Pseudospark Discharge
As High Power Plasma Switches
As high Density Electron Beam Source
As Extreme Ultraviolet (EUV)/Soft X-ray Source

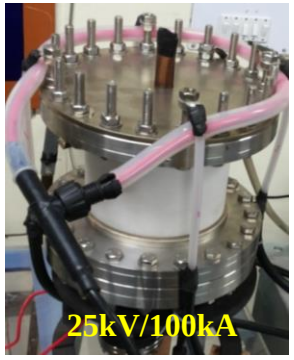
High Power Pseudospark Switches @ CSIR-CEERI

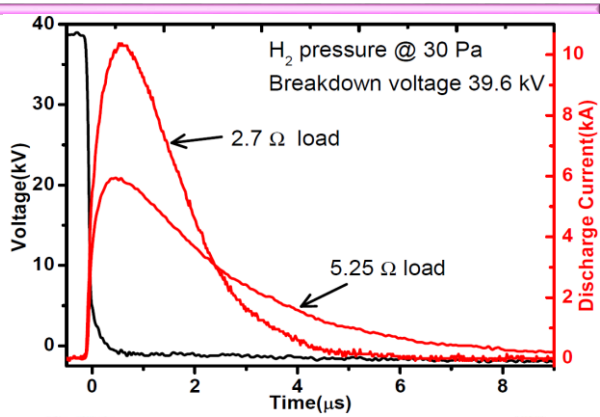


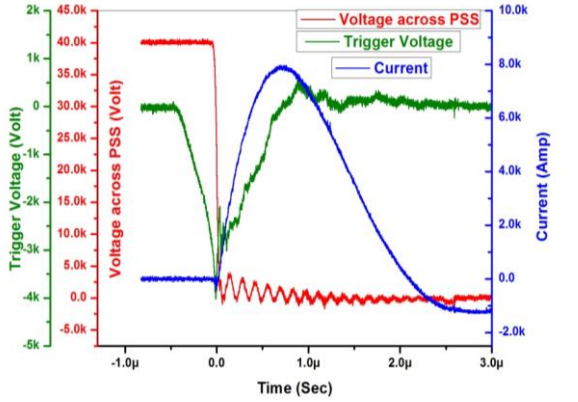
Indian Patent No. 1220/DEL/2015, Published on 04/11/2016.

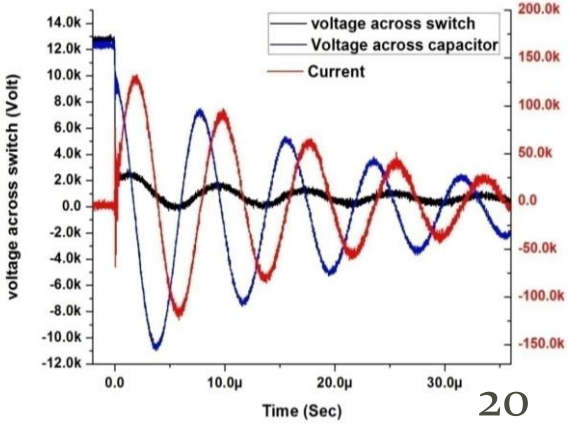
- IEEE Trans. on Dielectrics and Electrical Ins., Vol. 22, no. 6, pp. 3299-3304, 2015.
- Rev. Sci. Instrum. 86, 103508, 2015 .
- Plasma Sources Sci. Technol., 27, 035003, 2018.
- IEEE Trans. Electron Devices vol. 67, no. 12, pp. 5600-5604, 2020.



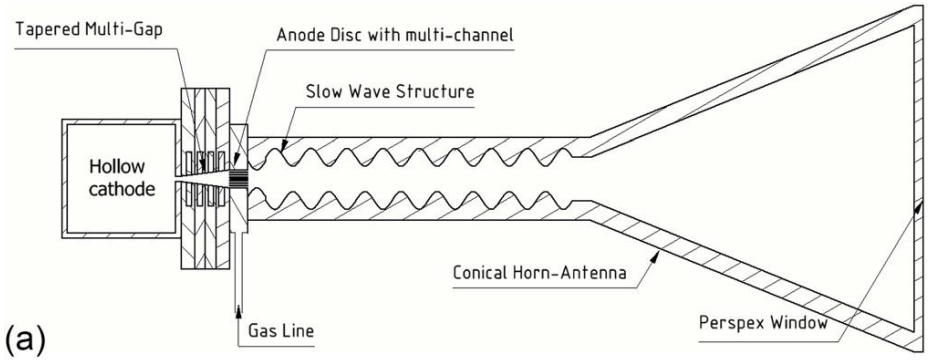


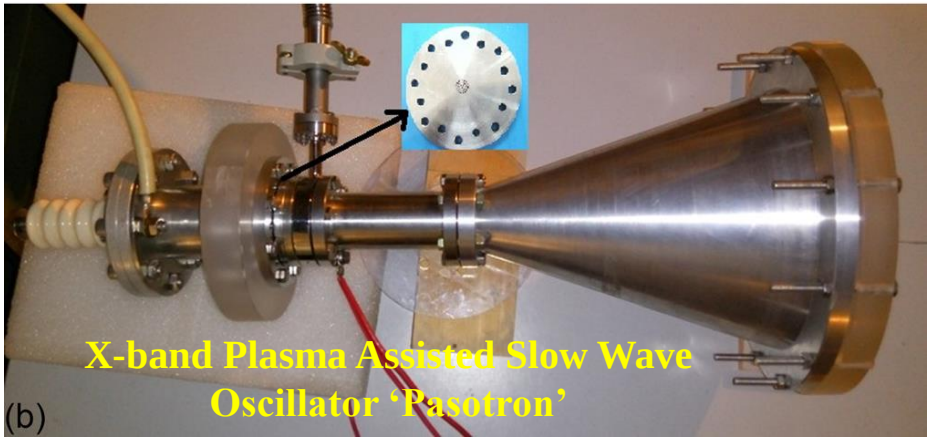


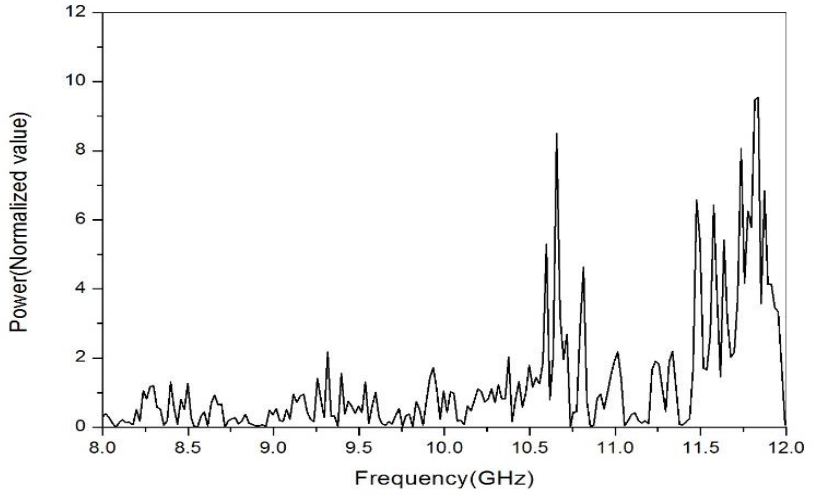


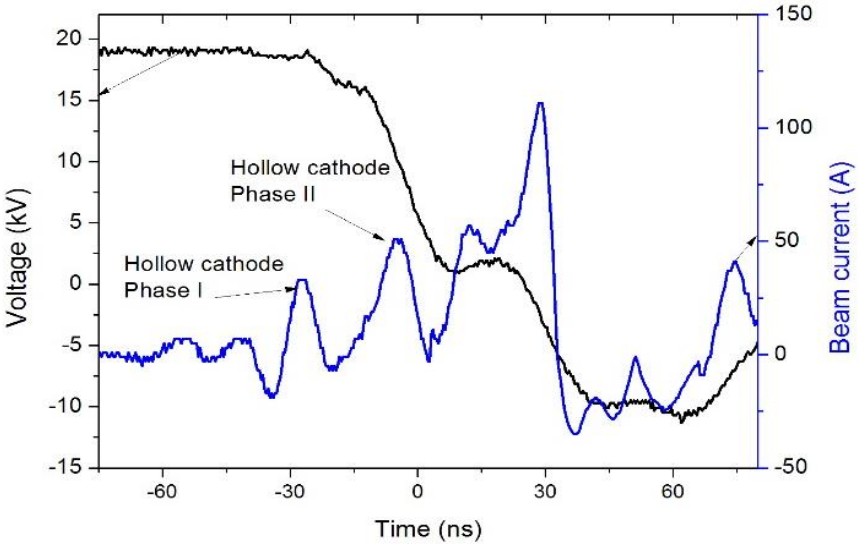


PS Discharge based PASOTRON @CSIR-CEERI







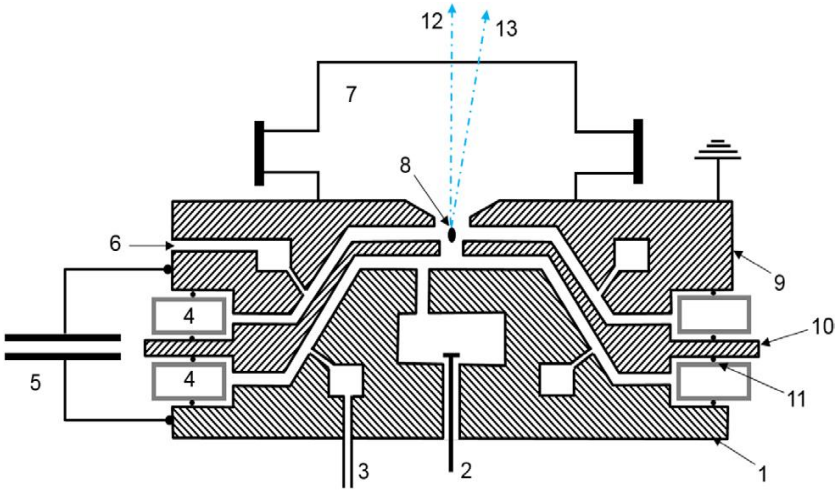


Indian Patent No.:359771, granted on 26.02.2021

Niraj Kumar *et al*, *Applied Physics Letters, 111, 213502, 2017.*

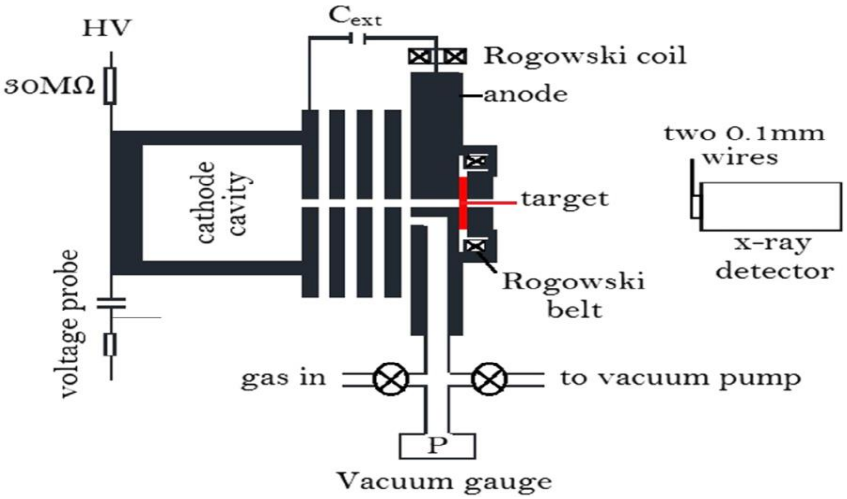
PS Discharge Based EUV/Soft X-ray Sources

- **Pinch Plasma**
  - Due to pinch effect, plasma is compressed upto 10^{17}-10^{19} cm^{-3} and heated to ≥10eV
  - Leads the EUV/Soft X-ray radiations
  - However, the current reaches to greater than 10 kA which requires the large cooling area for the cooling the electrode systems



J. Phys.D: Appl. Phys. 50, 345601, 2017.

- **High density and energetic electron beam**
  - PS discharge can produce high current density 10^4–10^6 A/cm^2 and energetic electron beam generation 10-40 keV
  - The scattering of beam electrons by the gas atoms produces x-ray bremsstrahlung and induces soft x-ray, or EUV emission.



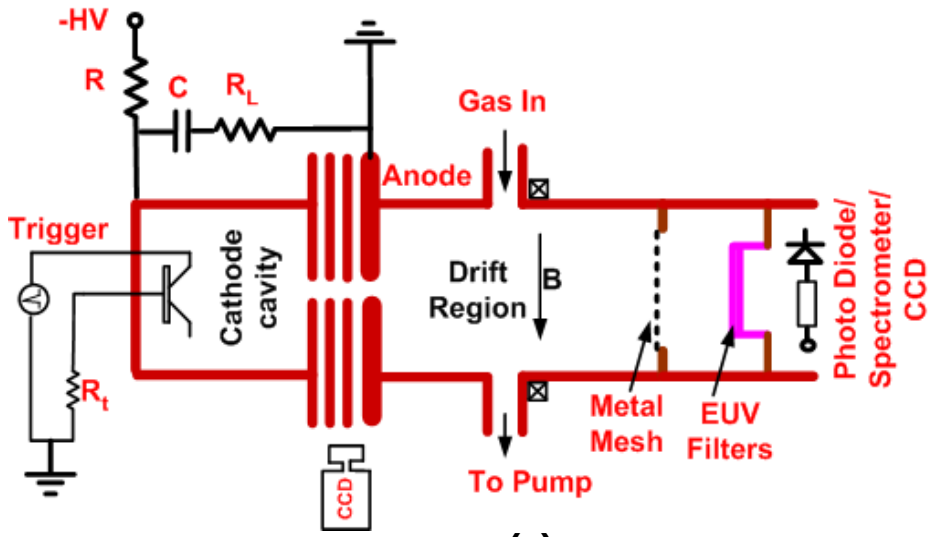
Nuclear Inst. and Methods in Physics Res. B 335, 74–77, 2014.

Methodology

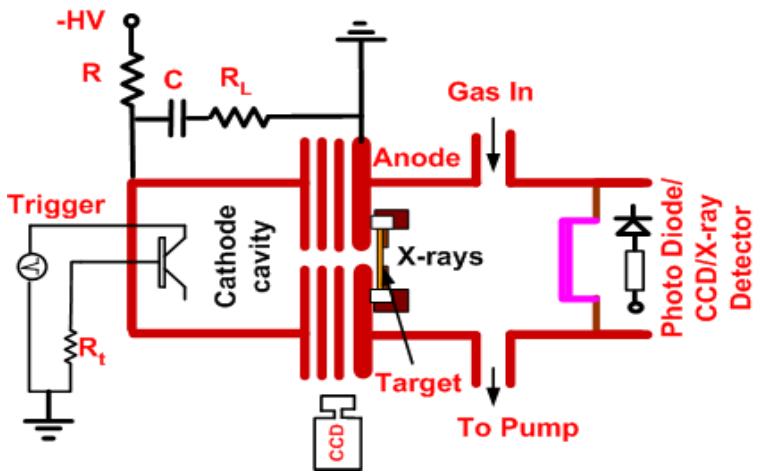
PS discharge design and simulation

Development of PS discharge based high density and energetic electron beam source

Characterization of PS discharge and generated energetic electron beam pulses



(a)



(b)

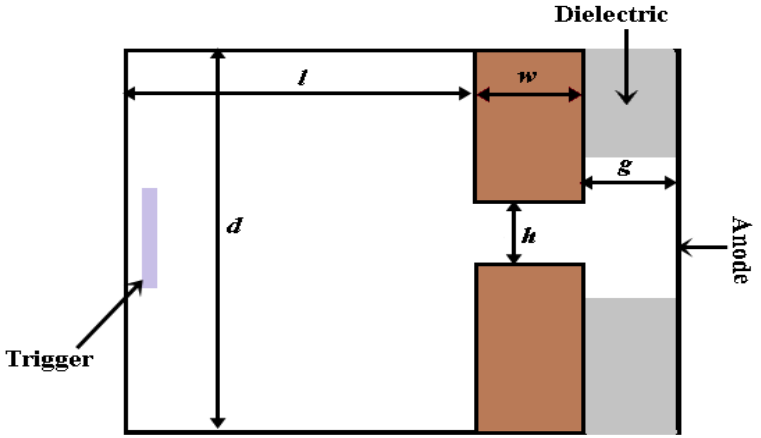
Testing and evaluation of EUV/X-ray radiation source

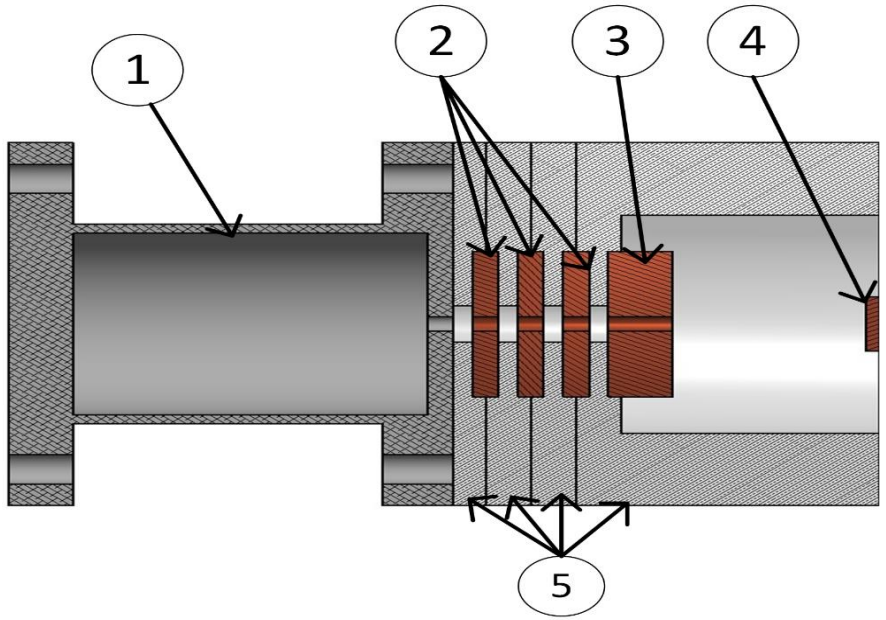
Measurement and characterization of EUV/X-ray radiation

Investigation of scattering of beam electrons and atomic processes in the background gas

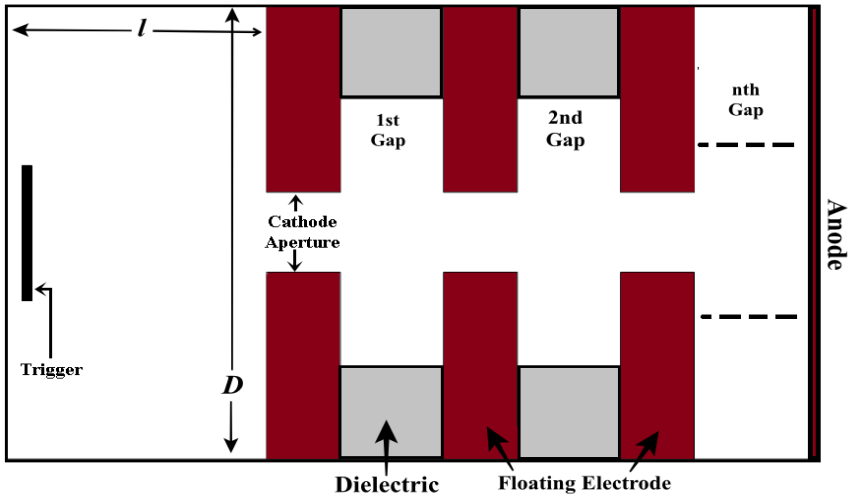
PD-PCE Source: Components

- Single-gap Configuration





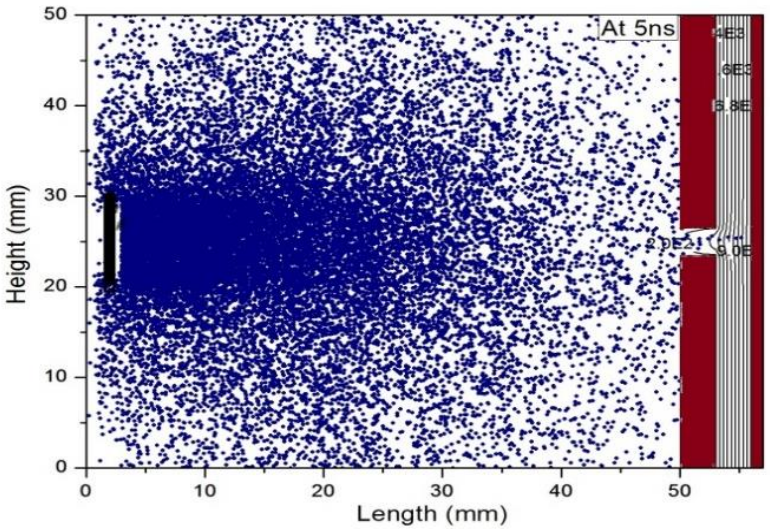
- Multi-gap Configuration

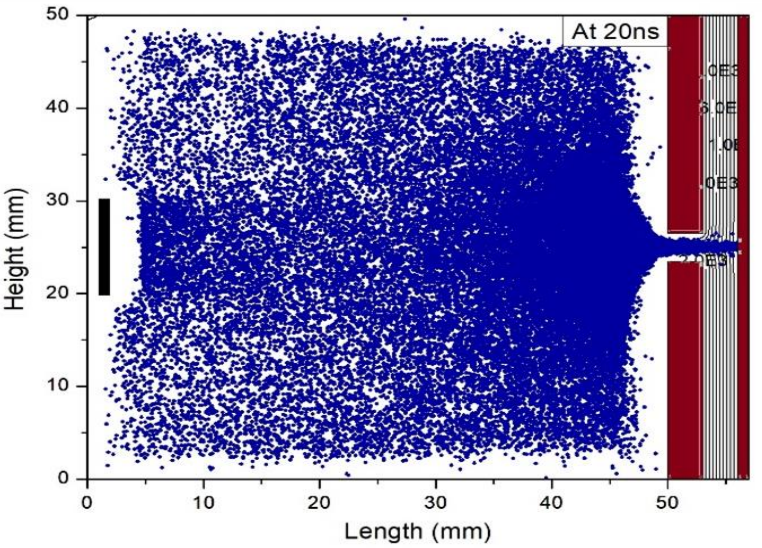


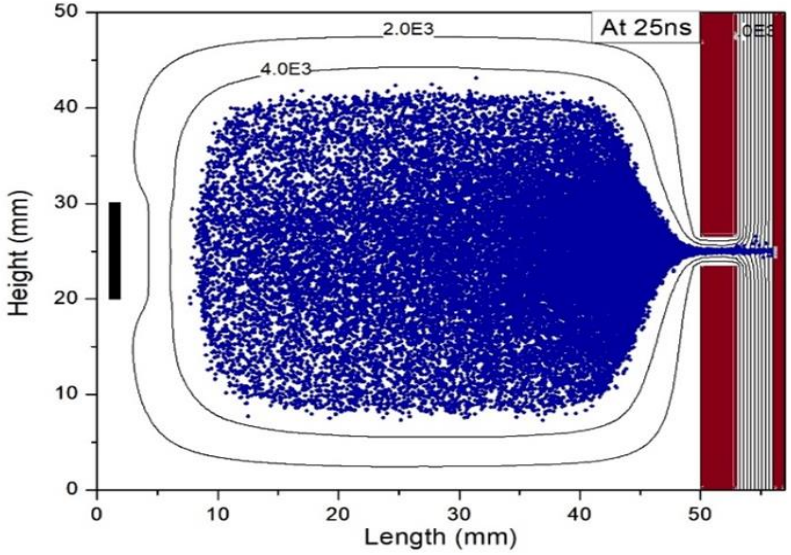
1: Hollow Cathode Cavity, 2: Intermediate electrodes. 3: Anode, 4: Collector, 5: Perspex Insulators

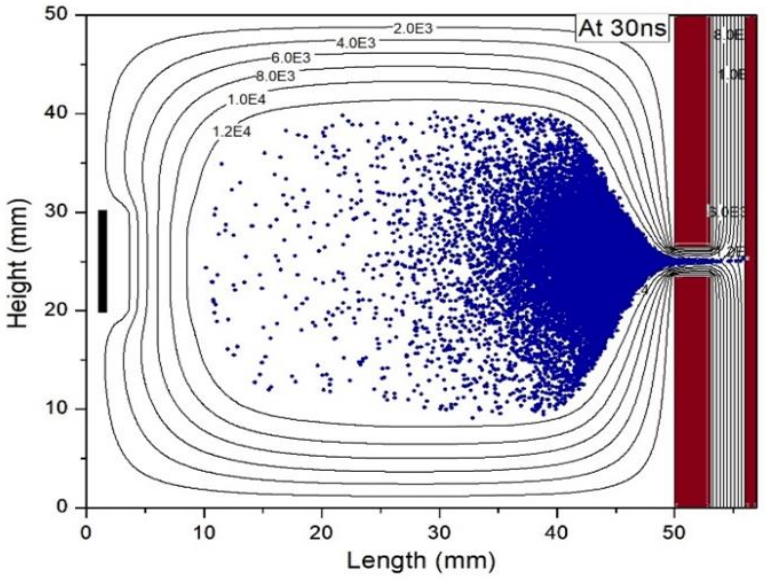
Single gap PD-PCE source

2-mm cathode aperture @ 20-Pa gas pressure





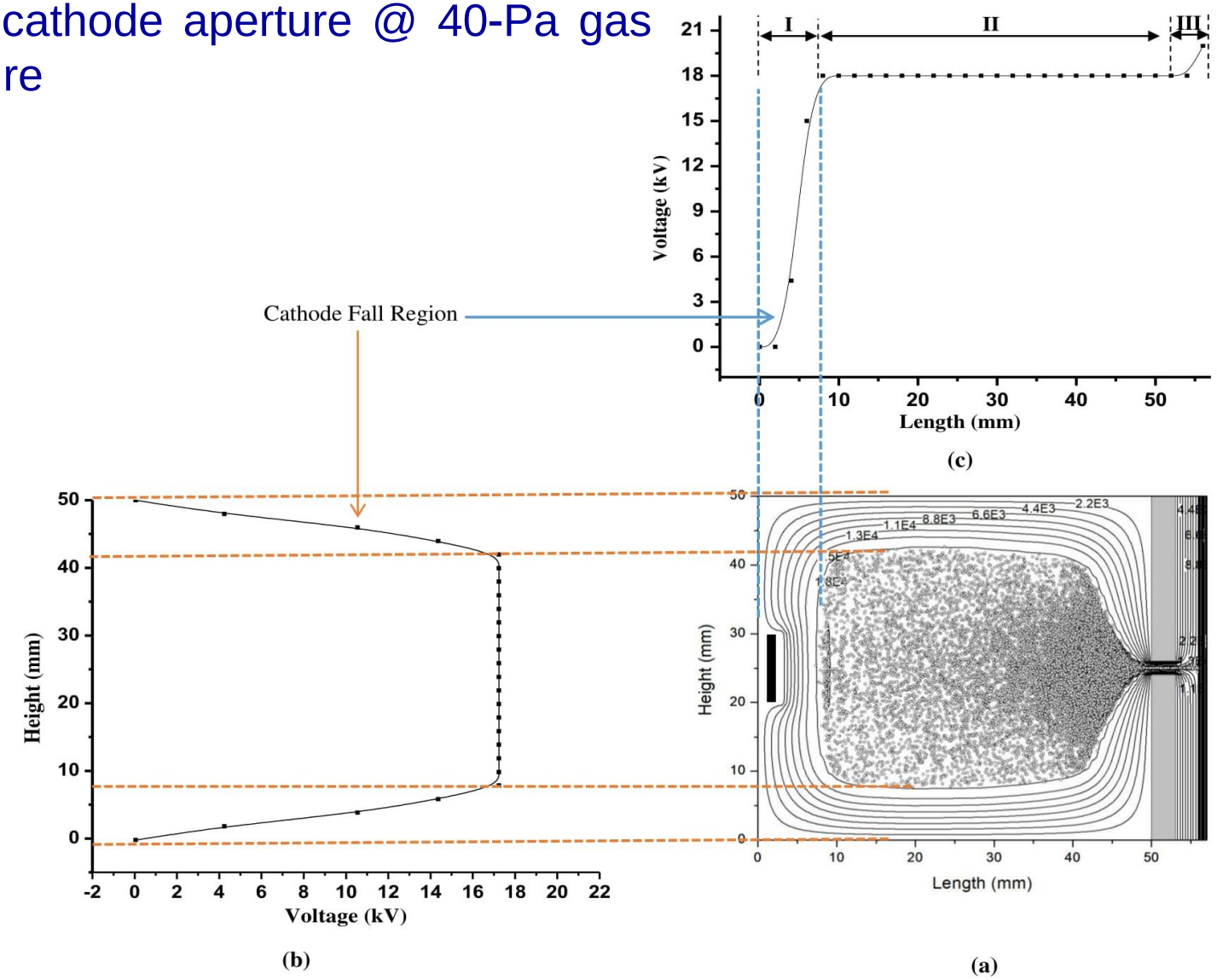




Varun and U. N. Pal, IEEE Trans. Electron Devices, vol. 65, No. 4, pp. 1542-1549, April 2018

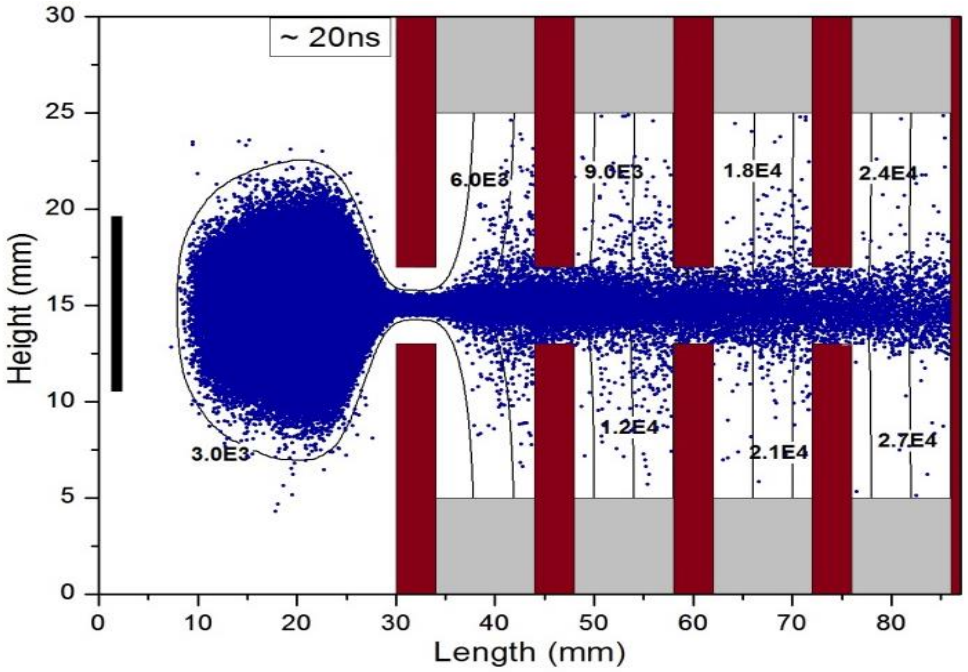
Single gap PD-PCE source

2-mm cathode aperture @ 40-Pa gas pressure

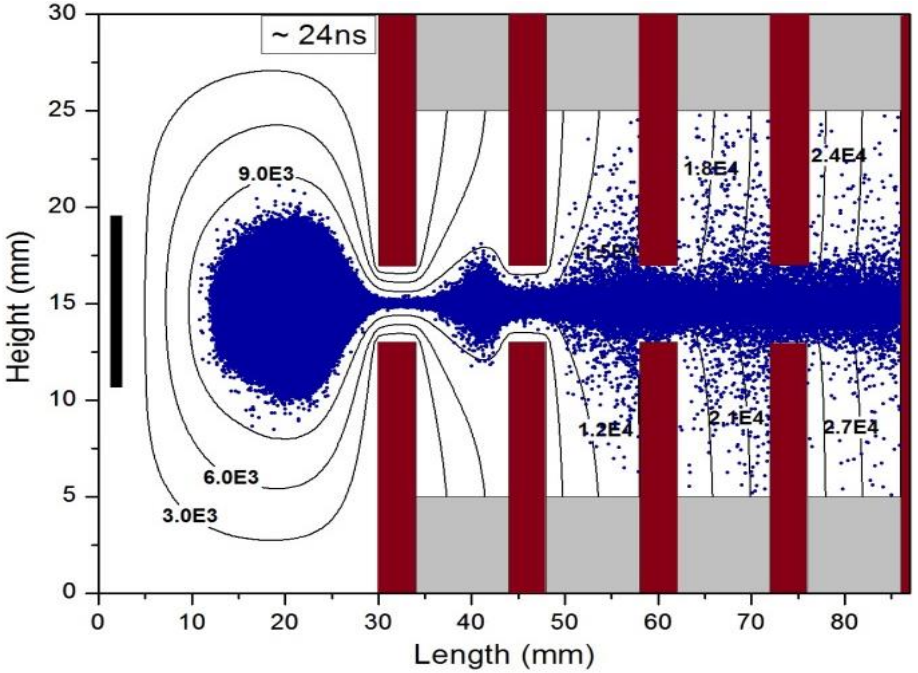


Varun and U. N. Pal, IEEE Trans. Electron Devices, vol. 65, No. 4, pp. 1542-1549, April 2018

Multi gap PD-PCE source

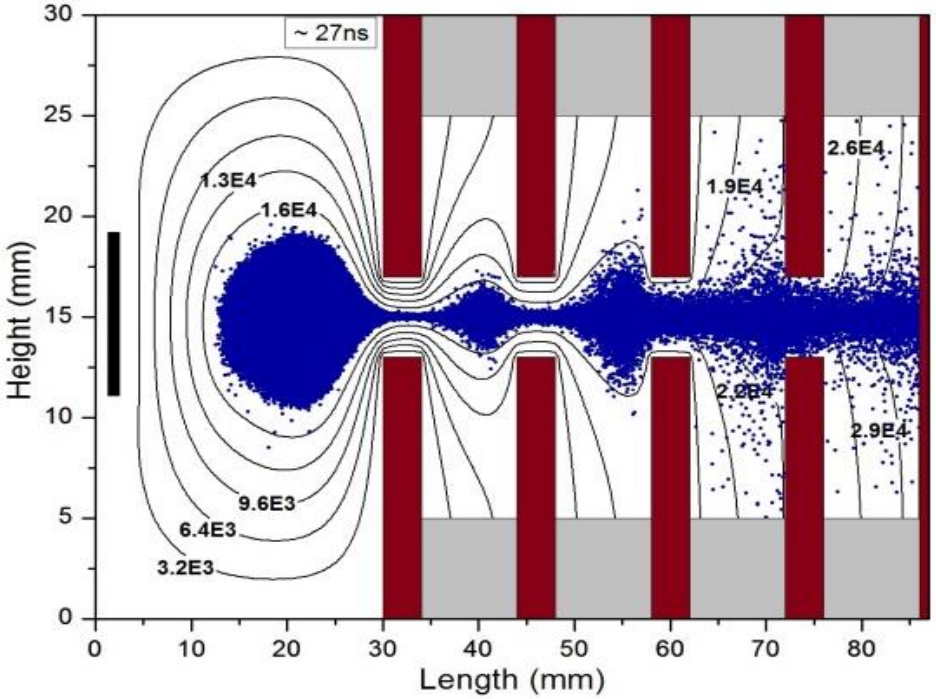


(a) ~171 A current

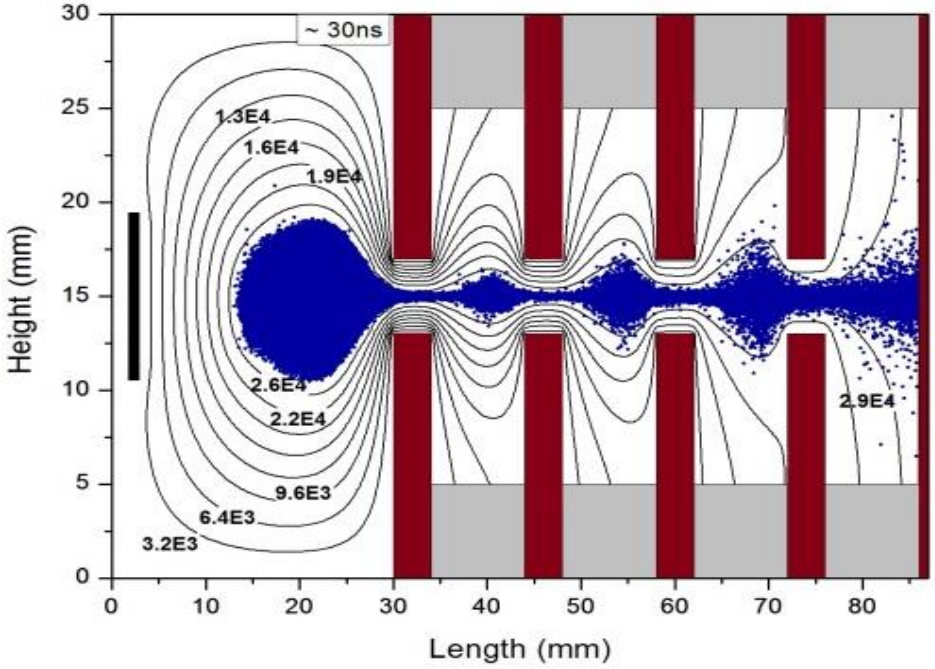


(b) ~472 A Current

Multi gap PD-PCE source



(c) ~927 A current

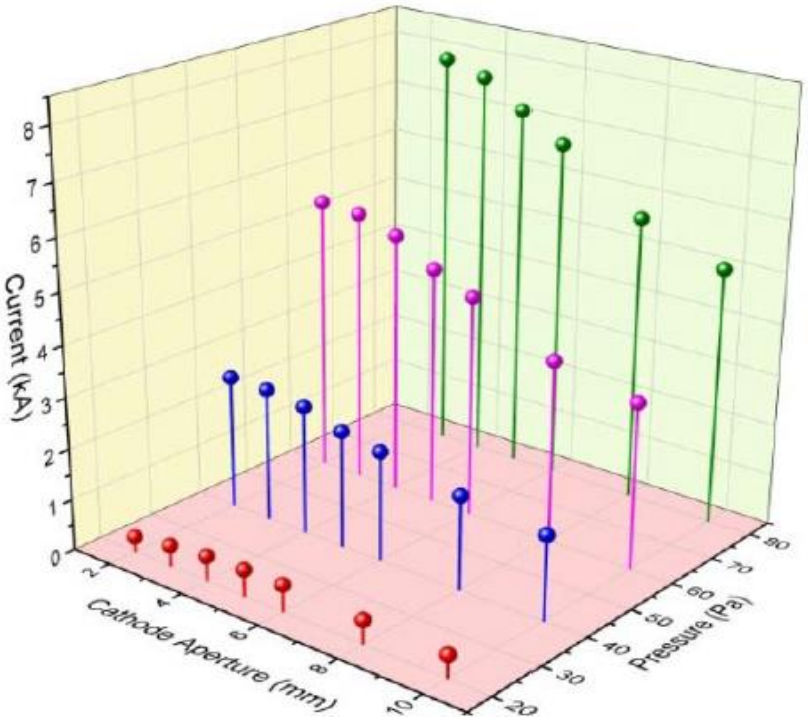


(d) ~1.3 kA current

Parameters Effecting the PS Discharge

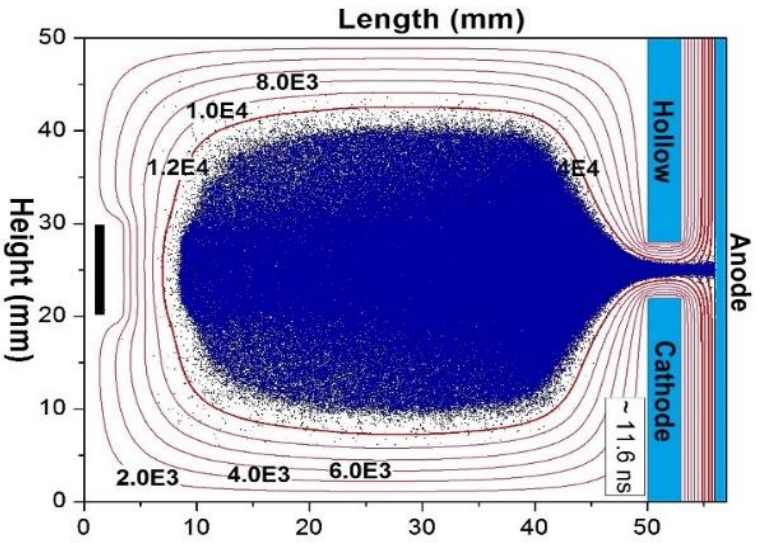
PS discharge based e-beam primarily depends on:

- **Geometrical parameters**
  - Hollow cathode and anode apertures: shape and size
  - Number of gaps and spacing
  - Cathode-Anode Material properties
- **Operating and circuit parameters**
  - Applied voltage
  - Operating gas and pressure
  - Trigger energy
  - Discharge circuit parameters.

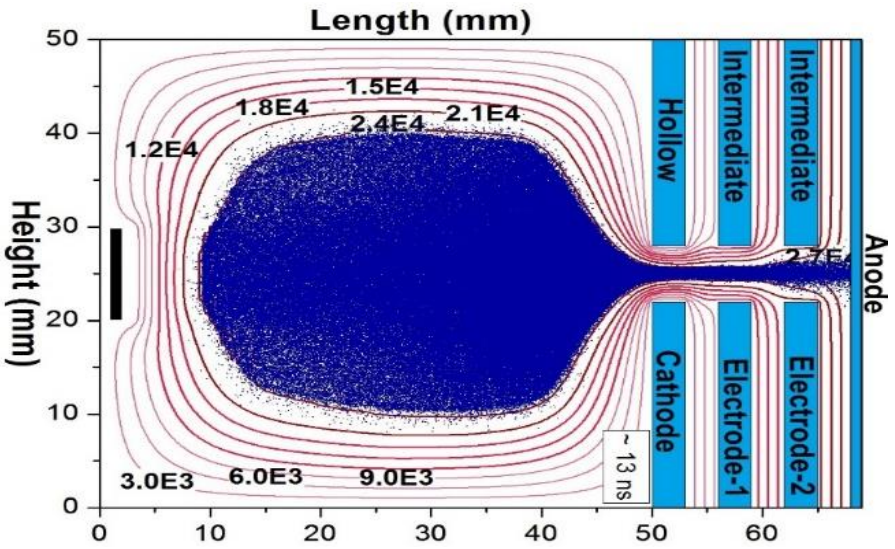


Varun and U. N. Pal, IEEE Trans. Plasma Sci., vol.46, no. 6, pp. 2003-2008, June 2018.

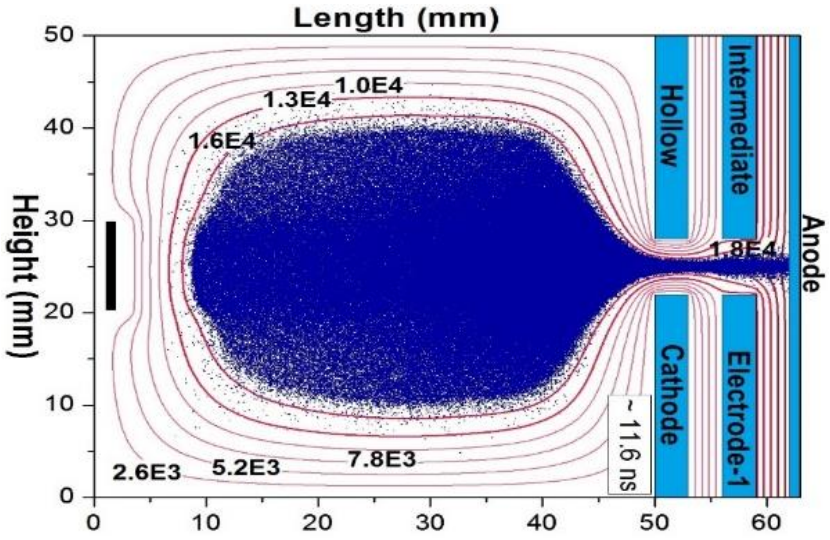
PD-PCE Sources for Electron Beam Generation



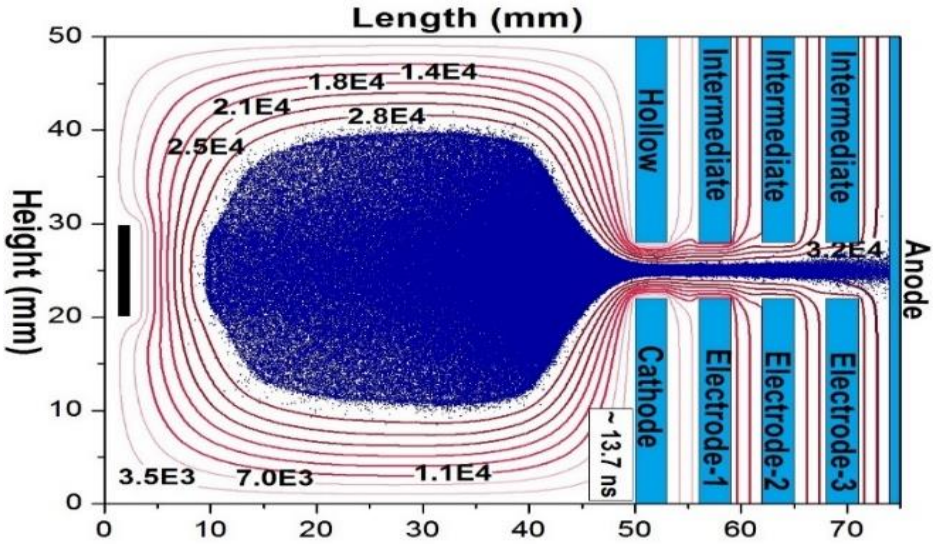
(a) 1-gap PD-PCE Source, @20 kV



(c) 3-gap PD-PCE Source, @30 kV

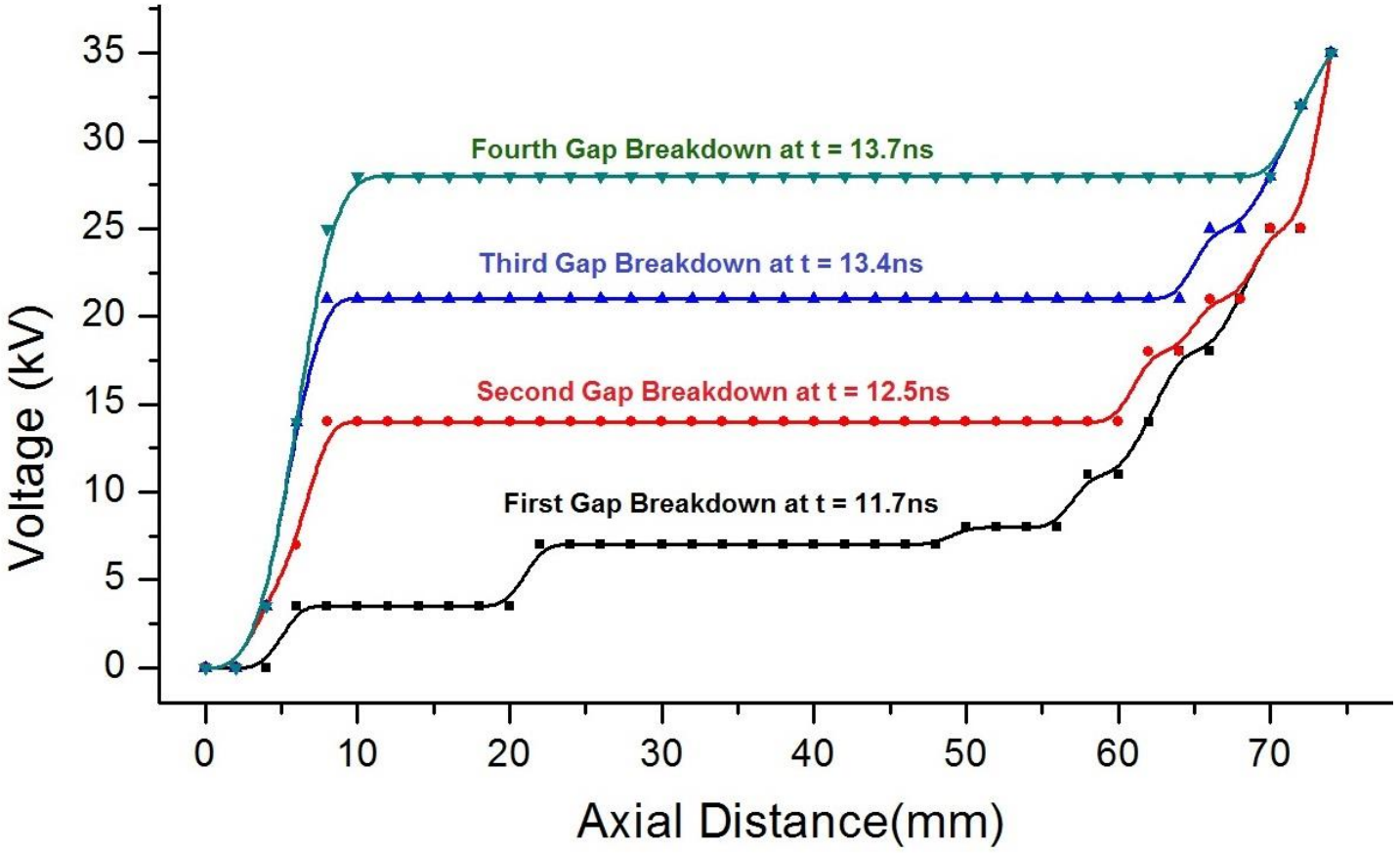


(b) 2-gap PD-PCE Source, @25 kV



(d) 4-gap PD-PCE Source, 35 kV

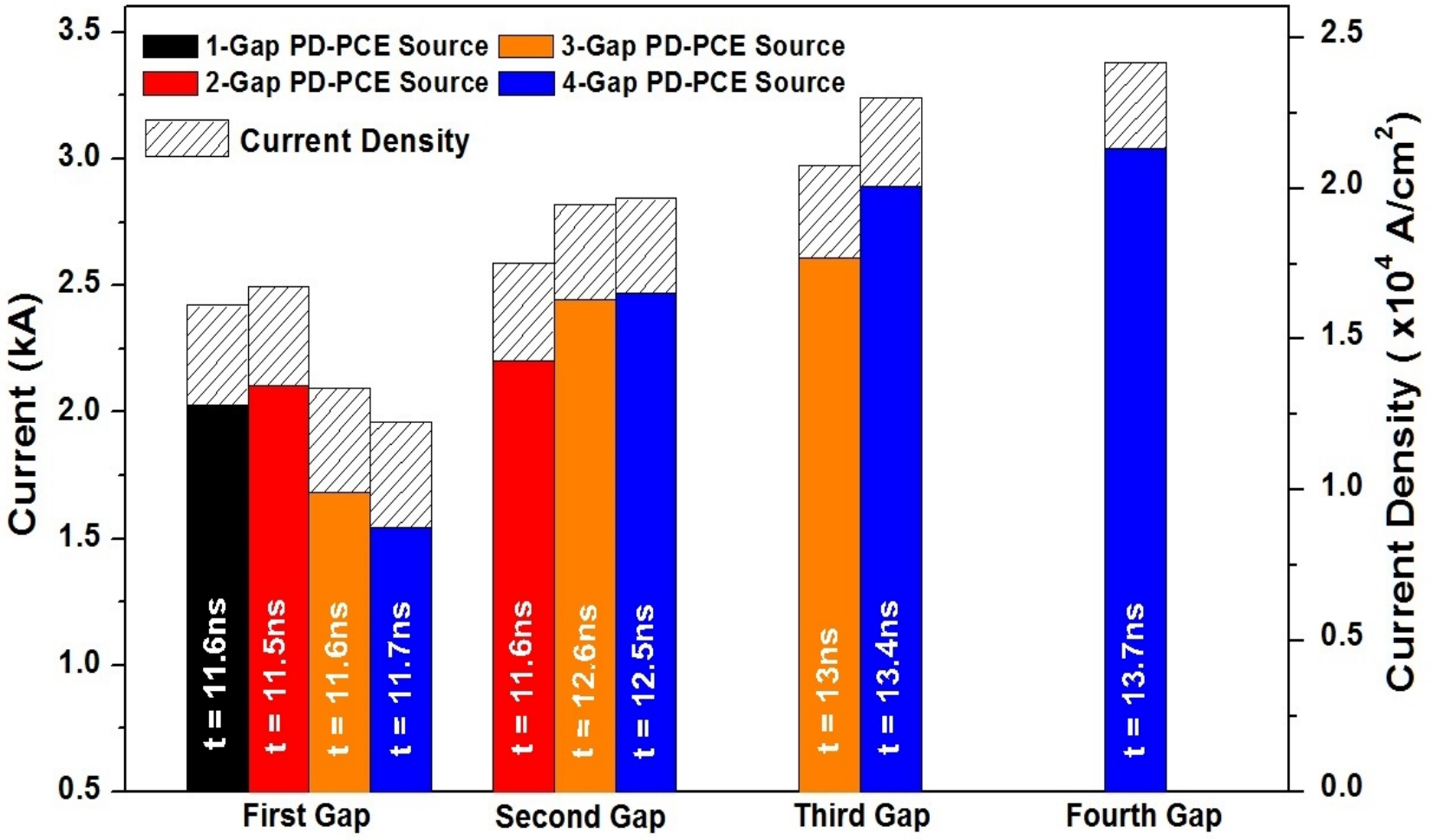
PD-PCE Sources for Electron Beam Generation



Potential distribution after breakdown in the respective gaps in the 4-Gap PD-PCE source with 40 Pa and 6 mm cathode aperture

Varun, A. W. Cross, K. Ronald and U. N. Pal, IEEE Trans. Electron Devices, Vol. 67, no. 4, pp. 1793-1796, Apr. 2020

PD-PCE Sources for Electron Beam Generation

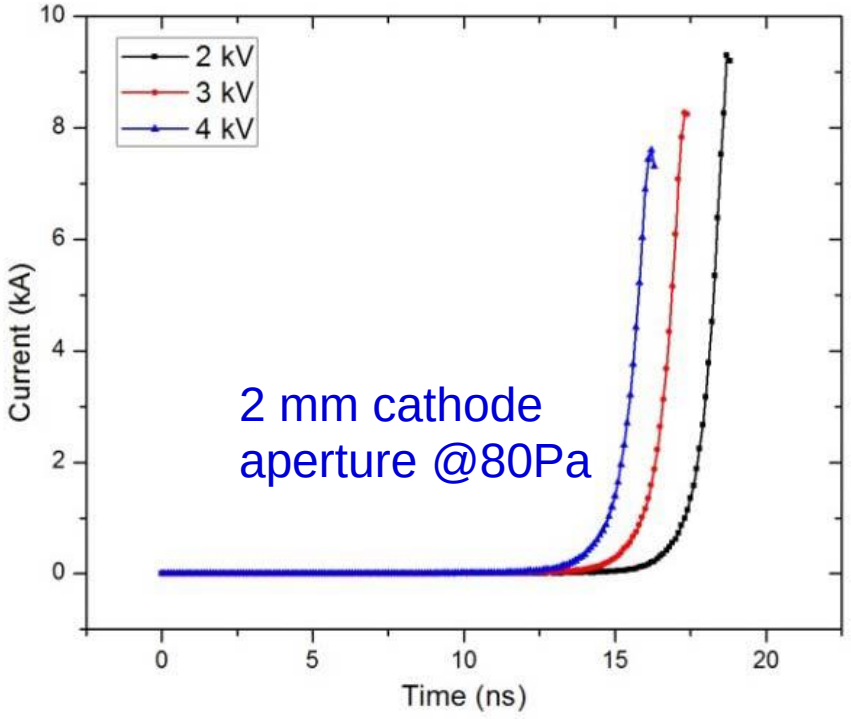


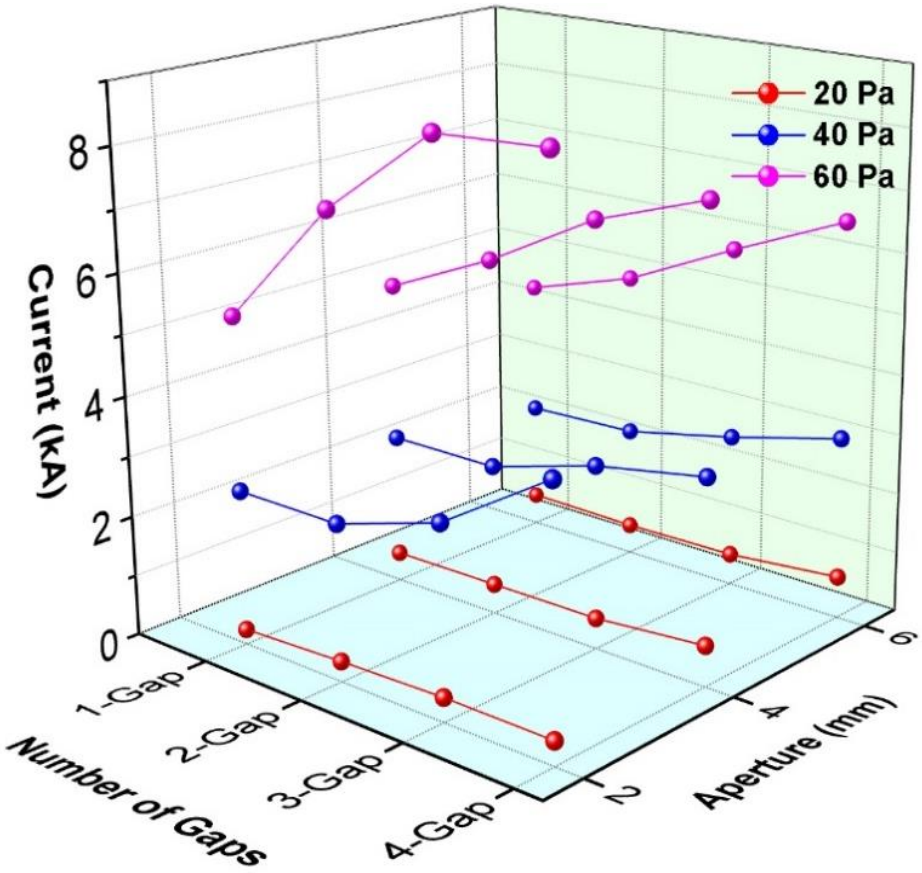
Comparison of different gap PD-PCE Source

Varun, A. W. Cross, K. Ronald and U. N. Pal, IEEE Trans. Electron Devices, Vol. 67, no. 4, pp. 1793-1796, Apr. 2020

PD-PCE Sources for Electron Beam Generation

- Peak electron beam current increases with the increase in gas pressure as well as number of gaps in PD-PCE source



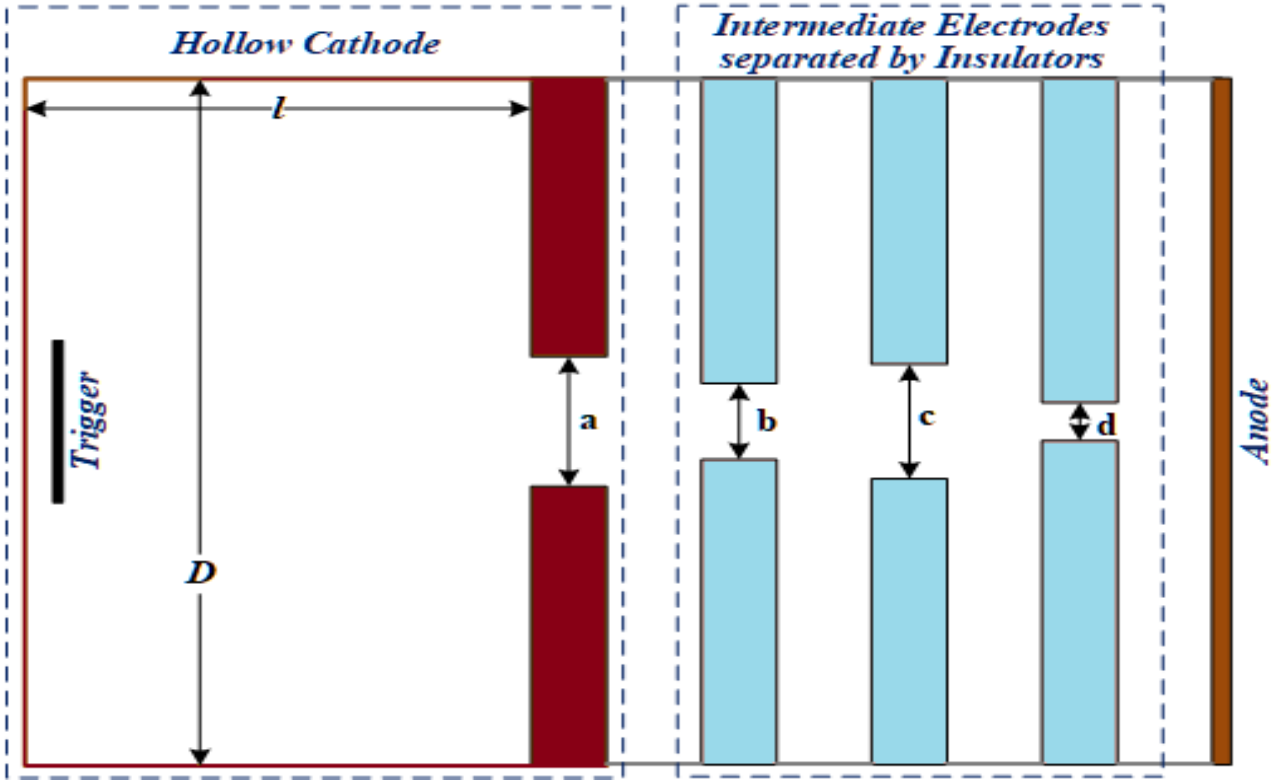


- Small cathode aperture with higher gas pressure required higher trigger energy.
- Increasing trigger energy also leads the lower peak current e-beam generation.

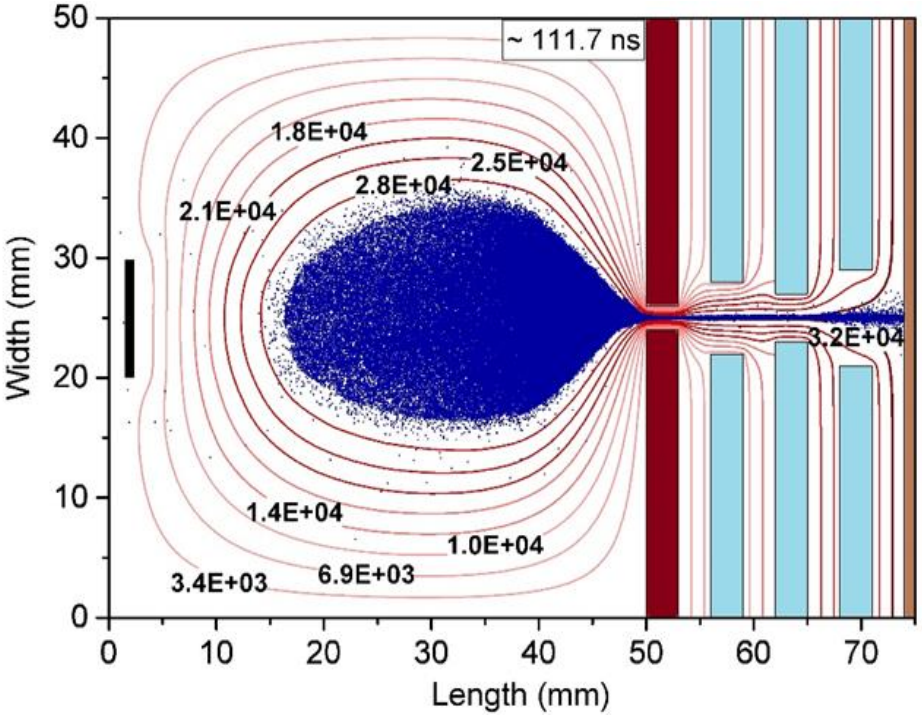
Varun, A. W. Cross, K. Ronald and U. N. Pal, IEEE Trans. Electron Devices, Vol. 67, no. 4, pp. 1793-1796, Apr. 2020

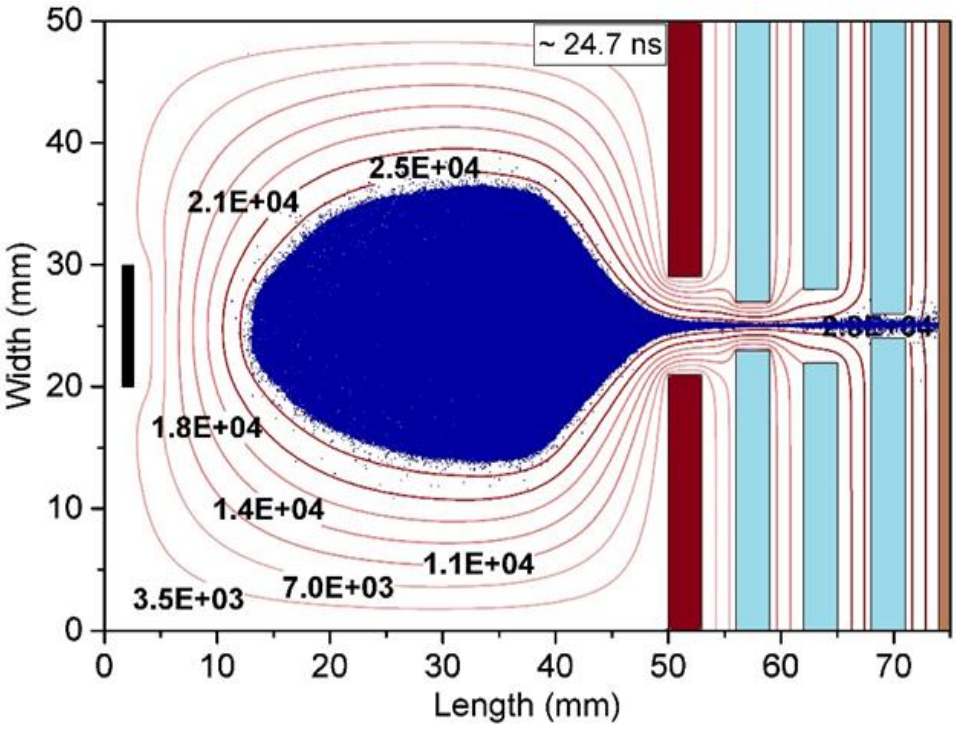
Impact of Irregular Electrode Aperture

- The initial penetrated potential affects the discharge initiation process inside the HC cavity



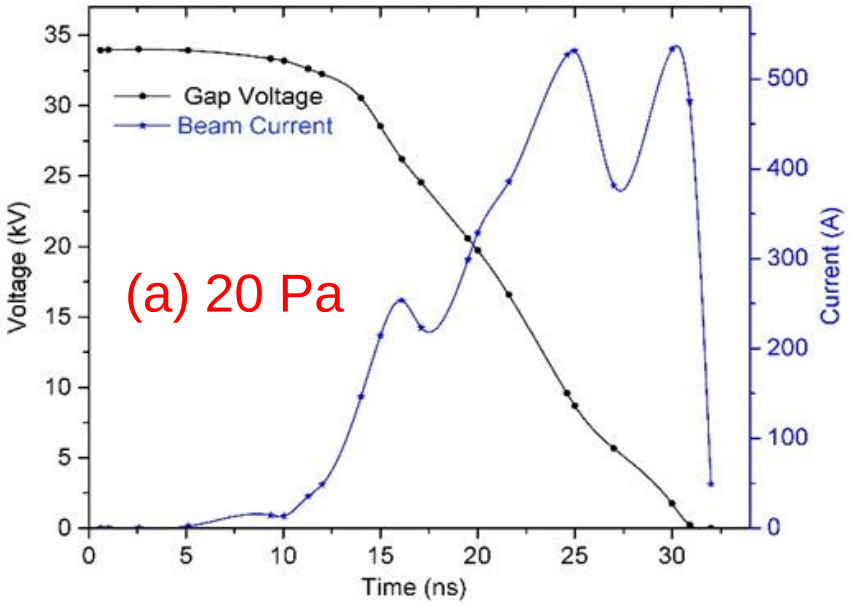
PD-PCE Sources for Electron Beam Generation

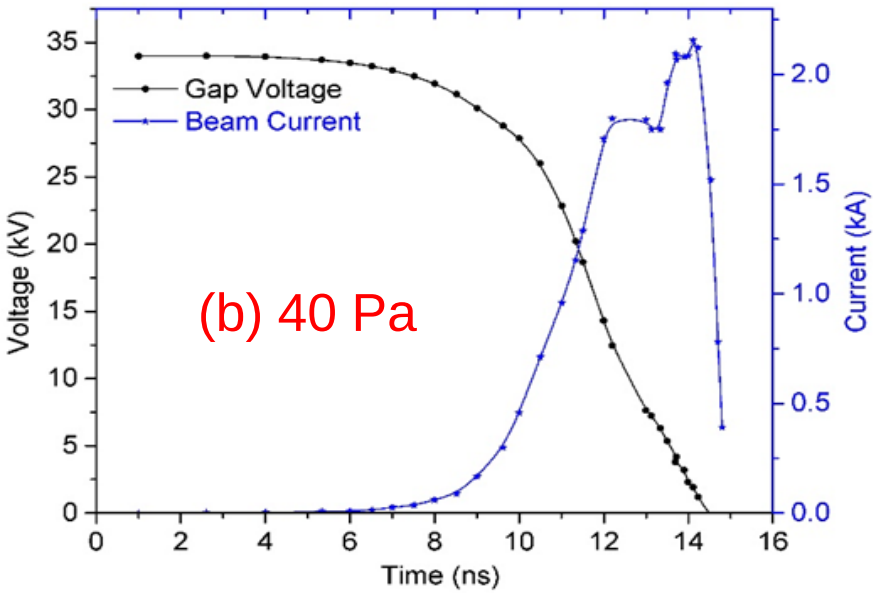


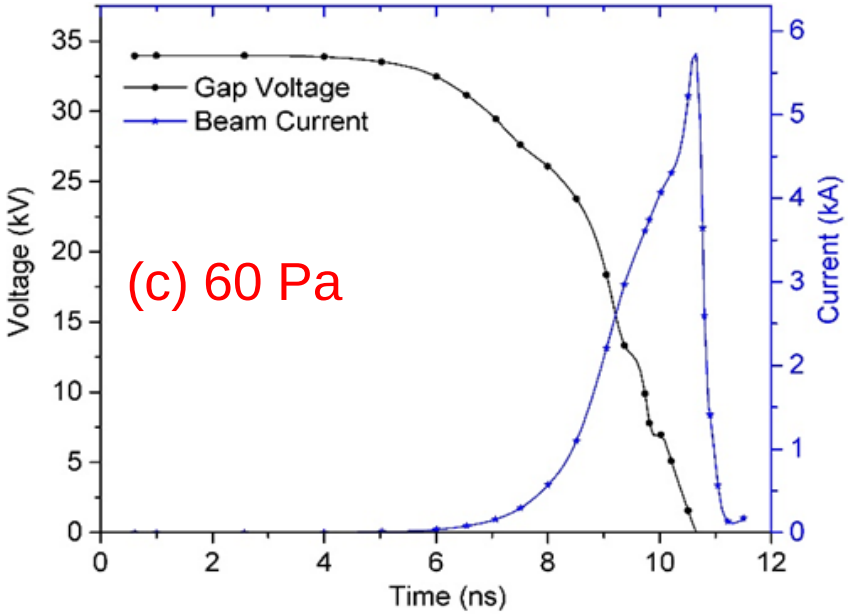


Varun and U. N. Pal, IEEE Trans. Electron Devices, Vol. 67, no. 5, pp. 2182-2187, May. 2020

PD-PCE Sources for Electron Beam Generation

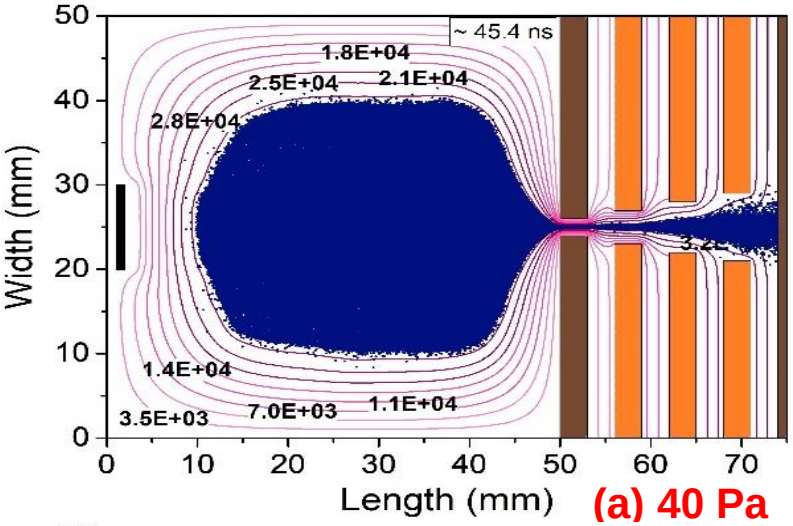




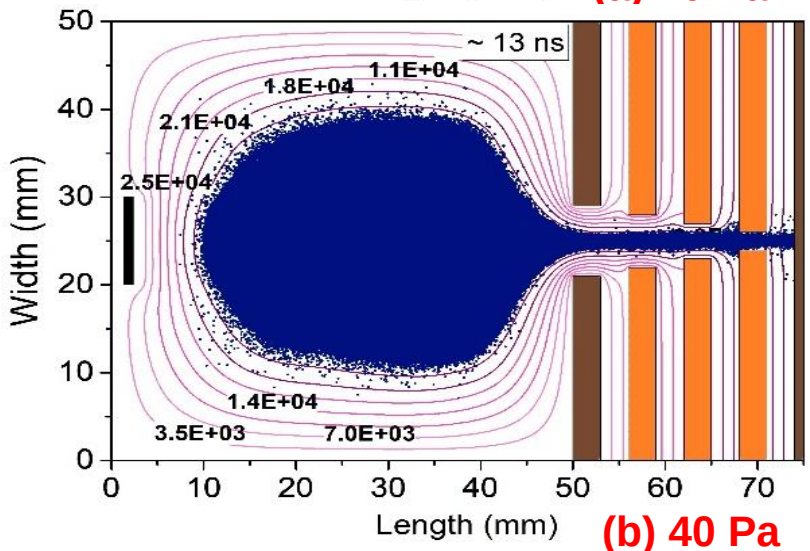


Varun and U. N. Pal, IEEE Trans. Electron Devices, Vol. 67, no. 5, pp. 2182-2187, May. 2020

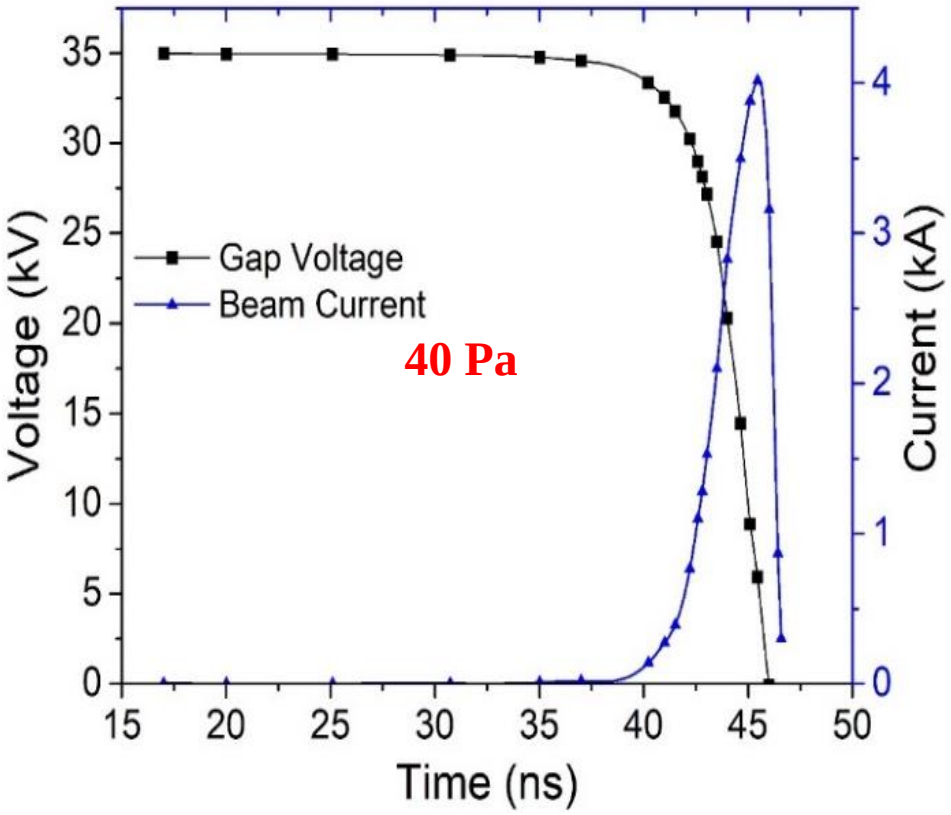
PD-PCE Sources for Electron Beam Generation



(a) 40 Pa



(b) 40 Pa

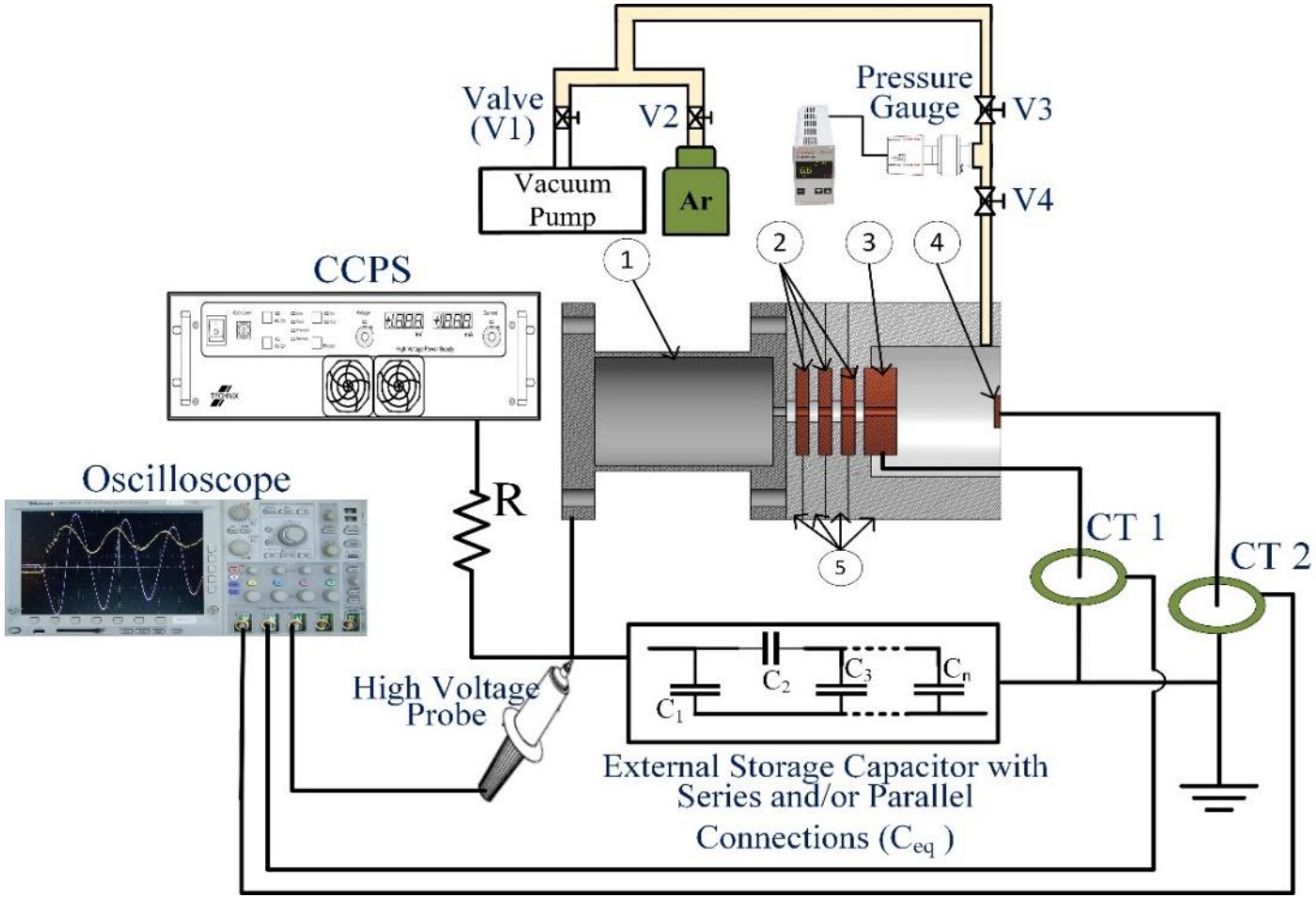


Quenching

- If size of last electrode less than the size of HC aperture

Experimental Setup

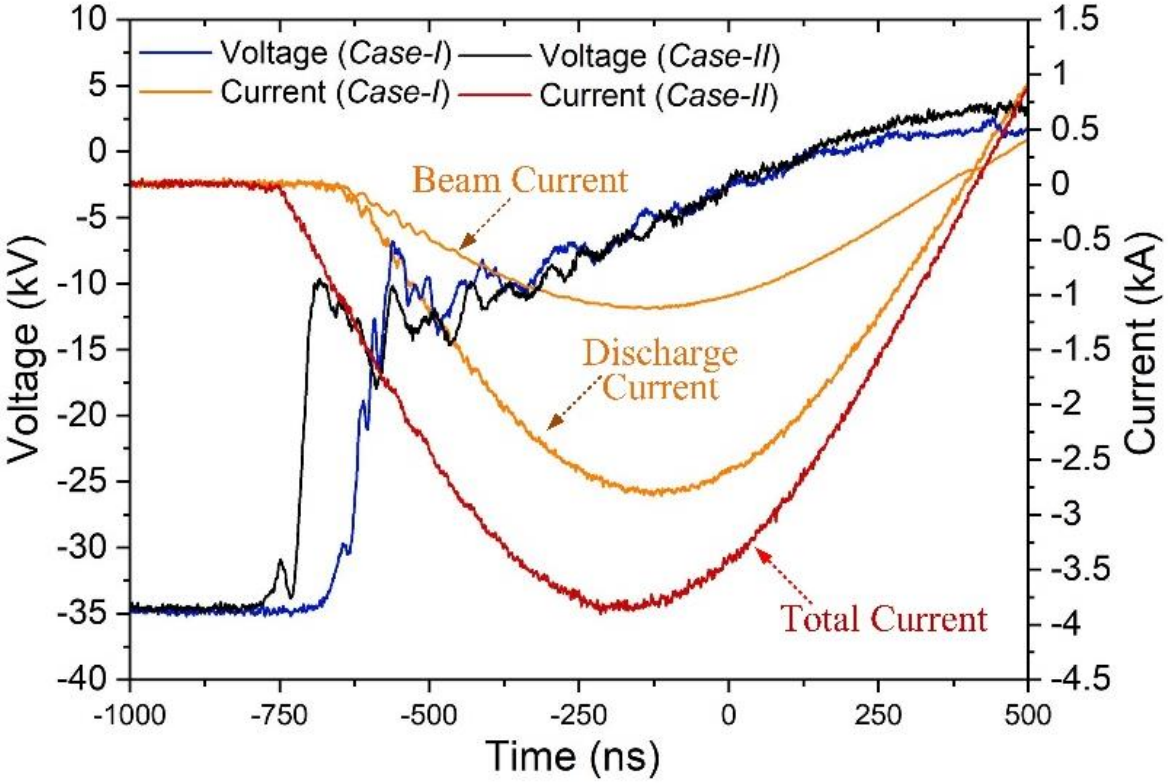
Experimental Analysis for e-beam Generation



Experimental setup for the characterization of high density and energetic electron beam at different operating parameters; 1: Hollow Cathode Cavity, 2: Intermediate electrodes. 3: Anode, 4: Collector, 5: Perspex Insulators

Experimental Analysis for e-beam Generation

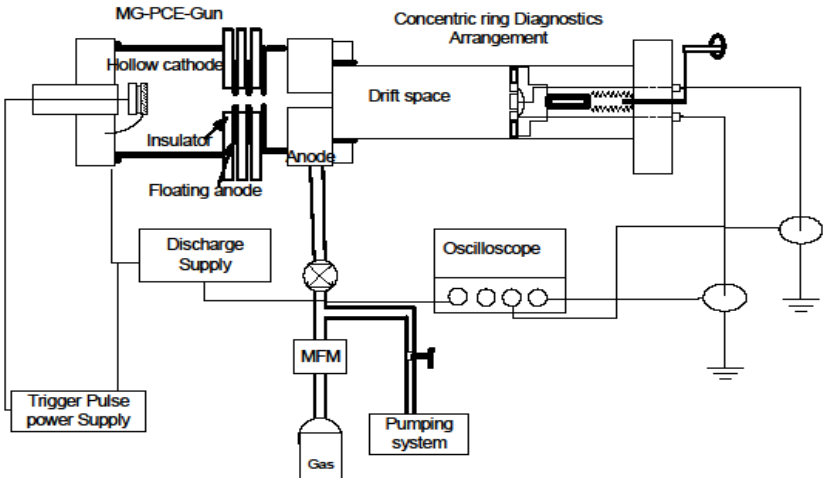
Experimental Investigation of Modified Multi-Gap PD-PCE Source in He gas

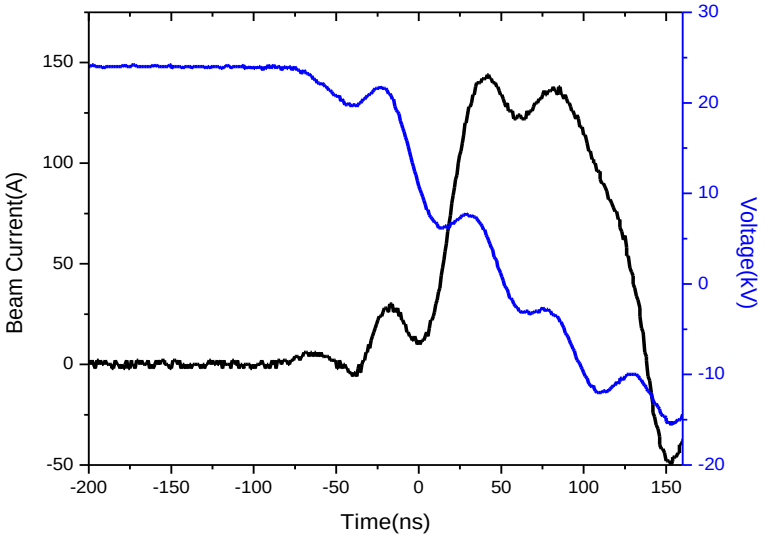


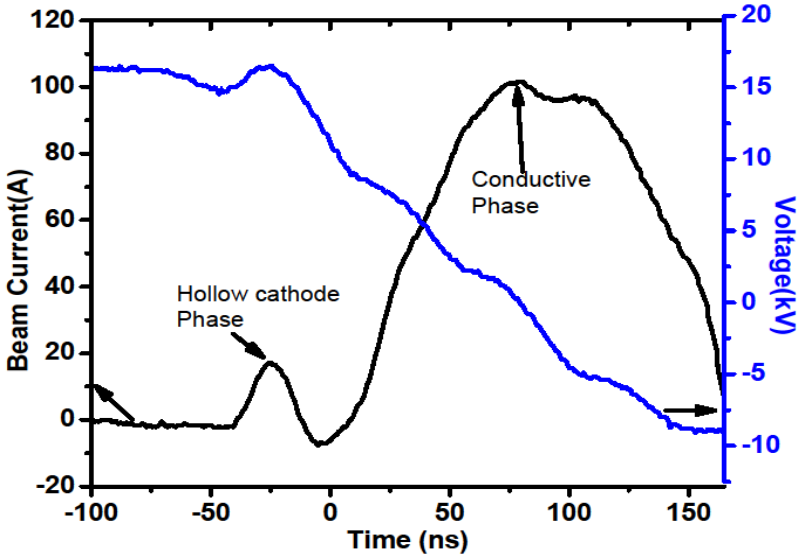
- **Electron Beam**
  - Maximum : 1.4 kA
  - Current density: 1.1×10^4 A/cm^2
  - Minimum : 28 A
  - Current Density: 2.2×10^2 A/cm^2

- **Total Current**
  - Maximum : 5.4 kA
  - Minimum : 184 A
  - Voltage: 5-35 kV

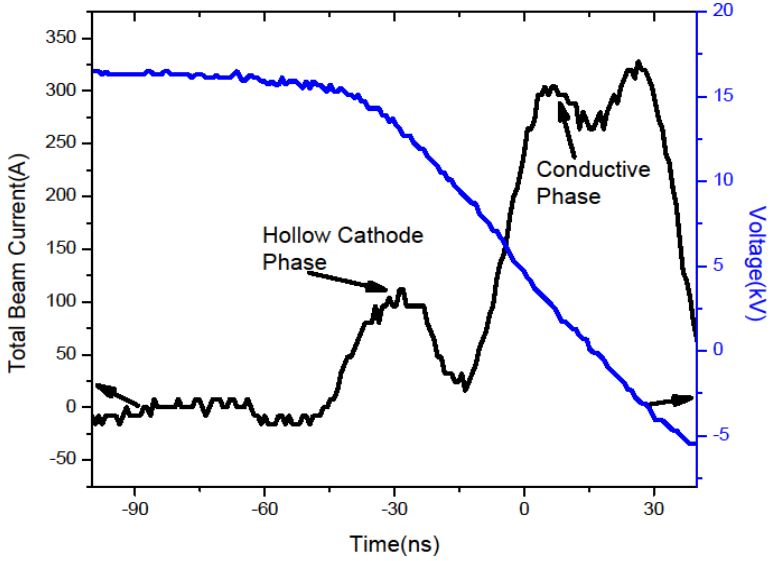
Experimental Analysis for e-beam Generation







self breakdown for Ar pressure 18 Pa



Trigger based breakdown for Ar pressure:15 Pa

Niraj Kumar, et al, *Review of Scientific Instruments, 033503, 87(3), 2016.*

Conclusion

- Discussed the space charge current enhanced in Plasma Filled MW Devices
- PD-PCE source: A technique for short pulse high density electron beam generation
- PS discharge based short pulse suitable for EUV/Soft X-ray, Microwave, and Material Science Applications
- Investigations have been carried out for the simulation and experimental characterization of PS discharge, and the generation of high density electron beam for different geometrical and operating parameters.

Acknowledgements

- Director, CSIR-CEERI
- AcSIR, Ghaziabad
- Guide: Dr. Udit Narayan Pal
- Plasma Team and VEDD Group Members
- Mentors
- Friends and Colleagues

धन्यवाद/Thanking you

Annexure III:

Journey of Amarjit Singh from Phagwara to Pilani

सीएसआईआर-सीरी समाचार
CSIR-CEERI NEWS

A Quarterly Bulletin Vol. 60(1) January, 2021 Website: www.ceeri.res.in

JOURNEY OF AMARJIT SINGH FROM PHAGWARA TO PILANI

B. N. Basu

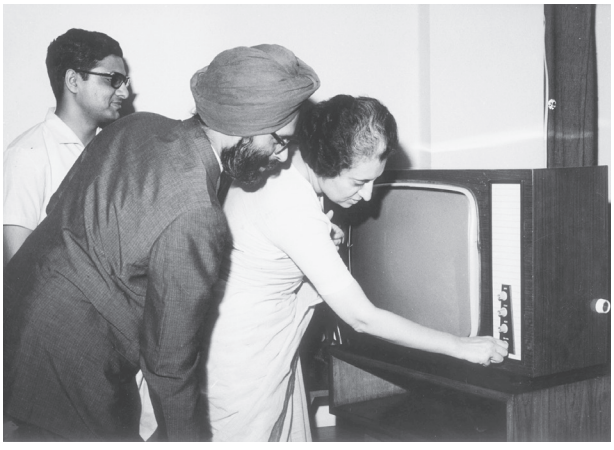
Adjunct Professor, Supreme Knowledge Foundation Group of Institutions, Mankundu -712139
Formerly, Professor, Electronics Engineering Department, Institute of Technology, Banaras Hindu University (BHU), now known as IIT-BHU, Varanasi - 221005
<www.bnbasu.com>

—Dedicated to Dr S.S.S. Agarwala—

An Introduction with an Apology from the Author for Digressions

My association with Dr. Amarjit Singh (AS) and CSIR-CEERI Pilani goes a long way back in time when I was employed briefly as Scientist-B at CSIR-CEERI (19th September 1977 - 28th July 1978). At CSIR-CEERI, I was fortunate to be a member of the team led by Dr. S.N. Joshi, under the overall guidance of Dr. S.S.S. Agarwala[1] , that was credited with developing the first-ever travelling-wave tube (TWT) in India. Motivated by AS and with support from Dr. Agarwala, I undertook the task of measuring the AM-to-PM conversion coefficient of the TWT with Dr. Joshi. It was an honour for me to learn that the measured value, based on the data which Dr. Joshi and I had collected, helped AS to obtain for CSIR-CEERI Pilani the project of developing TWTs for ISRO. Professor OPN Calla provided the support of ISRO to CSIR-CEERI through a project on the development of a ground-station TWT for ISRO. Dr. Surendra Pal, similarly, supported CSIR-CEERI in initiating a project on the development of the first ever space-TWT (C-band) at CSIR-CEERI for ISRO; he associated me with a review committee for the project.

While at CSIR-CEERI I also worked on the electromagnetic analysis of helical slow-wave structure (SWS), the outcome of which was documented as research work in two of CSIR-CEERI's internal reports in quick succession. For one of the reports, Dr. Joshi was my co-author[2,3].



Dr. Amarjit Singh (Director) demonstrating the Black & White Television developed by CSIR-CEERI at Prime Minister Smt. Indira Gandhi's residence

[1]In addition to this article, I have dedicated one of my earlier works a book titled Technical Writing [1] also to Dr. Agarwala

Besides this, I did not have other publications then in related areas. It was thus that Dr Agarwala was taken by surprise when I was invited by AS to deliver a preparatory lecture on Pierce electron gun as a primer to the lectures series by the eminent scientist Dr. J.R.M. Vaughan of Litton Industries at CSIR-CEERI. That I had worked on electron gun was not evidenced by any of my publications so far, and Dr. Agarwala's surprise was justifiable given that. Incidentally, I also got an invitation to attend Dr. Vaughan's lecture series, whence it was my turn to be surprised to find that Dr. Vaughan held in his hand my handwritten lecture note! He had chanced upon the note in the drawer of a table in the dining hall of the CSIR-CEERI guesthouse, and to my gratification, I noted that he used the note extensively during the delivery of his first two lectures of the series.

My next close association with CSIR-CEERI was as a Distinguished Visiting Scientist of CSIR at CSIR-CEERI while I was serving at Electronics Engineering Department of Institute of Technology (IT), Banaras Hindu University (BHU), Varanasi (now known as IIT-BHU). This distinction allowed me to carry out collaborative R&D with CSIR-CEERI in the area of vacuum electron devices more precisely, in the microwave tubes area with support from Dr. Agarwala and Prof.(s) S.N. Joshi, L.M. Joshi, R.S. Raju, A.K. Sinha, Lalit Kumar, R.K. Gupta, S.K. Ghosh, and many others. I was able to play a key role in establishing memoranda of understanding between (i) CSIR-CEERI and IT-BHU and (ii) CSIR-CEERI and Seoul National University. I visited CSIR-CEERI a good number of times to deliver lectures, attend conferences and serve on the selection committees for recruitment of scientists for CSIR-CEERI. I also participated in several project review committees of CSIR-CEERI, notably the DST Steering Committee for a multi-institutional project on the development of gyrotron with CSIR-CEERI as the nodal centre. In continuation of my association with CSIR-CEERI, I now co-chair with the director of ISRO a committee that monitors a project on the indigenous development of space-TWTs for ISRO-SAC, Ahmedabad, at CSIR-CEERI.

At the time of my leaving CSIR-CEERI for Regional Institute of Technology (RIT), Jamshedpur (now known as NIT, Jamshedpur) in 1978, both AS and Dr. Agarwala advised me to continue doing my work on electromagnetic analysis of helical SWS. I was able to do so with the active support from Dr. Raju of CSIR-CEERI. Dr. Sinha, a research scholar at RIT who partnered me in this work, subsequently joined CSIR-CEERI as a Scientist-B.

It was during one of my visits to CSIR-CEERI along with AS that I was advised by him to analyse the stop-band created in the omega-beta dispersion characteristics of helical SWS due to the asymmetry of the dielectric helix-supports arranged around the helix. I, in turn, passed on the problem to Dr Sinha, who developed the needed analysis and documented it[4]. Later on, Dr. Sinha became instrumental in establishing a gyrotron laboratory at CSIR-CEERI with support from Professor Chandra Shekhar, the then director of CSIR-CEERI, and Prof. Joshi, while executing a multi-institutional DST-sponsored project which led to the development of the first-ever gyrotron in India. Incidentally, after his retirement from CSIR-CEERI, AS continued to pursue his interest in the area of gyrotron with his research at the University of Maryland. His efforts were directed at improving the efficiency of gyrotrons using a multi-stage depressed collector in the device.

I mention here another incident of my CSIR-CEERI association which greatly humbled me. In an unprecedented gesture, Prof. Chandra Shekhar, together with Prof. S.N. Joshi, honoured me for my modest research efforts in the area of microwave tubes with a special felicitation function held at CSIR-CEERI Pilani immediately after my retirement from BHU. As far as I am aware, this has never happened before in the history of CSIR-CEERI.

In what follows, I present *a review of the life and work of AS* from the perspective of a vacuum electron devices community member based on the information collected from different sources[5-11].

However, AS has research contributions in other research areas of electronics engineering, too. The achievements of Dr. Singh in those research areas have been kept outside the purview of this article, which is, therefore, only a partial sketch of AS's contributions.

The above preamble recounting some of my associations with CSIR-CEERI and AS is nothing but an attempt to justify my privilege of writing this article, which I hope the reader will take in the spirit intended.

I have organised the article into six sections. Sections 1 and 2 provide an account of the education of AS, beginning with his schooling at Phagwara, followed by details of higher education leading to a doctorate from Harvard University. In section 3, the journey of AS from Harvard University to CSIR - National Physical Laboratory (CSIR-NPL), New Delhi, via Delhi University is narrated. The founding of CSIR-CEERI at Pilani where AS carried out most of his scientific missions and the journey of AS from CSIR-NPL Delhi to CSIR-CEERI Pilani are outlined in sections 4 and 5 respectively. The concluding section, 6, is an attempt on my part to point out to the youngsters of the vacuum electron devices community how they could derive inspiration from the life and work of legendary AS so that they take up challenges that come their way with perseverance and dedication to achieve objectives they have set forth for themselves.

In this article, I have extensively used the acronym 'AS' for Amarjit Singh right from the beginning.

1. Early Education

AS was fortunate to have in his father, Sardar Jagdish Singh, a renowned science teacher who taught at a high school in Phagwara, Kapurthala, Punjab. His father used to demonstrate science experiments for instance, using Wimshurt machine, a class of electrostatic generators, to motivate his students to learn. When he was a child, his father demonstrated to him at home how to prepare oxygen. Thriving in this scientific environment at home, AS tried to experimentally implement James Watt's principle of steam engine. AS was also fortunate to have in his school Mr. Banwari Lal, a science teacher par excellence, who stoked his enquiring mind by lending him books from his personal library. Reading these books AS learned more science than what was taught at school. Hertz's experiment attracted him particularly, eventually leading to his interest in communication engineering[5-11].

2. Higher Education

One of the faculty members from whom AS received immense inspiration was Prof. J.B. Seth of Sikh National College, Lahore, where he had joined after school for a Physics Honours course. All his classes, however, used to be held at Lahore University, and it was from here that he obtained his master's degree in Physics in 1945. Sir C.V. Raman, who was the examiner of his thesis titled "A Small Shielded Transmitter", was greatly impressed with his work and praised it highly. For further higher studies, AS benefited from the "Sargent Scheme" (named after British civil servant John Sargent, Educational Adviser to the Government of India) that enabled him to go to Ohio State University for Radio Engineering course and thereafter to Harvard University for Applied Physics course. The objective of his doctoral thesis, set by advisor Prof. Roland W.P. King, was to extend the tuning range of magnetron[5,6].

3. Return from Harvard University first to Delhi University and then to NPL New Delhi

On his return to India from Harvard University, AS was offered appointment at Punjab University, Defence Science Organisation and Delhi University. He chose to join the Physics Department of Delhi University as lecturer, teaching Electronics and History of Science to postgraduate and undergraduate students. Unfortunately, the Physics Department did not find anything 'pure' physics in the extension of his research in 'applied' physics on magnetrons carried out by AS at Harvard University. Fortunately, however, AS discovered four SCR 584 (fire-control) radar sets lying around

in the Department that had been procured earlier from defence disposals with the intention of reusing the magnetrons in the radar sets for developing a medical LINAC. As it happened, AS was familiar with the working principle and circuitry of SCR 584 radar, having studied it at Harvard University, and he used the knowledge to make one of the radar sets operational at Delhi University. In the meantime, posts of Scientific Officers at CSIR-NPL New Delhi were advertised by its first Director, Dr. K.S. Krishnan. But as luck would have it, AS was still on the contractual two-year service period at Delhi University and could not avail of the opportunity. However, he started working at CSIR-NPL during summer vacation and helped build up the facilities there for developing magnetrons[5,6].

Further, a talk by AS on the development of magnetrons based on his doctoral work at Harvard University was convened at CSIR-NPL by the would-be British Chapter of IRE in India. The audience, including Dr. K.N. Mathur, who was a senior colleague and close associate of Dr. Krishnan at CSIR-NPL, were highly impressed with the talk. Dr. Mathur proposed that AS be asked to join CSIR-NPL, a suggestion which was wholesomely accepted by Dr. Krishnan[5-11]. Subsequently, all hurdles in the way of AS in joining CSIR-NPL were overcome and he was able leave Delhi University for joining CSIR-NPL. Fortunately, he continued to enjoy access to the magnetrons of SCR 584 radar sets at Delhi University for the purpose of his research work at CSIR-NPL.

At CSIR-NPL, AS had as a co-worker another highly dedicated scientist, Nagesh C. Vaidya. In an exchange programme, Prof. Vaidya went to Sweden to earn his doctorate degree. He later joined CSIR-CEERI where he engaged himself in developing indigenously an electron microscope. From CSIR-CEERI Prof. Vaidya moved to BHU as Prof. and Head of Electronics Engineering Department, where he established Centre of Research in Microwave Tubes (CRMT). Incidentally, it was on an invitation from Prof. Vaidya that I left RIT Jamshedpur and joined CRMT. I have dedicated a book authored by me to Prof. Vaidya[12].

At CSIR-NPL, AS was successful in developing an interdigital magnetron with a wide tuning-range. Many distinguished visitors flocked to the laboratory to see the equipment, including the first Indonesian President, Sukarno. Dr. Krishnan also arranged the visit of Pt. Jawahar Lal Nehru to the laboratory, finding an opportunity when the latter was in CSIR-NPL to attend a conference of the directors of CSIR[5-11].

4. Foundation of CSIR-CEERI at Pilani

CSIR established Central Electronics Engineering Research Institute (CSIR-CEERI) at Pilani, the birthplace of Mr. G.D. Birla who had donated Rs. 21 lakh for the purpose. Pt. Nehru laid the foundation stone of CSIR-CEERI on 21st September 1953. The Birla Educational Trust (BET) allotted 14 staff quarters as temporary residential accommodation for the employees of CSIR-CEERI. Dr. N.B. Bhat was deputed from DRDO New Delhi as the Planning Officer of CSIR-CEERI. He engaged two architects to plan the design of CSIR-CEERI laboratories, one of whom had the experience of designing the CSIR - National Chemical Laboratory of CSIR along the lines of Bell Laboratories in the US. Incidentally, the two architects happened to be contemporaries of AS at Harvard University/MIT. Dr. Bhat relocated the foundation stone of CSIR-CEERI to the base of 110-ft tower built at CSIR-CEERI, similar to one at the Bell Laboratories. The tower served the purpose of sending and receiving microwave power over long distances. Dr. Bhat arranged for a power plant to supply electricity to the campus; he also planned for obtaining enhanced power supply from the hydroelectric power plant at Bhakra Dam. However, there was no sanctioned position of a Director at CSIR-CEERI then, and a change in designation from Planning Officer to Assistant Director-cum-Officer-in-Charge was not acceptable to Dr. Bhat. He returned to his parent organisation DRDO New Delhi after serving CSIR-CEERI[5-11] during 1954-56 (Table 1).

5. Journey of AS from CSIR-NPL to CSIR-CEERI

The loss of Dr. Bhatt from CSIR-CEERI

became a point of worry for Prof. M.S. Thacker, the then Director General of CSIR, who consulted Dr. Krishnan on this. Dr. Krishnan considered the possibility of relinquishing the services of AS at CSIR-NPL for meeting the need of CSIR-CEERI, and eventually, AS appeared for an interview at CSIR for the post of Assistant Director, CSIR-CEERI, and was offered the same. AS was, however, in a dilemma, as he had a simultaneous offer of a research position at Stanford University from Prof. M. Chodrow. Dr. Krishnan was in favour of AS joining CSIR-CEERI and tried to convince his wife, Ms. Surinder, of the advantages of her husband joining CSIR-CEERI when he chanced upon her once during her evening walks with family. Matters fell in place when AS discovered CSIR-CEERI Pilani to be much richer than CSIR-NPL in terms of equipment for the development of vacuum tubes, thanks to the substantial grant received from Technical Cooperation Mission (TCM) of USA. He overcame his dilemma and joined CSIR-CEERI in 1959 (Table 1) [5-11].

After joining CSIR-CEERI, AS came across Dr. B.H. Wadia who had returned to India after obtaining his doctorate from Stanford University. Dr. Wadia joined CSIR-CEERI as Assistant Director-cum-Officer-in-Charge. As the availability of residential quarters was a primary requirement to persuade competent staff to join CSIR-CEERI, Dr. Wadia at first engaged the services of CPWD to construct 52 residential quarters. The construction of the laboratories, offices and tower was assigned to qualified construction contractors selected through the standard bidding process of CSIR via public tender. Later on, it was decided that CSIR-CEERI could expedite the construction work of various facilities on its own provided the costs did not exceed the limit stipulated by CPWD[5-11].

There were only 15 scientists at CSIR-CEERI at the time when AS joined the Institute. In order to carry out R&D activities 4 Groups were formed: (i) Physical Electronics, led by Dr. B.H. Wadia; (ii) Special Circuits, led by Dr. A.K. Kamal; (iii) Audio Engineering, led by Dr. D.L. Subramaniam; and (iv) Vacuum Tubes, led by AS. The equipments received from the grant of TCM of USA were distributed among these groups according to their respective relevance to the groups, and Mr. Jaswant Singh, the principal foreman (who had migrated from CSIR-NPL to CSIR-CEERI) took the charge of the workshop machines.

However, soon after, CSIR-CEERI had to part with the services of Dr. Wadia and Dr. Kamal. Dr. Wadia left for IIT-Bombay and Dr. A.K. Kamal went back to France. Therefore, AS had to take over the charge of the Institute from Dr. Wadia despite his reluctance to do so, as he was then very much involved in R&D in the Vacuum Tubes group. After taking charge, AS expedited the construction work being carried out by the CPWD as well as by the Institute. He also developed other amenities (or expanded them) which included dispensary, school, auditorium, guesthouse complex, hostels for trainees, canteen, auditorium, open-air theatre, community centre with indoor and outdoor game facilities, TV tower, market complex, bank, post-office, etc. Incidentally, thanks to the initiative taken later by Prof. Chandra Shekhar, who was the Director of the CSIR-CEERI during 2003-2015 (Table 1), a railway booking counter came into being adjacent to the CSIR-CEERI campus.

AS also focussed on enhancing manpower at CSIR-CEERI. For this purpose, he invited scientists from the CSIR Scientist pool to join CSIR-CEERI. It was thus that Dr. G.N. Acharya and Dr. Birendra Prasad joined CSIR-CEERI and became leaders of the two new Groups namely 'Instrumentation' and 'Communication', respectively. Similarly, Dr. O.P. Gandhi joined CSIR-CEERI to take charge of the Vacuum Tubes Group from AS. Also, Dr. K.S. Balain joined CSIR-CEERI and became the leader of Solid-State Devices Group. Another addition to the Vacuum Tubes Group was Dr. S.S.S. Agarwala, whom I have already mentioned in the introductory section. With a postgraduate diploma of Membership of the Imperial College (DIC) in Electrical Engineering and PhD (Microwaves) from the University of London, both in 1958, Dr. Agarwala

first joined CSIR-NPL and then migrated to CSIR-CEERI. It was only apt that Dr. Agarwala was given the responsibility of developing TWTs, given that the theme of his PhD was "Investigation of a non-reciprocal slow-wave structure" and his experimental cold test setup of the SWS of a TWT at Imperial College of Science and Technology, London, was appreciated by none other than the legendary Prof. John Robinson Pierce.

Now that the expertise of both AS and Dr. Gandhi was available to CSIR-CEERI, the Vacuum Tubes Group was well set for an accelerated growth in its objective of developing a working model of the magnetron. The magnetrons available from the radar set procured by Dr. Bhat from defence disposal procurement helped, and the Group developed a magnetron and tested it in the said radar set. The performance of the radar set using the magnetron developed by the Group was successfully demonstrated from the CSIR-CEERI tower before the Indian Navy represented by a Commodore. Convinced of its efficacy, the Indian Navy specified their requirement of power and operating frequency of the magnetrons (S-band 500 kW), which set the laboratory and workshop at CSIR-CEERI in a batch production mode for meeting the requirement. Thus, a batch of 75 magnetrons was delivered to the Indian Navy. The Group also developed magnetrons to the specifications of Indian Air Force (S-band, 1.0 MW in six variants of frequency from 2910 to 3100 MHz). The technology of producing this class of magnetrons was later transferred to Central Electronics Limited. This was a landmark achievement of CSIR-CEERI under the leadership of AS. Jawaharlal Nehru, who visited CSIR-CEERI accompanied by his daughter Indira (Mrs. Gandhi, who later became the Prime Minister of India) (Fig. 1), congratulated AS and his team for the outstanding work. AS packaged and presented a magnetron developed by his team to Pt. Nehru.

Fig. 1. Pt. Nehru expressing curiosity about the magnetron developed by Dr. Amarjit Singh and his team[10].

Some of the magnetrons developed later by CSIR-CEERI include X band, 200 kW coaxial magnetron; and S-band, 1.0/2.0/2.6/3.0 MW tunable pulsed magnetron. A 35GHz, mm-wave magnetron was also developed at CSIR-CEERI. Recently, the technical know-how of a 2.6 MW, S-band magnetron has been transferred to M/s Panacea Medical Pvt. Ltd., Bengaluru, for production. Currently, the development of low-power CW magnetron, spatial harmonics magnetrons, and system-based on low-power CW magnetrons are being explored at CSIR-CEERI[10].

Now that AS had worked at CSIR-CEERI for more than three years as a scientist in the area of vacuum electron devices while at the same time discharging duty as Officer-in-Charge of the Institute, he felt an urge to explore frontier areas to gain more experience. He got an opportunity for the same in an offer of a visiting position from Prof. J.E. Rowe, the Director of Electronics Research Laboratory at the University of Michigan, for a period of one year. Without attempting to obtain study leave for the purpose, AS resigned from CSIR-CEERI and handed over the charge of the Institute to Dr. D.L. Subramaniam, leaving for Michigan in the year 1962. The problem assigned by Prof. Rowe to AS was to develop a high-frequency source through an electron beam passing the interaction region between two closely-spaced electrodes. The problem turned out to be one of developing a device that accrues beam-plasma interaction for an electron beam penetrating through a plasma medium, a device similar to Haeff tube or double-stream amplifier in which two intimately mixed electron beams of slightly different velocities interact with each other.

Such a device would do away with the SWS such as that required for a TWT[9,13]. Incidentally, I also carried out my doctoral research on a related problem under the tutelage of Prof. N.B. Chakrabarty of IIT-Kharagpur. (I have dedicated another of my books to Prof. Chakrabarty[14]).

During his stay at Michigan, AS visited Bell Telephone Laboratories to observe developments in the field of semiconductor devices that were competing with vacuum electron devices in function. An emergent political situation in India, the war between India and China, however, made it expedient for AS to return to India without completing his one-year tenure at Michigan University. He responded to an SOS from CSIR asking him to join back as the Director of the Institute. He rejoined CSIR-CEERI in 1963 (Table 1).

Table 1 Period-wise tenure of various scientists spearheading CSIR-CEERI[8]

Duration	Scientist	Position
1954-1956	Dr. N.B. Bhatt	Planning Officer
1957-1959	Dr. B.H. Wadia	Assistant Directo-cum-Officer-in-Charge
1959-1962	Dr. Amarjit Singh	Assistant Director/ Assistant Director-cum-Officer-in-Charge
1962-1963	Dr. D.L. Subramaniam	Assistant Director -cum-Officer-in-Charge
1963-1984	Dr. Amarjit Singh	Director
1984-1989	Dr. G.N. Acharya	Director
1989-1993	Dr. W.S. Khokle	Director
1993-1999	Dr. R.N. Biswas	Director
1999-2003	Dr. S. Ahmad	Director
2003-2015	Dr. Chandra Shekhar	Director
2015-2016	Dr. R.K. Sinha (Director, CSIO)	Director, Additional Charge
2016-2018	Prof. Santanu Chaudhury	Director
2018-2019	Prof. Raj Singh	Acting Director
2019-2020	Dr. D.K. Aswal (Director, CSIR-NPL)	Director, Additional Charge
2020 onward	Dr. P.C. Pancharia	Director (continuing)

Subsequently, CSIR-CEERI, under the overall leadership of AS, developed the know-how for TV receivers[6-8]. Likewise, CSIR-CEERI developed an indigenous control system for Diesel Electric Locomotives in a project sponsored by Bharat Heavy Electricals Limited, which was extensively employed by the Indian Railways in hundreds of their locomotives[6-8], and so on.

AS served CSIR-CEERI for about quarter of a century; see Table 1. The table also lists the tenures of other scientists who have spearheaded the progress of the Institute from inception to present. Prof. Chandra Shekhar, a former director of CSIR-CEERI (Table 1) and an illustrious follower of AS, chaired the felicitation function held at CSIR-CEERI to mark the 90th birthday of Padma Bhushan Amarjit Singh on 19th November 2014 (Figs. 2 and 3). The august audience present included the family members of Dr. Singh; a number of ex-employees of CSIR-CEERI; Prof. G. Raghuram, former director

Fig. 2. CSIR-CEERI greeting Dr. Amarjit Singh with flower bouquet on his 90th Birthday celebration on 19th November 2014[11].

Fig. 3. Padma Bhusan Amarjit Singh blessing the audience on his 90th Birthday celebration at CSIR-CEERI[11].

of BITS Pilani; Dr. Krisna Saraswat, Distinguished Alumnus of BITS Pilani; besides the employees of CSIR-CEERI and their families[11].

Dr. Amarjit Singh thanked his colleagues for their cooperation extended to him. In his brief speech he advised everyone to focus on their aims for the progress of their respective organisations and the nation. He drew example from the well-known incident in *Mahabharata*, where Arjuna is shown as having remained focussed on the eye of the fish to achieve his objective[11]. Prof. S.N. Joshi, the Coordinator of Microwave Tubes Area (previously, Vacuum Tubes Group) recounted the unparalleled contributions of Dr. Singh in general and the vacuum electron devices community in particular. He also talked about how Dr. Singh always remained concentrated on his objective, never compromising with anything on the way of his journey to truth. He also said that Dr. Singh showed us the 'day', beginning with the 'morning', which can be equated to the development of the first ever magnetron in the country, and circumvent all the hurdles on the way [10,11] through 'day', the latter a metaphor for life. Prof. Chandra Shekhar thanked the audience for their gracious presence at the event. He gave his salutation to the great scientist on his 90th Birthday. He also expressed his gratitude to Dr. K.S. Krishnan for convincing Dr. Singh to join CSIR-CEERI (as already elaborated earlier in this section), and touched upon the fact that it was the genius of Dr. Singh and his expertise in all branches of electronics engineering (vacuum electron devices, solid state devices, control system, communication, etc.) that helped CSIR-CEERI scale great heights and contribute significantly to the progress of the country. Prof. Chandra Shekhar concluded his speech with best wishes for the good heath of Dr. Singh with the Vedic prayer: "जीवेम शरदः शतम्, पश्येम शरदः शतम्, शृणुयाम शरदः शतं प्रब्रवाम शरदः शतम्, अदीनाः स्याम शरदः शतम्, भूयश्च शरदः शतात्"[11].

6. Conclusion

I have tried to present a brief review of the life of Dr. Singh mainly from the perspective of his outstanding contributions to the areas of vacuum electron devices/microwave tubes, as they are areas that I too have an interest in. I have not attempted to highlight the achievements of Dr. Singh in other areas of research. My endeavour through this small effort has been to bring to fore some of the events from Dr. Singh's life which has many a motivational message for all, but youngsters in particular, on the path to achieving their objectives in life. The life of Dr. Singh is a testimony to the fact that with passion, perseverance and focus, there are no hurdles that cannot be overcome.

Acknowledgment

I express my sincere gratitude to Prof. S.N. Joshi, formerly coordinator of Microwave Tubes Area of CSIR-CSIR-CEERI, Pilani as well as to Prof. Chandra Shekhar, formerly Director of CSIR-CSIR-CEERI, Pilani, for sparing their valuable time to discuss with me different aspects of this article. I am profoundly grateful to Ms. Sreelatha Menon for her helpful criticism and editing. I enjoyed working with Mr. Rohit Singh of CSIR-CEERI Library while editing the manuscript of this article. I express my profound gratitude to Prof. S.C. Dutta Roy and Prof. P.C. Panchariya.

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and Dr. S.N. Joshi giving their respective speeches in Felicitation of Padma Bhusan Amarjit Singh, the first Director of CSIR-CSIR-CEERI, on his 90th Birthday.

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Annexure IV:
Typical WhatsApp Chats with Thinkers in VED

16/03/2021, 14:14 - BNBasu Prof: 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 Mishra, Mr. TRK Janardan, Dr. LM Joshi, Dr. KS Bhat, Mr. RR Patnaik, Professor KP Ray, Dr. Shivendra Mourya, Mr. Guru Ikbal Singh (C/O Dr. GS Sidhu), and our members from various 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.

17/03/2021, 00:42 - BNBasu Prof: Furthermore, I am happy to add that, while agreeing to spearhead the brainstorming discussion, Dr. Lalit Kumar suggests that the discussion has to be driven by people from CEERI, MTRDC, SAC, SAMEER, BEL, PEDL, and others like VEM and Panacea.

17/03/2021, 23:19 - 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 Mishra, 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.

18/03/2021, 21:47 - Dr. Vishal Kesari: Topic: Multiphysics Analysis involving Fluid Flow using COMSOL Multiphysics®

Date & Time: 23 March 2021, 3 p.m. - 4 p.m. IST

Key aspects we will cover:

- Modeling the interaction of fluid flow systems with various other physical phenomena

- Coupling heat transfer in solids and fluids to model conjugate heat transfer

- Coupling fluid flow with structural mechanics and acoustics to model fluid-structure interaction and aero-acoustics

- Including chemical reactions and electromagnetic fields in flow systems to model electrokinetic flow and magnetohydrodynamics

Registration Link: https://www.comsol.co.in/c/bjyh

18/03/2021, 22:18 - SNJoshi CEERI: Good evening Vishal and thanks for sharing this information.

20/03/2021, 13:42 - Niraj Kumar CEERI: Initially there was proposal to have webinar on topic" high power BWO". I hope it is under pipeline. We would like have guidance from Prof. KP Maheshwari Sir and other senior colleagues.

20/03/2021, 13:47 - SNJoshi CEERI: Yes Niraj I also remember that. This must be in the notice of Prof.Basu.

20/03/2021, 13:52 - BNBasu Prof: Certainly yes. Mr. Raj Singh has already informed me that he is going to convene the webinar lecture on the subject in the month of May 2021. Dr. Lalit Kumar is likely to be available for his lecture in July 2021. We have relegated the webinar lecture on metamaterial of Professor Subal Kar; he has suggested some other time.

20/03/2021, 13:56 - BNBasu Prof: We are exploring the possibility of organizing the lecture of Professor KP Maheshwari on the development of the first ever relativistic backward-wave oscillator in a university in India

20/03/2021, 15:51 - Raj Singh IPR: Sir I am in conversation with distinguished speakers and will informe once something is finalised well in time.

20/03/2021, 16:12 - BNBasu Prof: Thanks Raj. Dr. Niraj Kumar and, in his absence, Ms Nalini Pareek has agreed to host the programme. Professor Y Choyal will coordinate the programme. We will request Dr. KS bhat to kindly chair the session in which Professor Maheshwari will deliver his lecture.

20/03/2021, 19:17 - Bansiwal MTRDC: Sir,

It would be great help If someone can provide references for precision machining facilities in Bangalore or may be outside Bangalore also who can take up work with govt offices. I mean who understands the govt procedures for payment and accept the order for small qty. One can send the details personally to me or can share in this group.

I am looking for vendors having CNC milling, turning and wire EDM facilities at one place.

Regards

20/03/2021, 23:52 - BNBasu Prof: While Dr. Vishal Kesari is busy in developing the Proceedings of the Webinar#5, the convener Mr. Raj Singh motivated me to plan Webinar#6. Accordingly, we propose the tentative programme as:

Webinar#6: 04-30 pm on 8th May, 2021

Convener: Mr. Raj Singh

Host: Dr. Niraj Kumar

Coordinator: Professor Y Choyal

Chairman: Dr. KS Bhat

Speaker: Professor KP Maheshwari

Topic: "Review of HPM Devices Encompassing Relativistic BWO"

Vote of Thanks: Dr. Udit Pal

Web Management: Dr. V Gahlaut and Dr. Uttam Kumar

21/03/2021, 13:23 - BNBasu Prof: I am happy to inform you that Dr. Lalit Kumar has kindly agreed to chair a brainstorming seminar as already brought out earlier on the group platform. The date is yet to be fixed. I request Dr. Surendra Pal, Professor KP Ray and Dr. BK Shukla to enrich the programme by their benign participation and contributions.

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 Mishra, Mr. TRK Janardan, Dr. LM Joshi, Dr. KS Bhat, Mr. RR Patnaik, Professor KP Ray, Dr. Shivendra Maurya, Mr. Guriqbal Singh 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.

The date of the above brainstorming event will be notified by the convener of the event Mr. Raj Singh in due course.

25/03/2021, 23:29 - BNBasu Prof: Proceedings of the Fifth Webinar are in the making. Dr. Vishal Kesari is working on it.

26/03/2021, 12:06 - BNBasu Prof: I have great pleasure to inform you that Indian Space Research Organisation (ISRO) is organising a workshop on "Scientific Writing" on 31st March 2021 from 10.00 to 13.00 Hrs. The idea behind this workshop is to guide the interested faculty, research scholars and students, how to prepare a scientific manuscript, what are all the points to be taken care while preparing a scientific paper and how to publish a scientific paper etc.

The sessions will be handled by two eminent speakers namely Ms. Swati Meherishi, Editorial Director-Applied Science and Engineering, Springer and

Dr. S.V.S. Narayana Murty, Scientist, Vikram Sarabhai Space Centre, ISRO, Trivandrum. It is also planned to have a half an hour interactive session with the participants. A brief bio-data of the speakers is attached for the kind perusal.

The interested participants may kindly write to us (respond@isro.gov.in <mailto:respond@isro.gov.in>) with their name, Email ID and Phone number, so that we would be able to send the link one day before the event to their Email IDs. The links will be sent on a first come first served basis.

I request you to kindly provide maximum publicity for this event. I am sure the interested faculty and research scholars would be highly benefited from this workshop.

With best regards

26/03/2021, 17:27 - BNBasu Prof: Yes. My book on Technical Writing dedicated to Dr. SSS Agarwala has examples from VEDs. This is a general subject encompassing VEDs. On 24th March, I delivered a webinar talk organized by a department of Calcutta University.

The topic was Aspects of Paper Writing.

I delivered a similar talk at CEERI in 2019 before the lockdown due to Pandemic.

I am happy to post the recent issue of CEERI News that would be of interest to our Group. There you get an article to read on Dr. Amarjit Singh, the doyen of vacuum electron devices. The article is dedicated to our Guru Dr. SSS Agarwala.

29/03/2021, 13:01 - BNBasu Prof: On this auspicious day, I am happy to inform you that Dr. Vishal Kesari is going to release the Proceedings of Webinar#5 within a few days.

30/03/2021, 11:10 - BNBasu Prof: I have been informed by Dr. Vishal Kesari that he would release the Proceedings of Webinar#5 by tomorrow. It's a huge task. I wish Dr. Kesari all the best in his effort.

30/03/2021, 23:51 - Dr. Lalit Kumar: TERAHERTZ TRAVELING-WAVE TUBE ON A RECTANGULAR WAVEGUIDE FOLDED IN A CIRCULAR SPIRAL", by Kurayev et al. was sent to me by the authors, if anyone is interested pass on your email address for forwarding the interesting article.

31/03/2021, 07:56 - Dr. Lalit Kumar: sent to those interested including Prof. Basu.

31/03/2021, 18:46 - Dr. Vishal Kesari: Please find proceedings of webinar#5. Thanks to all for their motivation and support.

Regards

Vishal Kesari

01/04/2021, 22:47 - BKShukla IPR Gandhinagar: Wed, 7 Apr at 19:00 CEST Online event https://fb.me/e/1pHq7GD74?ti=wa

01/04/2021, 23:16 - Vikram IIT BHU: https://science.thewire.in/the-sciences/scientists-suggest-us-embassies-were-hit-with-high-power-microwaves/

Author: Edl Scahmiloglu

02/04/2021, 09:12 - BNBasu Prof: Edl Schamiloglu wrote the foreword of the book "High Power Microwave Tubes" authored by me with Vishal Kesari as my coauthor, under the imprint of Claypool and Morgan.

02/04/2021, 16:15 - BNBasu Prof: I am going to post a letter from Professor Claudio Paolini, which would be of interest to those students who are desirous of attending IVEC-2021.

02/04/2021, 16:15 - BNBasu Prof: Dear Professor Basu,

I would like to inform of the call for the IEEE EDS Student Fee grants for supporting PhD students to attend IVEC2021 and the mini course.

The rules are in:

https://atpi.eventsair.com/QuickEventWebsitePortal/ivec2021/website/ExtraContent/ContentSubPage?page=2&subPage=2

I hope to award 25-29 grants on competitive basis. Deadline 15th April 2021.

I would be grateful if you could share the call among interested applicants.

Many thanks

Best wishes

Claudio

06/04/2021, 00:52 - BNBasu Prof: Sixth Webinar on 8th May, 2021 at 4-30 pm

Tentative Programme

Web Management: Dr. V Gahlaut and Dr. Uttam Kumar

Convener: Mr. Raj Singh

Host: Dr. Niraj Kumar

Vote of Thanks: Dr. Udit Pal

Session 1: Expert talk

Session 1 Coordinator: Professor Y Choyal

Session 1 Chairman: Dr. KS Bhat

Session 1 Speaker: Professor KP Maheshwari

Session 1 Topic: "Review of HPM Devices Encompassing Relativistic BWO"

Session 2: Young researcher's talk

Session 2 Coordinator: Mr. Varun

Session 2 Speaker: Ms. Nikita Gurjar

Session 2 Topic: "Sheet beam formation using a plasma cathode electron gun"

07/04/2021, 10:25 - BNBasu Prof: Modified tentative programme follows.

07/04/2021, 10:25 - BNBasu Prof: SIXTH WEBINAR ON 8TH MAY, 2021 AT 4-30 PM

TENTATIVE PROGRAMME

_____

WEB MANAGEMENT: Dr. V Gahlaut and Dr. Uttam Kumar

CONVENER: Mr. Raj Singh

HOSTING: Dr. Niraj Kumar/Dr. Srima Nandi

VOTE OF THANKS: Dr. Udit Pal

_____

SESSION 1: EXPERT TALK

Session 1 Coordinator: Professor Y Choyal

Session 1 Chairman: Dr. KS Bhat

Session 1 Speaker: Professor KP Maheshwari

Session 1 Topic: Review of HPM Devices Encompassing Relativistic BWO

_____

SESSION 2: YOUNG RESEARCHER'S TALK

Session 2 Coordinator: Mr. Varun

Session 2 Speaker: Ms. Nikita Gurjar

Session 2 Topic: Sheet Beam Formation Using a Plasma Cathode Electron Gun

07/04/2021, 10:54 - BNBasu Prof. added +91 91230 10227

07/04/2021, 11:37 - BNBasu Prof: A tapered multi-gap multi-aperture pseudospark-sourced electron gun based X-band slow wave oscillator

N Kumar, RP Lamba, AM Hossain, UN Pal, ADR Phelps, and R Prakash

Citation: Appl. Phys. Lett. 111, 213502 (2017); View online: https://doi.org/10.1063/1.5004227

Published by the American Institute of Physics

Abstract:

The experimental study of a tapered, multi-gap, multi-aperture pseudospark-sourced electron gun based X-band plasma assisted slow wave oscillator is presented. The designed electron gun is based on the pseudospark discharge concept and has been used to generate a high current density and high energy electron beam simultaneously. The distribution of apertures has been arranged such that the field penetration potency inside the backspace of the hollow-cathode is different while passing through the tapered gap region. This

leads to non-concurrent ignition of the discharge through all the channels which is, in general, quite challenging in the case of multi-aperture plasma cathode electron gun geometries. Multiple and successive hollow cathode phases are reported from this electron gun geometry, which have been confirmed using simulations. This geometry also has led to the achievement of ~(of the order of)71% fill factor inside the slow wave oscillator for an electron beam of energy of 20 keV and a beam current density in the range of 115–190 A/cm2 at a working argon gas pressure of 18 Pa. The oscillator has generated broadband microwave output in the frequency range of 10-11.7 GHz with a peak power of ~(of the order of)10kW for ~(of the order of)50 ns.

07/04/2021, 12:01 - BNBasu Prof: Some organizations studying the effect of filling microwave tubes with plasmas

- All-Russian Electrotechnical Institute (VEI), Moscow
- Hughes Research Laboratories, Malibu
- University of Maryland
- Ukrainian Physics-Technical Institute, Kharkov
- University of California, Ervin
- University of California, Berkley
- National University of Defense Technology, Changsha
- Center for Electromagnetic Research, Zhengzhou University of Technology, Zhengzhou

Indian efforts:

- Devi Ahilya University, Indore
- IIT-Delhi
- CEERI, Pilani
- MTRDC, Bangalore

07/04/2021, 12:20 - BNBasu Prof: From a lecture note by Dr. Udit N Pal:

Plasma Cathode Electron (PCE) Gun

Why PCE gun?

- In normal vacuum tubes, ions from the plasma drift toward the gun at high energy. This high energy ion bombardment will normally damage the cathode. To mitigate this issue is to replace the material cathode with a plasma cathode.
- (PCE gun) overcomes the limitations of most high-power microwave tubes which employ either thermionic cathodes that produce limited current-density beams, or field emission cathodes that offer high current density but provide only short pulse widths (<1 msec).
- The PCE gun provides both high-current density (5O-1000 A/cm2) and long-pulse operation (>100 msec).

Plasma Cathode Electron Gun (PCE gun)

Why PCE-gun?

 In normal vacuum tubes, ions from the plasma drift toward the gun at high energy frequency. This high energy ion bombardment will normally damage the cathode. To mitigate this issue is to replace the material cathode with a plasma cathode.

 (PCE gun) overcomes the limitations of most high-power microwave tubes which employ either thermionic cathodes that produce limited current-density beams, or field emission cathodes that offer high current density but provide only short pulse widths (less than 1 msec).

 The PCE gun provides both high-current density (5O-1000 A/cm2) and long-pulse operation (greater than 100 msec).

07/04/2021, 12:31 - Ansari BHU: Sir I have a question...

How one can mathematically calculate the approximate current density of annular electron beam (liner) for EXPLOSIVE ELECTRON EMISSION Model as the beam current is going to developed in the same emission model basee on the various factors (A K gap, Circuit Impedance etc.)?

07/04/2021, 12:42 - BNBasu Prof: Could my original deduction of the space-charge limiting current for an annular beam help? In a tutorial at VEDA held at Guahati I presented the deduction (most probably). Should I share it with you?

07/04/2021, 12:55 - BNBasu Prof: More importantly, let the experts in the area from IPR and CEERI provide more inputs to you. Professor Choyal and Professor Maheshwari can also help you.

07/04/2021, 16:58 - BKShukla IPR Gandhinagar:

https://nucleus.iaea.org/sites/fusionportal/Pages/Careers-for-Women-in-Fusion.aspx

07/04/2021, 17:09 - BNBasu Prof: See section 3.6 of "High power microwave tubes", Vol. 1 by Vishal Kesari and B N Basu.

07/04/2021, 19:47 - BNBasu Prof: He can consult

1) Page 102, An introduction to the Physics of nonneutral Plasmas by R C Davidson, Addison Wesley Pubs Comp.

2) Chapter 2, an introduction to Physics of Intense Charged Particle Beams, Plenum Press.

07/04/2021, 19:48 - BNBasu Prof: The above message is for Mumtaz from Professor Y Choyal.

11/04/2021, 00:37 - Ajesh Palliwar:

https://techcrunch.com/2021/04/08/claiming-a-landmark-in-fusion-energy-tae-technologies-sees-commercialization-by-2030/

11/04/2021, 08:11 - Raj Singh IPR: I think CEERI can be the better source. From IPR Shukla ji can better comment if some one is working on electron beam emission, may be Neutronics Division.

11/04/2021, 13:11 - BNBasu Prof: I draw the attention of the VED Thinkers Group, in particular, our younger group members, to an article in the newspaper Hindustan Times, vide the website appended at the end of this

note. There you will be find an account of how, when he was 26 years old, Dr. Surendra Pal, one of our group members, contributed to the development of the India's first satellite Aryabhata (to be specific, its entire telecommunication systems). Dr. Pal is well known to our group for his support to the development of space-TWTs at CEERI.

https://epaper.hindustantimes.com/Home/MShareArticle?OrgId=1141c22bcad&imageview=0

12/04/2021, 09:28 - RK Gupta CEERI: Dr. Basu, very well written article by Dr. S Pal. All younger should read it.

12/04/2021, 12:01 - SNJoshi CEERI: Thanks Basu Saheb for sharing this nice article. Though for me as well as others Prof.Surendra Pal is well known figure, however, this article is an eye opener for the present generation of Scientists, which have lot of facilities and infrastructure.

14/04/2021, 15:23 - BNBasu Prof: The session 2 of the sixth webinar has been modified. Mr. Raj Singh as the convener of the programme will eventually post the programme in the last week of April 2021. The tentative programme may be read as follows.

14/04/2021, 15:23 - BNBasu Prof: SIXTH WEBINAR ON 8TH MAY, 2021 AT 4-30 PM

TENTATIVE PROGRAMME

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WEB MANAGEMENT: Dr. V Gahlaut and Dr. Uttam Kumar

CONVENER: Mr. Raj Singh

HOST: Dr. Srima Nandi/Dr. Niraj Kumar

VOTE OF THANKS: Dr. Udit N Pal

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SESSION 1: EXPERT TALK

Session 1 Coordinator: Professor Y Choyal

Session 1 Chairman: Dr. KS Bhat

Session 1 Speaker: Professor KP Maheshwari

Session 1 Topic: REVIEW OF HPM DEVICES ENCOMPASSING RELATIVISTIC BWO

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SESSION 2: YOUNG RESEARCHER'S TALK

Session 2 Coordinator: Mr. Mumtaz Ali

Session 2 Speaker: Mr. Varun

Session 2 Topic: ANALYSIS OF PSEUDOSPARK DISCHARGE BASED PLASMA CATHODE ELECTRON SOURCE

14/04/2021, 18:41 - Dr. Vishal Kesari:

Post Doctoral Fellowship Position in Dept. of E&C Engg

https://www.iitr.ac.in/administration/pages/Openings+Post_Doctoral_Fellowship_Position.html

18/04/2021, 20:55 - Dr. Lalit Kumar: Ansari if you could call me to explain your question, may be I could give some pointers.

20/04/2021, 00:31 - Raj Singh IPR: Webinar #6

8th May, 2021

Time: 5:00 PM - 6:30 PM

Tentative Programm

WEB Management: Dr. Vishant Gahlaut and Dr. Uttam Kumar

Convener: Mr. Raj Singh

Host: Dr. Srima Nandi/ Dr. Niraj Kumar

Vote of Thanks: Dr. Udit Pal

Session 1: Expert Talk

Coordinator: Professor Y Choyal

Chairman: Dr. KS Bhat

Speaker: Professor KP Maheshwari

Topic: Review of HPM Devices Encompassing Relativistic BWO

Session 2: Young Researcher's Talk

Coordinator: Mr. Mumtaz Ali

Speaker: Mr. Varun

Topic: Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

24/04/2021, 14:50 - BNBasu Prof: Hats off to Niraj and his team for developing the first ever pasotron in India

25/04/2021, 11:55 - BNBasu Prof:

REVIEW OF SCIENTIFIC INSTRUMENTS 86, 013503 (2015)

Experimental investigation of a 1 kA/cm^2 sheet beam plasma cathode electron gun

Niraj Kumar, UN Pal, DK Pal, Rahul Prajesh, and Ram Prakash

CSIR-Central Electronics Engineering Research Institute (CSIR-CEERI), Pilani, Rajasthan 333031, India

Academy of Scientific and Innovative Research (AcSIR), New Delhi, India

In this paper, a cold cathode based sheet-beam plasma cathode electron gun is reported with achieved sheet-beam current density of the order of 1 kA/cm2 from pseudospark based argon plasma for pulse length of the order of 200 ns in a single shot experiment. For the qualitative assessment of the sheet-beam, an arrangement of three isolated metallic-sheets is proposed. The actual shape and size of the sheet-electron-beam are obtained through a non-conventional method by proposing a dielectric charging technique and

scanning electron microscope based imaging. As distinct from the earlier developed sheet beam sources, the generated sheet-beam has been propagated more than 190 mm distance in a drift space region maintaining sheet structure without assistance of any external magnetic field. C 2015 AIP

[http://dx.doi.org/10.1063/1.4906592]

25/04/2021, 18:45 - Y. Choyal Prof. DAVV: Few papers on BWOs by professor Maheshwari and/or his group members are included with this message:

1) Paper 1 on basics of BWOs.

2) Paper 2 on end reflection effect in BWOs.

3) Paper 3-5 explores finite guide magnetic effect in BWOs.

4) Paper 6 explores Rayleigh hypothesis for BWOs.

5) Paper 7 deals with BWO excitation with constrained large orbit monoenergetic electron beam.

6) Papers 8 and 9 summaries our work on BWO development.

25/04/2021, 19:59 - BNBasu Prof: Thank you so much, Professor Choyal. Our group will ever remember you for sharing these immense and outstanding contributions from you and Professor KP Maheshwari!

25/04/2021, 20:15 - Dr. Lalit Kumar: The presentation does not clearly identify/ label the work done at CEERI. Mr. Niraj Please share your publication related to experimental development of a Pasotron at CEERI. (I am aware about the on PCE and Pseudo spark switches)

25/04/2021, 20:36 - BNBasu Prof: I am sharing the full paper from the CEERI group on the PCE gun and the pasotron.

I have put my effort according to the suggestion of Dr. Lalit Kumar. I am sure Dr. Niraj will further enrich the group according to the suggestion of Dr. Lalit Kumar.

26/04/2021, 13:12 - Dr. Lalit Kumar: Thanks Prof. Basu for sharing this interesting paper describing initial experiment on a plasma device. I wonder, if the work was continued to improve the devices?

26/04/2021, 13:51 - BNBasu Prof: To the best of my knowledge Dr. Niraj has a strong team now. He has been putting his focus on the subject. He must come out with more publications preferably in IEEE-ED. I am sure Professor Edl Schamiloglu will encourage him, too. Above all, you are there for the country.

29/04/2021, 12:59 - BNBasu Prof: Professor Gun-Sik Park has been felicititated with the prestigious IVEC John R Pierce Award!

I have been visiting his lab very regularly at Seoul National University for the past two decades.

BNBasu Prof: He's a great inspiration for the VED community. On behalf of our group, I congratulate him. Obviously, he informed me long ago of this award he was going to be felicititated with.

29/04/2021, 15:07 - SNJoshi CEERI: Thanks Basu Saheb for intimating about this prestigious award conferred on Prof.Gun-Sik -Park.

30/04/2021, 16:28 - Dr. Vishal Kesari: Upcoming events for the month of May. If any of these topics catch your eye, click the link to view details and register. I hope to see you there and look forward to interacting with you!

Web Workshop:

19 May, 3pm-4pm IST: Modeling High-Frequency Electromagnetics with

COMSOL Multiphysics ®

https://www.comsol.co.in/c/brxz

COMSOL Days:

20 May, 12:30pm IST onwards: COMSOL Day: Acoustics

https://www.comsol.co.in/c/bs0r

27 May, 1:30pm IST onwards: COMSOL Day: Semiconductor Technology

https://www.comsol.co.in/c/bs0h

01/05/2021, 01:17 - Ajesh Palliwar:

https://www.youtube.com/watch?v=z86zC_26gGc

02/05/2021, 11:24 - Ajesh Palliwar:

https://www.youtube.com/watch?v=cA90gQchuHA

02/05/2021, 12:51 - Raj Singh IPR: Dear All, hope you all are hale and healthy along with your near and dear. World in general and India in particular is passing through tough phase. We have to face this period with calm and courage, helping each other as much as possible and keeping ourselves and our family also safe. Rest all depend upon Almighty. Nature or God we say, is trying to show his strength. I do not see any other logic to find the rationale behind what all is happening. Pray for you all's wellness.

Please find here, the final schedule for the 6th webinar going to be held on next Saturday, 8th May from 5 to 6:30 PM.

02/05/2021, 12:52 - Raj Singh IPR: Webinar #6

8th May, 2021

Time: 5:00 PM - 6:30 PM

Final Schedule

WEB Management: Dr. Vishant Gahlaut and Dr. Uttam Kumar

Convener: Mr. Raj Singh

Host: Dr. Srima Nandi/ Dr. Niraj Kumar

Vote of Thanks: Dr. Udit Pal

Session 1: Expert Talk

Coordinator: Professor Y Choyal

Chairman: Dr. KS Bhat

Speaker: Professor KP Maheshwari

Topic: Review of HPM Devices Encompassing Relativistic BWO

Session 2: Young Researcher's Talk

Coordinator: Mr. Mumtaz Ali

Speaker: Mr. Varun

Topic: Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

04/05/2021, 21:45 - Akash Prajapati IIT BHU: Found an article you may be interested in: https://spectrum.ieee.org/tech-history/space-age/the-11-greatest-vacuum-tubes-youve-never-heard-of

04/05/2021, 21:49 - SNJoshi CEERI: Very very interesting and informative vedio. Just scanned and will go through it in detail. Thanks a lot Akash Prajapati ji for sharing. Good evening and best wishes.

SN Joshi

04/05/2021, 23:17 - BNBasu Prof: O. Girka, Ivan V. Pavlenko, and Manfred Thumm, "Zeroth radial modes of azimuthal surface waves in dense plasma-loaded, coaxial helix traveling-wave-tube-like waveguides," Physics of Plasmas 28, 043106 (2021)

https://doi.org/10.1063/5.0045139

Abstract

An analytical model of coaxial traveling-wave-tube-like waveguides with plasma filling has been justified and utilized to analyze the eigenmodes. Very often, introducing plasma into vacuum electronic devices leads to essential advantages as compared with evacuated tubes. The cylindrical structure under the present consideration consists of a central dielectric rod, placed inside a plasma coaxial layer with a metallic helix sheath on its outer interface, and a metal screen separated from the plasma by another dielectric layer. The dispersion properties of electromagnetic waves propagating across the external axial static magnetic field in such traveling-wave-tube-like waveguides are studied and summarized. The presence of a dense plasma coaxial layer makes the media nontransparent for waves in the electron cyclotron frequency range. However, surface type electromagnetic waves can propagate in this case. These waves are called azimuthal surface waves (ASWs). The helix sheath causes coupling of ordinarily and extraordinarily polarized ASWs. The zeroth radial ASW modes have been found to be most dangerous for parasitic wave excitation in dense plasma-loaded, coaxial traveling-wave-tube-like waveguides.

05/05/2021, 10:52 - BNBasu Prof: Dear VED Thinkers Group Members,

We request all the members of VED consortium to join the Google meet cloud atleast 5 minutes before the schedule time on May 8 in order to commence the webinar in an efficient way.

Members are requested to keep their video (and if possible audio also) mute during the talk in order to use bandwidth in a better way.

Video and audio may be unmute during the discussion.

Timings: 5:00 PM to 6:30 PM

Date: 8th May

The meeting web link is as follows:

https://meet.google.com/pum-tztq-ive

Dr. Uttam Goswami

05/05/2021, 12:02 - BNBasu Prof: Dear VED Thinkers Group Members,

We request all the members of VED consortium to join the Google meet cloud atleast 5 minutes before the schedule time on May 8 in order to commence the webinar in an efficient way.

Members are requested to keep their video (and if possible audio also) mute during the talk in order to use bandwidth in a better way.

Video and audio may be unmute during the discussion.

Timings: 5:00 PM to 6:30 PM

Date: 8th May

The meeting web link is as follows:

https://meet.google.com/pum-tztq-ive

Dr. Uttam Goswami

05/05/2021, 12:02 - BNBasu Prof: Webinar #6

8th May, 2021

Time: 5:00 PM - 6:30 PM

Final Schedule

WEB Management: Dr. Vishant Gahlaut and Dr. Uttam Kumar

Convener: Mr. Raj Singh

Host: Dr. Srima Nandi/ Dr. Niraj Kumar

Vote of Thanks: Dr. Udit Pal

Session 1: Expert Talk

Coordinator: Professor Y Choyal

Chairman: Dr. KS Bhat

Speaker: Professor KP Maheshwari

Topic: Review of HPM Devices Encompassing Relativistic BWO

Session 2: Young Researcher's Talk

Coordinator: Mr. Mumtaz Ali

Speaker: Mr. Varun

Topic: Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

05/05/2021, 16:31 - Subhradeep Chakraborty CEERI:

https://www.serbonline.in/SERB/npdf?HomePage=New

06/05/2021, 03:24 - BNBasu Prof: This is the January 2021 issue of the CSIR-CEERI News. In an article written by me I have given a glimpse of the contributions of the legendary Dr. Amarjit Singh, the erstwhile Director of CSIR-CEERI, in the area of vacuum electron devices. My article is dedicated to Dr. SSS Agarwala, another legendary in the area.

I take this opportunity to expose my profound gratitude to Dr. PC Panchariya, the Director of CSIR-CEERI.

I express my profound gratitude to Dr. PC Panchariya

06/05/2021, 07:12 - BNBasu Prof: Dear VED Thinkers Group Members,

We request all the members of VED consortium to join the Google meet cloud atleast 5 minutes before the schedule time on May 8 in order to commence the webinar in an efficient way.

Members are requested to keep their video (and if possible audio also) mute during the talk in order to use bandwidth in a better way.

Video and audio may be unmute during the discussion.

Timings: 5:00 PM to 6:30 PM

Date: 8th May

The meeting web link is as follows: https://meet.google.com/pum-tztq-ive

Dr. Uttam Goswami

08/05/2021, 14:10 - Raj Singh IPR: Webinar #6

8th May, 2021

Time: 5:00 PM - 6:30 PM

Final Schedule

WEB Management: Dr. Vishant Gahlaut and Dr. Uttam Kumar

Convener: Mr. Raj Singh

Host: Dr. Srima Nandi/ Dr. Niraj Kumar

Vote of Thanks: Dr. Udit Pal

Session 1: Expert Talk

Coordinator: Professor Y Choyal

Chairman: Dr. KS Bhat

Speaker: Professor KP Maheshwari

Topic: Review of HPM Devices Encompassing Relativistic BWO

Session 2: Young Researcher's Talk

Coordinator: Mr. Mumtaz Ali

Speaker: Mr. Varun

Topic: Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

08/05/2021, 14:11 - Raj Singh IPR: Dear VED Thinkers Group Members,

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Timings: 5:00 PM to 6:30 PM

Date: 8th May

The meeting web link is as follows: https://meet.google.com/pum-tztq-ive

Dr. Uttam Goswami

09/05/2021, 09:25 - Amitavo RC CEERI: Thanks a lot. Yesterday webinar was fantastic and was very much informative for us. Thanks to Dr. Srima Nandi for hosting this webinar so nicely.

09/05/2021, 10:06 - Subhradeep Chakraborty CEERI: It is a pretty long time after which I attended a technical session hosted by Srima Madam..... Reminiscing the Mankundu Days

09/05/2021, 10:31 - +91 99835 26447: Thanks a lot Srima ma'am...webinar was very interesting and very informative for us.

09/05/2021, 10:31 - Ansari BHU: yesterday webinar was very good and informative. Its always delight to here whom you have follow (Prof. Maheshwari) during the PhD, I was one of them. I would like to add few words about the host Dr. Srima Nandi, she was extremely good with her skills and hosting the technical webinar on this platform.

Thank You and Regards,

Mumtaz

09/05/2021, 10:46 - Akash Prajapati IIT BHU: The 6th webinar was a great success. Thanks a lot to the organizers specially Dr. Srima ma'am for hosting the presentation of experts and question hour very well and within time.

09/05/2021, 11:08 - SNJoshi CEERI: Good morning and greetings to all the members of this vibrant group alongwith your respective families.

We appreciate the way this group is being nurtured by none other than Prof. B N Basu, who has been taking lot of pains always to make this group very active and fruitful, with the active participation of Dr. Raj Singh and his dedicated team.

Today I specialy want to pay my gratitude to Prof. Basu for inviting Dr. Srima Nandi to this group and I am in particular is very happy that she has accepted the offer and hosted the 6th Webinar yesterday (May 8, 2021) very meticulously. I admire her communication and organising capabilities. Though her background is different, but she has made herself quite conversant with

the technical terms used by this group. It is my priviledge that I know her for more than one decade, as I used to regularly participate in the conferences at SKFGI, Mankundu (WB) relating to the area of Microwave Tubes. In all these events, she used to have a key role in organising these events under the umbrella of Prof. BN Basu and Prof.B N Biswas. I once again thank her for joining this group and express my best wishes in her endeavors.

09/05/2021, 11:09 - Barik CEERI: Thanks to all the organizers, speakers and specially Dr. Srima Nandi for nicely hosting of yesterday's webinar. It was very useful and informative talk given by Prof. KP Maheshwari.

09/05/2021, 11:32 - SNJoshi CEERI: Dear Prof. Maheshwari good day. I pay my gratitude to you for delivering your expert talk under the umbrella of this group. We know each other as well as Prof.Y Choyal for few decades, and you both have contributed a lot in the activities of CSIR- CEERI. I also got several opportunities to interact with both of you and also witnessed your activities.

I am quite confident that this group must have been benefitted a lot by your very educative and interesting talk.

I also take this opportunity to thank Mr Varun for his contributions as well as for his excellent presentation. I expressmy best wishes and blessings to him.

09/05/2021, 11:33 - LMJoshi CEERI: Good Morning dear group members. It was great learning experience to listen to eminent speakers during Webinar VI. The discussions that followed each lecture were equally educative. Thanks to Prof. Basu, Mr. Raj Singh, Dr. Uttam, Dr. Vishant and Dr. Vishal Kesari for their untiring efforts to provide such a wonderful platform which has truly become international now.

Special thanks to Dr. Srima Nandi for joining the group and co-hosting the seminar. It was very pleasant to witness her expertise and skills to host the seminars after a long gap since I visited SKFGI to participate in a conference.

09/05/2021, 13:05 - KP Maheshwari: Thank you Dr. Joshi for your kind inspiration and continuing support.

09/05/2021, 14:07 - Hasina Khatun CEERI: Thanks to thinkers in VED group for yesterday webinar. It is always great pleasure to hear Prof. K P Maheshwari. Thank you Maheshwari Sir for enlighten us with your wonderful work.

And special thanks to Dr. Srima Nandi to make the webinar so lively. Thank you Ma'am for hosting the webinar so nicely.

09/05/2021, 14:27 - Niraj Kumar CEERI: It was wonderful and nice talk by Maheshwari Sir and Varun. Also, it was nice hosting by Dr. Nandi ma'am.

09/05/2021, 15:12 - +91 83744 07644: Thanks to all the organizers, speakers, and Dr. Srima Nandi ma'am for nicely hosting webinar.

09/05/2021, 16:59 - Mahto NIT Patna: Thanks to Dr. Srima Nandi madam to nicely organizing thr webinar and it was to a great pleasure to listen Prof. K. P. Maheshwari

09/05/2021, 17:47 - Arjun Res. Scholer BHU: It was a nice talk given by prof. K. P. Maheshwari Sir and Mr. Varun. The webinar was nicely organised by Dr. Srima Nandi Ma'am.

09/05/2021, 18:25 - Bhanu MTRDC: As usual it was wonderful and informative talk by Maheshwari Sir and Varun. But also, it was nice hosting by Dr. Nandi ma'am.

09/05/2021, 19:11 - Raj Singh IPR: Today in the morning I thought of writing a note of thanks to the speakers and audience of yesterday's webinar but when I saw my mobile I found a long line of note of thanks and thought that my work is over. But as a convener I am supposed to write a note of thanks.

Nice friends, it was really nice, yesterday's webinar. It was full of knowledge and contents. Talk by Prof. Mahesgwari was as usual superb piece of science innovation and technological excellence. His way of presentation was with his full weight behind the talk. He has such a nice grip on the subject that the knowledge pour out automatically. Salute to you sir. Hope you will oblige us with your continuous association with this group.

Talk by Nirav was really very very detailed and every aspect of PS Discharg Based Plasma Cathod Electron Source was discussed. Thanks Nirav for such a fabulous piece of scientific presentation.

But yesterday's webinar was special in more than one way. The session was not only scientifically marvelous but the way it was conducted by Dr. Srima Nandi was superb, beyond expectations. I am privileged to Thank you Dr. Nandi on behalf of this group.

I would also like to thank Prof. Claudio Paoloni and Dr. Rosa to join this webinar and making it a truly global scientific event.

At the end, I would like to thank you all audience whose whole hearted involvement gives a real meaning to this event.

Thank you all.

Have a nice time.

Wish you all a hale and hearty time ahead.

Please follow COVID appropriate behavior.

Put on mask, avoid crowd, and keep isolation as much as possible.

09/05/2021, 19:48 - BNBasu Prof: I appreciate your remarks very much. However, the talk in the second session was not delivered by Dr. Niraj Kumar. It was delivered by Mr. Varun. However, during the question-and-answer session, I requested Dr. Niraj Kumar to illuminate the group by saying a few words about the CEERI activities in the area of the pasotron. He did it brilliantly.

09/05/2021, 20:26 - Raj Singh IPR: Today in the morning I thought of writing a note of thanks to the speakers and audience of yesterday's webinar but when I saw my mobile I found a long line of note of thanks and thought that my work is over. But as a convener I am supposed to write a note of thanks.

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10/05/2021, 09:23 - Surendra Pal Prof: https://youtu.be/7awAaTJCPME

10/05/2021, 17:51 - BNBasu Prof: Dr. PC Panchariyo, the Director of CEERI, Pilani sent the following message to me:

"Sorry sir

Due to covid cases in colony and pressure to do some help for oxygen generation. We are working on coverting nigtrogen plant into oxygen which can help for at least 10 beds in ICU.

I completely missed".

11/05/2021, 00:08 - BNBasu Prof: Sir, yesterday I attended only one session upto 6:30 pm. I didn't know Dr. Srima Nandi earlier. But now onwards I shall remember her for her flawless and wonderful hosting of the webinar. Honestly speaking I think she has conquered the heart of all the participants of the webinar for extremely good management of the event. One can learn from her how to host an event perfectly.

11/05/2021, 00:11 - BNBasu Prof: The above message is from Dr. Sarit Pal of BC Roy Engineering College, Durgapur, West Bengal.

11/05/2021, 08:10 - Akash Prajapati IIT BHU: Found an article you may be interested in: https://www.eurekalert.org/pub_releases/2020-04/uot-chm042020.php#%2EYJlcFHaoK7E%2Elinkedin

11/05/2021, 08:17 - BNBasu Prof: Very exciting! Thank you for sharing this.

11/05/2021, 08:29 - Subhradeep Chakraborty CEERI: In the fifth webinar, there was a consensus on holding a brainstorming session in a webinar on

the different aspects of bottlenecks on manufacturing microwave tubes and their components including cathodes. Such a brainstorming session would be a very timely initiative for all VED researchers in our country.

11/05/2021, 08:43 - BNBasu Prof: Yes, Thank you for reminding me. We will discuss this with the chairman of the program. Professor KP Ray and Dr. Braj K Shukla are likely to coordinate the program. The program may be scheduled sometime in July. I will discuss with Mr. Raj Singh who will kindly convene the program.

11/05/2021, 08:44 - BNBasu Prof: In the beginning of the sixth webinar of Thinkers in Vacuum Electron Devices Group, I said the following.

Thank you for giving me this opportunity to say a few words about an article of historical value written by me on the contributions of the legendary Padma Bhusan Dr. Amarjit Singh, the erstwhile Director of CEERI-Pilani, in the area of vacuum electron devices. The article is published in the January 2021 issue of the CSIR-CEERI News.

My article is dedicated to Dr. SSS Agarwala, another legendary in the area.

I express my profound gratitude to Professor SC Dutta Roy, the erstwhile Chairman of the Research Council of CEERI-Pilani, to provide me a lot of inputs. Professor Chandra Skekhar, the Chancellor of Academy of Scientific and Innovative Research (Ac-SIR) and the erstwhile Director of CEERI-Pilani and Dr. SN Joshi, the erstwhile Head of Microwave Tube Area of CEERI-Pilani, critically examined the manuscript. Ms Sreelatha Menon, Editor of Universities Press, Hyderabad, has edited the manuscript of my article.

When I was trying to find a suitable medium in which to publish my article, I could reach Dr. PC Panchariya, the Director of CEERI-Pilani. It was made possible with the help of Dr. SA Akbar, Chief Scientist of CEERI-Pilani, to reach Dr. Panchariya.

Dr. Panchariya showed his gesture and requested me to contribute the article to the CSIR-CEERI News.

Therefore, I wish to use this platform of Thinkers in Vacuum Electron Devices Group to express my sincere gratefulness to Dr. PC Panchariya to help the article to see the light of day.

11/05/2021, 13:01 - Y. Choyal Prof. DAVV: Researcher from Univ. of Tokyo and JAERI in their paper JOURNAL OF SPACECRAFT AND ROCKETS, Vol. 41, No. 1, pp 151, 2004 have introduced the concept of a launcher boosted by electromagnetic waves. Here is a text from their paper.

When electromagnetic waves are beamed from the ground intermittently and focused in the atmosphere, breakdown occurs near the focus, and plasma is formed. The plasma absorbs the following part of beamed energy and expands outward generating shock waves. The shock waves reflect on a nozzle surface of a vehicle, generating impulsive thrust. Because the energy is provided from the ground and the atmospheric air is utilized as a propellant, neither energy source nor propellant need to be loaded onto the vehicle. Consequently, this type of launcher can achieve a high payload ratio at a remarkably low launch cost.

11/05/2021, 15:55 - Surendra Pal Prof: It is a concept but needs atmosphere. However for higher heights there is a concept that EM energy impinging on a metallic diafrom plate, from a high power microwave beam will give rise to equal and opposite reaction and this doesn't require atmosphere. Such system can be used for small thrusters in satellites. It works on solar energy and Microwave source.Lab level thrusters was tested. A few milli-g thruster was tested in my lab, when I was in ISRO. However we could not proceed further due to meeting the time schedules of other systems.

11/05/2021, 16:06 - BKShukla IPR Gandhinagar: This is a concept, I presented at IIT Roorkee, VEDA conference. Actually with the development of megawatt level Gyrotron it has become point of research to launch the satellite using high power microwave. It's microwave rocket with beamed propulsion but this will need thousands of Gyrotron with several Gigawatt power. So at this moment it is just a concept may be useful in future with even higher power Gyrotrons (2MW type).

11/05/2021, 16:44 - +91 94273 02802: Microwave Plasma based Thruster can be used as first stage which can lift the vehicle till 20 km or so where atmosphere is present. Beyond this Microwave Thermal Thruster is being explored by researchers, this is based on heat exchanger where microwave will illuminate the surface, which has to be covered with suitable rf absorber (development of material with special properties which is much more than rf absorption is a real challenge), the heat generated can be transferred to propelnt to which will generate thrust.

12/05/2021, 11:28 – Srima Nandi:

First of all I apologise profusely for procrastinating.

Thanks to Mr. Raj Singh, the convener, for giving me this opportunity to host the program. I extend my gratitude to Dr. SN Joshi sir for introducing me. I was confident that if I did any mistake, my co-host, the great scientist, Dr. Niraj Kumar would correct me.

I had to learn the terminologies, which I had to know apriory from Professor Basu sir. He helped me a lot regarding this. I used to sit in his office when he was in SKFGI, Mankundu and see him guiding many research scholars. This gave me an opportunity to learn many technical terms from him. I would like to share an incident with you all. When he was lecturing before the faculty members of SKFGI regarding TWT (I was present during his lecture), he suddenly asked me "Srima, what is TWT?"

I was taken aback. But I knew the answer and told him the full form of TWT much to the surprise of the audience. This was how I learned many technical terms from him.

I am overwhelmed by the appreciation given for my work by the esteemed group members on this platform.

For me it was a great learning experience and being a part of this enriching webinar was a great honour for me.

With warm regards,

Srima

20/05/2021, 11:14 - Akash Prajapati IIT BHU: Found an article you may be interested in: https://m.youtube.com/watch?v=cvsj0nqHwic

20/05/2021, 16:51 - KP Maheshwari: Thanks for your kind and encouraging words. K. P. Maheshwari.

23/05/2021, 14:56 - Akash Prajapati IIT BHU: Found an article you may be interested in Technology developed for particle accelerator that can be used to uncover the hidden rock art

https://eduplay.rnp.br/portal/video/embed/110333