IVEC EVENTS OCTOBER 22, 2020

- **Opening Remarks**
- **Technical Sessions**
- **Poster Sessions**
- **Closing Remarks**
- **Introduction to IVEC 2021**

Technical Sessions

Session 14: Space TWTs

Chair: Will Menninger, L3 Electron Devices Division

14.1 - NEC Network and Sensor Systems,Ltd. Q/V-band Helix TWT for Future High Throughput Satellite Uplink Applications

- *Naofumi Kosugi, Daiki Matsumoto, Tetsuo Machida, Takatsugu Munehiro, Yoshinori Mori*
  NEC Network and Sensor Systems, Ltd.
- *Travis Stewart*
  NEC Corporation of America

  NEC Network and Sensor Systems, Ltd. has developed a Q/V-band(47.2 - 51.4GHz) 250Wpeak 150Wcw TWT(Traveling-Wave-Tube). This was accomplished with attention to detail in the design of performance and reliability in support of future HTS(High Throughput Satellites) uplink application. This paper presents the summary of thisdevelopment, which is based on NEC's vast experience, gained from the Ka-band 500W/550W TWTs, well as the space application TWTs.

14.2 - Low-Power/High-Power SPACE-Qualified RADAR TWTs for Earth Observation

- *Ernst Bosch, Philip Birtel, Martin Albrecht*
  Thales Deutschland GmbH

  Today's changing environment on earth needs many different possibilities to watch and predict events or to support the better understanding of earth conditions. One special application is the observation from space support by optical or radar. Both techniques have their strength and weakness and are linked to the size of the objects to be observed or situation to be predicted. In

case of Radar application, the full frequency spectrum from several kHz up to 50 GHz or maybe in the future beyond are of interest. The table below and picture underline the need. Therefore the space radar applications is a very bounded segment, this market has enjoyed continuous growth over the recent years fuelled by the mentioned increasing field of applications, from scientific missions for earth observation and disaster warning (e.g. Tsunami detection, global warming effects, etc.) and to reconnaissance missions targeted at crisis areas around the world. Traveling Wave Tubes (TWTs) have been used for a long time now for space radar applications in the field of earth observation, reconnaissance and altimetry. There are two main technologies for space radar systems: the first one is SSPA active array, the second one is direct radiative antenna fed by TWT amplifiers. Thales MIS has more than 30 years of experience of developing and supplying TWT amplifiers for space radar applications as part of commercial programs such as ERS, RADARSAT, CASSINI, ENVISAT, Oceansat, Fen Yun3, just to name a few, a

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14.3 - Progress on a 71 – 76 GHz Folded Waveguide TWT for Satellite Communications

- *Craig W. Robertson, Adrian W. Cross, Kevin Ronald*
  University of Strathclyde

- *Christopher Gilmour, David Dyson*
  TMD Technologies Ltd

- *Peter G. Huggard, Fiachra Cahill, Mat Beardsley*
  Science and Technology Facilities Council

- *Roberto Dionisio*
  European Space Agency

A high frequency folded waveguide travelling wave tube (TWT) has been designed to test this delay line technology for applications in satellite communications. Simulations predict an output power ~100 W over the frequency range of 71 – 76 GHz can be achieved for an input power of ~9 mW (40dB gain) using such a folded waveguide. Measurements of the vacuum windows brazed into their jackets indicate better than 17dB return loss over the required frequency range. The collector will be single stage depressed and the cooling solution has been tested using a thermal source.

14.4 - NEC Network and Sensor Systems, Ltd. Development of the DBS Band 1250W peak, 750W CW, Helix TWT for Direct Broadcast Satellite Uplink

- *Taishi Masuda, Daiki Matsumoto, Tetsuo Machida, Takatsugu Munehiro, Yoshinori Mori, Kenji Nakajima*
  NEC Network and Sensor Systems,Ltd.

- *Travis Stewart*
  NEC Corpolation of America

NEC Network and Sensor Systems, Ltd. has developed a DBS band 1250W peak 750W CW helix Traveling Wave Tube (TWT) for Direct Broadcast Satellite uplink. The TWT covers the full extended DBS band of 17.3 to 18.4GHz. The overall efficiency is greater 30% at rated power. The measured data of electrical characteristics and the results of two reliability verification tests to ensure high reliability are shown in this paper.

14.5 - Design and Development of an X-Band Pulsed Helix TWT for Space Application

- *Talur Chanakya, U. V. Chandramouli, Subrata Kumar Datta*
  Microwave Tube Research and Development Centre

- *S. Senthil Kumar*
  Bharat Electronics

A compact X-band power booster TWT was designed and developed for space applications that provides minimum of 350W of peak RF output power with 25% duty over a bandwidth of 800MHz with RF efficiency of 22% and minimum gain of 27 dB. This TWT uses an electron gun operating at a cathode voltage of 6 kV and current of 275 mA with beam filling factor of 0.5. The electron beam is focused using PPM structure with peak field of 2600G generated using Sm2Co17 magnets. The SWS comprises tungsten tape helix supported by three azimuthally, symmetrically placed T-shaped APBN support-rods inside a metallic envelope. The dimensions of SWS were derived using the in-house parametric codes and optimized using Eigen-mode solver of CST Studio to achieve the required dispersion characteristics. The beam-wave interaction analysis was carried out using the in-house 1D-codes and was optimized using 3D PIC simulations. The SWS employs positive velocity taper near the output coupler in order to enhance RF interaction efficiency and to reduce the second harmonic content. The length of the SWS is around 93 mm. A 3-stage depressed collector is used to enhance the overall efficiency of the TWT. A prototype TWT is developed and tested for performance and has achieved overall efficiency of 45% with TWT length of 250 mm and weight of 980 grams. This TWT is subjected for operational temperature cycling at +70C and -20C and also random vibration to verify the structural integrity and has met the requirements

Session 15:
Modeling: RF & Secondaries

Chair: John Petillo, Leidos, Suite 201

15.1 - Density Functional Theory Calculations for the Simulation of Secondary Electron Yield

- *Ivana Matanovic, Ryan S. Johnson, Raul E. Gutierrez, Edl Schamiloglu*
  University of New Mexico

- *Maciej P. Polak, Dane Morgan*
  University of Wisconsin

  Suppressing the harmful multipactor effect by, for instance, reducing secondary electron yield (SEY) is crucial in the design of RF space technologies. Therefore, improving fundamental understanding of how structural and electronic features of materials affect the SEY is necessary. In this benchmark work, we use density functional theory calculated properties to simulate, via Monte Carlo method, the SEY of simple metals copper and silver. As in these simulations, the dielectric property i.e. the energy and momentum dependent energy loss function plays a major role, we focus our study on the computational procedures necessary to obtain reliable first principles data.

15.2 - Theoretical Modeling of Secondary Electron Yield Using First-Principles Input: Comparison with Experimental Measurements

- *Maciej Polak, Dane Morgan*
  University of Wisconsin

- *Ivana Matanovic, Ryan Johnson, Raul E. Gutierrez*
  University of New Mexico

  Secondary electron yield of a material is a crucial factor in designing many electronic devices, from electron multipliers to high-power radio frequency devices used in the aerospace industry. In the latter, it is key in mitigating the highly destructive multipactor, where a low value of secondary electron yield is desired. In this work we present results for select elemental metals obtained using a newly developed, state-of-the-art, Monte Carlo code for modeling secondary electron emission with entirely first principle input. The results are compared with the available experimental data.

15.3 - Modeling Stability of Vacuum Electronic Devices with the Large-Signal Code TESLA-Z

- *Igor A. Chernyavskiy, Alexander N. Vlasov, John C. Rodgers, Baruch Levush*
  Naval Research Laboratory

- *Thomas M. Antonsen*
  Leidos, Inc.

  We present a new approach to the study of the stability of Vacuum Electronic devices using the large-signal code TESLA-Z. The approach combines a precomputed complex impedance matrix for the structure Z with a TESLA computed admittance matrix Y of the beam-tunnel loaded with an electron beam. The gain matrix G for a given device then can be found as the product of the Z-matrix of the structure and admittance matrix Y of the beam-tunnel. Subsequent analysis of the eigenvalues of the gain-matrix G uses the Nyquist method to determine the stability of the

device. We discuss details of the new algorithms and illustrate its application using available examples.

15.4 - Efficient and Flexible Geometry-Driven Circuit Simulation Environment Using Impedance Matrices

- *Aaron Jensen, David Chernin*
  Leidos

- *Alexander Vlasov, Igor Chernyavskiy*
  US Naval Research Laboratory

- *Khanh Nguyen*
  Beam-Wave Research, Inc

Impedance matrices are calculated by AWR's Analyst-MP and used in NRL's Tesla-Z to predict the performance of various traveling wave tube (TWT) geometries. A generalized Analyst-MP script for creating single and multi-beam folded, serpentine and hybrid TWT geometries has been developed and is discussed. Geometry deconstruction, matrix calculation and reconstruction using our new Z-build code are discussed. Finally a stability calculation and circuit optimization using impedance matrices is presented.

15.5 - Stopband and Coupling-Coefficient Estimation for Asymmetries in Helical Delay-Lines

- *Moritz Hägermann, Arne F. Jacob*
  Institute of High-Frequency Technology, Hamburg University of Technology

- *Philip Birtel*
  Thales Deutschland GmbH, Electron Devices

The pi-point stopband in helical delay-lines due to asymmetries is analyzed. For this, we model the structure as a conductor-backed coplanar waveguide. The stopband is evaluated from the effective transmission-line parameters and the results are compared to full-wave simulation. Although the approach is quite general, we only consider non-ideal support-rod positions in this contribution. Finally, the stopband is modeled by applying the coupled-mode theory, including a simple coupling-coefficient estimation.

15.6 - An Efficient Eigensolver for Extended Interaction Klystrons Based on Finite Element Method

- *Li Xu, Hangxin Liu, Xing Li, Zhonghai Yang, Bin Li*
  University of Electronic Science and Technology of China

This paper presents an efficient eigensolver based on finite element method (FEM) for metallic-lossy multigap cavities in extended interaction klystrons (EIKs). By modeling a W-band sheet-beam EIK (SBEIK), the eigensolver is validated. Moreover, it is found that our eigensolver is much more efficient than the widely used commercial FEM code i.e. HFSS, which would be very useful for the design of multigap cavities of EIKs.

Session 16: Components

Chair: John Jelonnek, Karlsruhe Institute of Technology (KIT)

16.1 - Additive Manufacture of RF Loads for ITER

- *Robert Lawrence Ives, David Marsden, Thuc Bui, George Collins*
  Calabazas Creek Research, Inc.

- *Jeffrey Neilson*
  Lexam Research

- *Tim Horn, Christopher Ledford*
  N.C. State University

The ITER fusion research facility will employ twenty four, MW-class gyrotrons for electron cyclotron heating of the fusion plasma. Each of these gyrotron will require an RF load for commissioning and periodic maintenance and testing. These loads must dissipate more than 1 MW of long pulse / continuous RF power with less than 0.5% of the power reflected back into the transmission line. This program is investigating additive manufacturing to reduce the cost and improve the performance.

16.2 - Progress of the 0.346-THz BWOs with Double-Corrugated Waveguide Structure

- *Ye Tang, Xingwang Bian, Lin Zhang, Ying Li, Qiru Lu, Pan Pan, Jun Cai, Jinjun Feng*
  Beijing Vacuum Electronic Research Institute and Vacuum Electronics National Lab

- *Yuan Zheng, Logan Himes, Michelle Gonzalez, Neville C. Luhmann Jr*
  University of California

- *Rosa Letizia*
  University of Lancaster

- *Diana Gamzina*
  SLAC National Acceleration Laboratory

- *Claudio Paoloni*
  Lancaster University

  The 0.346THz back-ward wave oscillator (BWO) is proposed for a source for fusion plasma diagnostics. The progress of a joint international effort devoted to the realization of novel backward-wave oscillators at 0.346THz and above with output power in the 1W range is reported herein.

16.3 - A Vacuum Window Based on Metamaterial

- *Jingxuan Shen, Ningfeng Bai, Changsheng Shen, Xiaohan Sun*
  Southeast University

- *Pan Pan, Jun Cai, Jinjun Feng*
  Beijing Vacuum Electronics Institution

  This paper presented a vacuum window based on metamaterial. The vacuum window is designed at 94.95 GHz and the dielectric is sapphire piece with thickness at 0.4mm. In the cold-test simulations, the VSWR is 1.0029 at 94.95GHz and the bandwidth achieves 30 GHz with VSWR below 1.2.

16.4 - Research on Broadband High-Power Compact Oversized TE_{01} Hexa-Polar Waveguide Bend

- *Ding Li, Zewei Wu, Xiaoyi Liao, Yong Luo*
  University of Electronic Science and Technology of China

  This paper proposes a broadband compact and oversized TE01 hexa-polar waveguide bend in Ka-band. Due to the introducing of hexa-polar waveguide, the degeneration between the TE01 mode and TM11 mode is destroyed. The influence of the relative perturbation on the coupling capacity is analyzed and the waveguide bend is designed based on the analysis results. The results prove that it achieves a transmission bandwidth with 9.6 GHz at the 95% level for TE01 mode (relative bandwidth is over 30%).

16.5 - Design of A High-Order TE32 Mode Converter Operating at the Terahertz Band

- *Weijie Wang, Yue Wang, Kaiwen Zhou, Guo Liu, Wei Jiang, Zewei Wu, Jianxun Wang, Yong Luo*
  UESTC

  A methodology to excite the circular TE32 mode is proposed in this paper. This topology can also be used to excite other high-order modes. This TE32 mode converter will be used in ceramic testing for a high-order mode gyrotron-traveling-wave-tube. The simulation results show the

S21 and S11 are over -0.4 dB and less than -14 dB respectively within 214-224 GHz. The transmission S21 of the unwanded TE31, TE12 and TE51 modes are below -18 dB, -14 dB and -15 dB, respectively. Simulation results show this TE32 mode converter has excellent transmission performance and high mode purity (?94%).

Session 17:
Microfabrication & THz II

Chair: Richard Kowalczyk, L-3 Communications Electron Devices

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17.1 - Design and Test of Copper Printed RF Cavities

- *Christopher Nantista, Diana Gamzina*
  SLAC National Accelerator Laboratory

- *Christopher Ledford, Timothy Horn*
  North Carolina State University

- *Paul Carriere, Pedro Frigola*
  Radiabeam Technologies

Additive manufacturing of high-quality copper using electron beam melting techniques has demonstrated significant progress for its suitability for production of vacuum electronics components. Additively manufactured low oxygen level copper wafers, as printed and annealed, have been tested in a hemispherical cavity for accurate surface resistivity measurements. Strings of coupled cavities for S-band and X-band travelling wave tubes have been designed for vertical additive manufacturing in powder bed systems enabling significant cost reduction. The RF cavity string design have been additively manufactured, processed, and RF tested.

17.2 - Design of a 693-GHz Folded-Waveguide Traveling-Wave Tube Amplifier

- *Mudit Pasagadagula, Anshul Chandel, Jagadishwar R. Sirigiri*
  Bridge12 Technologies, Inc.

- *Yuan Zheng, Neville C. Luhmann, Jr.*
  University of Calufornia, Davis

We present the design of a 693 GHz, 50 mW folded waveguide traveling-wave tube (FWTWT) amplifier with a round beam for application in plasma diagnostics in burning plasma experiments. The design of the circuit, electron beam transport system, and the vacuum windows are carried out with theoretical analysis followed by numerical simulations. Simulation results show a maximum power output of 140 mW and a maximum gain of 26 dB. Simulations predict a 3 dB circuit bandwidth of 40 GHz.

17.3 - Design and Microfabrication of a Double Corrugated Waveguide for G-Band TWTs

- *Rupa Basu, Laxma R. Billa, Jeevan M. Rao, Nicholas Renninson, Benjamin Rodgers, Rosa Letizia, Claudio Paoloni*
  Lancaster University

- *Logan Himes, Yuan Zheng, Neville C. Luhmann*
  University of California Davis

- *Diana Gamzina*
  SLAC National Accelerator Laboratory

A G-band (210 – 250 GHz) Traveling Wave Tube (TWT) is in the fabrication stage. The TWT specifications are gain in the range 30 - 40 dB with more than 1 W output power. The double corrugated waveguide is chosen as the slow wave structure for the relatively easy fabrication. The TWT is based on a single SWS section, instead of the typical configuration with two sections separated by a sever typical at microwave frequency. The short wavelength at G-band determines the size of the parts to be less than 100 microns. The design and the fabrication had to be harmonised to achieve a high precision fabrication. A high end Computer Numerically Controlled milling machine was used. The fabrication result confirms the capabilities of the fabrication process.

17.4 - Efficient Regime of Hybrid Surface-Radiating Waves in a THz Clinotron

- *Eduard Khutoryan*
  O. Ya. Usikov Institute for Radiophysics and Electronics of NAS of Ukraine & University of Fukui

- *Sergey Ponomarenko, Sergey Kishko, Konstantin Lukin, Alexei Kuleshov*
  O. Ya. Usikov Institute for Radiophysics and Electronics of NAS of Ukraine

- *Yoshinori Tatematsu, Seitaro Mitsudo, Masahiko Tani*
  Research Center for Development of Far-Infrared Region

Peculiarities of a THz non-resonant clinotron in a regime of surface-radiating backward wave arising due to periodically modified grating have been presented. The simulation results demonstrate that the feedback and efficiency of the radiation output of the proposed regime is much higher in comparison with conventional surface wave clinotron in a THz range.

17.5 - A Novel Waveguide-Loaded Scheme for Oscillation Suppression of Sheet Beam Traveling-Wave Tube

- *Yixin Wan, Jianxun Wang, Zeng Liu, Zewei Wu, Wei Jinag*
  University of Electronic Science and Technology of China

  Oscillations are known to be one of the most critical problem in the design of high power traveling-wave tubes (TWTs). In this paper, a novel waveguide-loaded scheme for high order mode oscillation suppression of sheet beam traveling-wave tube is proposed. By loading the transverse staggered waveguides selected on both sides of the interaction circuit, the high-order oscillation mode is significantly suppressed. The simulation demonstrates the possibility of this novel scheme for sheet beam TWT design in G band. This scheme offers a new approach to solve oscillation problems of TWTs.

Session 18:
Thermionic Cathodes

Chair: Max Mankin

18.1 - Investigations into the Physics of Miram Curves - keynote

- *John J Petillo, Serguei Ovtchinnikov, David P Chernin*
  Leidos

- *Dongzheng Chen, John Booske, Ryan Jacobs, Dane Morgan*
  University of Wisconsin

- *Abhijit Jassem, Yue Ying Lau*
  University of Michigan

  We report on new findings and the identification of the physics that determine the shape of the Miram Curve for electron emission from cathodes. The Miram curve for a specific cathode surface describes the normalized current density as a function of cathode temperature. Understanding this curve is key to predicting the performance vs. lifetime of many electron gun sources. Since the cathode lifetime decreases rapidly with increased operating temperature, the electron gun in many practical devices is operated at a temperature just over the onset of space-charge-limited emission in the Miram curve. We have made significant progress toward understanding the shape of the Miram curve through theoretically-based studies combined with simulation using the MICHELLE code, including simulations based on microscopic work function sampling of the surface. These findings shed new light on the primary mechanisms that determine the Miram curve shape in terms of the work function makeup of the surface.

18.2 - First-Principles Model of Miram Curve from Polycrystalline Tungsten Cathodes

- *Dongzheng Chen, Ryan Jacobs, Dane Morgan, John Booske*
  University of Wisconsin-Madison

Previously, we constructed a first-principles statistical model to predict the non-uniform emission from polycrystalline tungsten cathodes, which incorporated microstructure characterization results, crystallographic-orientation-specific work function values via density functional theory (DFT), and temperature-limited (TL) emission physics. This previous model could only predict the TL region of the Miram curve and not the transition between TL and full-space-charge-limited (FSCL) regions. In this work, we have expanded our model to predict emission along the entire Miram curve, including the transition from TL to FSCL regions, without any empirical assumptions on work function distribution or empirical emission equations. This more advanced model provides a pathway to understanding the complex physics of emission from heterogeneous cathode surfaces, which is a key issue for the commercial production and use of thermionic cathodes in vacuum electronic devices.

18.3 - Searching for Low Work Function Perovskite Oxides using Density Functional Theory

- *Tianyu Ma, Ryan Jacobs, Dane Morgan, John Booske*
  University of Wisconsin-Madison

The work function is a crucial parameter for electron emitters used in vacuum electronic devices as lower function allows higher current density and/or lower operating temperature. Perovskite oxides are a novel class of materials for potential use in electron emission applications due to their tunable work functions, robust stability, and good electronic conductivity. In this work, we performed a high-throughput screening based on Density Functional Theory (DFT) simulations and predicted BaMoO3 to be promising emitter materials with low work function, good stability and high electronic conductivity. Our work also provides a general materials design principle governing the work function of perovskites, which is that perovskites with nearly empty electronic d-bands have the lowest work functions.

18.4 - Experimental Investigation of Bulk and Thin Film Perovskite $SrVO_3$ as a Thermionic Cathode Material

- *Lin Lin, Ryan Jacobs, Samuel D. Marks, Paul G. Evans, Dane Morgan, John Booske*
  University of Wisconsin-Madison

First-principles calculations based on Density Functional Theory (DFT) previously revealed that perovskite SrVO3 is a promising candidate for thermionic emission applications. In this work, polycrystalline bulk and epitaxial thin film SrVO3 samples have been experimentally examined. Both bulk and epitaxial SrVO3 can exhibit low work function, consistent with DFT calculations and corresponding promising thermionic emission behavior. SrVO3 is a potentially good thermionic emitter material and points more broadly to perovskite materials as a family of compounds which may further the development of next-generation thermionic electron emitters.

18.5 - Long Lifetime Oxide Cathode for HIRFL-CSR Electron Cooler

- *Xiaoxia Wang, Shui Zhang, Xingqi Wang, Qinglan Zhao, Yun Li*
  Institute of Electronics, Chinese Academy of Sciences

In this paper the characteristic of a type of oxide cathode for HIRFL-CSR electron cooler is discussed, which includes the measurement of the DC emission current density and the lifetime of the cathode. The results show that the cathode has good emission uniformity with 0.5 A/cm2 at 700C ~ 800C and its actual service lifetime is over 25000 hours.

Session 19:
Modeling: TWTs

Chair: Filippo Capolino, University of California, Irvine

19.1 - Adjoint Approach to Optimization and Sensitivity Analysis of Beam Wave Interaction in Vacuum Electronic Devices - keynote

- *Alexander N. Vlasov, Igor A. Chernyavskiy*
  Naval Research Laboratory

- *Thomas M. Antonsen, Jr., David P. Chernin*
  Leidos Inc.

We demonstrate a new approach to optimization and sensitivity analysis of beam-wave interaction in any vacuum electronic device (VED) that consists of a circuit interacting with a linear beam through a series of gaps. The basis of the method is a consequence of the Hamiltonian form of the equations that govern the beam-wave interaction, which implies the conservation of symplectic area for two perturbed solutions. Using this property of the system we have derived a relationship between the perturbed solution and an adjoint solution to the linearized equations. We show that proper selection of the adjoint solution allows obtaining compact symplectic equations. Consequently when the adjoint solution is obtained using a simulation code, it may be used to evaluate the multi-dimensional derivatives needed for efficient optimization and for sensitivity analysis. For sensitivity analysis the single adjoint solution allows to construct a sensitivity function which acts like a Green's function for many variable parameters of the system. The approach applies to small or large signal operation of standing and traveling wave devices using either single or multiple beams.

19.2 - Progress with DIMOHA for Fast Time-Domain Simulations of Traveling-Wave Tubes

- *Frederic Andre, Damien Minenna*
  Thales AVS

- *Khalil Aliane, Jerome Puech*
  Centre National d'Etudes Spatiales

- *Yves Elskens, Alexandre Poye, Fabrice Doveil*
  Aix-Marseille University

We presented at previous IVEC conferences a new model for traveling-wave tubes (TWTs). Since then, we used this model to build the DIMOHA algorithm as an alternative to current particle-in-cell (PIC) and frequency domain codes. Its validity is assessed against these codes and against measurements from several TWTs. We present simulations for an 80 watts TWT in Q band presently in development. An industrial version of DIMOHA is under construction for the design and characterization of TWTs.

19.3 - Stability Analysis of VE Amplifiers Based on Determinant Equations

- *Vadim J. Jabotinski, Thomas M. Antonsen, Jr.*
  Leidos

- *Alexander N. Vlasov, Igor A. Chernyavskiy*
  Naval Research Laboratory

A general method for calculating self-excitation thresholds for a large class of standing and traveling wave structures used in klystrons, traveling wave tubes, and other vacuum-electronic devices is presented. We determine circuit parameters of RF structures that are changed due to the presence of electron beam, and analyze stability of the obtained matrices. Determinant equations defined by such stability matrices are derived. The use of the method for structures with round and arbitrary geometry beam tunnels is discussed. Analytical stability evaluation described here greatly complements the large signal beam-wave interaction CHRISTINE and TESLA family codes as well as EM PIC codes such as NEPTUNE.

19.4 - Analysis of Power Holes in Helix Traveling-Wave Tubes with Non-Uniform Delay-Lines

- *Moritz Hägermann, Michael Wulff, Arne F. Jacob*
  Hamburg University of Technology

- *Philip Birtel*
  Thales Deutschland GmbH, Electron Devices

The influence of non-uniform delay lines on the parasitic effect of power holes in helix traveling-wave tubes is investigated. For the analysis, we introduce a helix geometry which favors power hole occurrence. The harmonic backward-wave is assumed to be excited through output-coupler mismatch. Whereas homogeneous delay lines can only cause a single power hole, the

analysis shows that tapered helices may lead to multiple gain dips at different frequencies where each power hole can be assigned to a section of the delay line.

19.5 - Pierce Theory for the Traveling-Plasma-Wave Amplifier

- *David Smithe*
  Tech-X Corporation

- *John Albrecht, Matt Hodek*
  Michigan State University

In a traditional TWT, the beam velocity and slow-wave-structure are synchronized to the same speed, while space charge effects are a small correction, which appear as the so-called QC (space charge) parameter in Pierce's analysis. In this paper, we look at a complementary device, where space charge effects dominate, and the beam velocity is a small correction. The space charge effects produce a traveling plasma wave, which for solid-state two-dimensional gas (2DEG) densities, can be an appreciable fraction of the speed of light, and thus can synchronize with the wave on a slow-wave-structure. The drift velocity in solid state is orders of magnitude slower, and so is a small correction, but it can still provide an energy reservoir for amplification. Pierce analysis carries forward in the usual manner, however synchronization is via the 2DEG QC term, rather than the drift term. One finds that wave hybridization occurs, with a growing mode, as in a conventional TWTA. But since a solid state beam is involved, collisional drag and diffusion effects must also be added to the usual Pierce analysis, and so then the question is whether the gain can exceed the drag. We develop a design spreadsheet, and using the physical characteristics of a high electron mobility (HEMT) 2DEG layer, show that gain should indeed be possible.

19.6 - Design Method of Focusing Magnetic Field for Restraining Dynamic Defocusing of High Efficiency TWT

- *Jiahui Fan, Quan Hu, Yulu Hu, Xiaofang Zhu, Bin Li, Tao Huang, Xiaolin Jin, Li Xu*
  University of Electronic Science and Technology of China

In order to suppress the dynamic defocusing problem of the electron beam that often occurs in high-efficiency space TWT, this paper provides an effective focusing magnetic field design method and takes a traveling wave tube of a certain band as an example to introduce and explain. Under the premise of not affecting other working indexes, the focusing magnetic field designed by this method effectively suppresses its dynamic defocusing problem.

Session 20:
TWTs

20.1 - A Large Bandwidth Double-layer Asymmetric Planar Microstrip Line Ka Band Traveling Wave Tube

- *Wenchen Xiang, Ningfeng Bai, Xiaohan Sun*
  Southeast University

- *Pan Pan, Jun Cai, Jinjun Feng*
  Beijing Vacuum Electronics Institution

- *Yang Xie, Wei Hong*
  Nanjing University of Science and Technology

We present a double-layer asymmetric microstrip line slow wave structure (ADL MML-SWS) amplifies dual band signals at Ka-band this paper. This ADL MML-SWS has two signals at the same time, which can be excited by two electron beams. The center frequency of the low-band signal is 30 GHz and the center of high-band signal is 38 GHz. At 30GHz, the output power is 28.125w, with a gain of 37.5dB, and at 38GHz, the output power is 30.03w, with a gain of 37.8dB. The structure has a wide bandwidth, covering the entire Ka-band of 27GHz-42GHz, and the gain in the entire band is nearly constant, varies in 2 dB.

20.2 - A Thermal Analysis Method for Dielectric Supported Ring-bar Meander Line Slow Wave Structure

- *Yang Dong, Hexin Wang, Zijun Chen, Zhanliang Wang, Zhigang Lu, Huarong Gong, Zhaoyun Duan, Yubin Gong*
  University of Electronic Science and Technology of China

- *Shaomeng Wang*
  Nanyang Technological University

The thermal characteristics are important for the proper operation of the high-power traveling wave tube (TWT). And they are affected by internal thermal losses, which mainly come from high-frequency loss and electron interception loss. The high-frequency loss can be calculated by setting the material of the slow wave structure (SWS) as PEC and lossy, respectively, and combining the power flow curve. Taking the thermal loss as heat source and processing the SWS in sections, the temperature distribution of the SWS can be obtained by thermal simulation, in which the thermal contact conductance has a greater influence on the maximum temperature.

20.3 - Collector Efficiency Enhancement in TWTs through Beam-Refocusing Section

- *A. Mercy Latha, S.K. Ghosh*
  CSIR-CEERI

- *Vishant Gahlaut*
  Banasthali University

  Travelling wave tubes are generally known for their broadband operation, high gain and high efficiency of ~60%. Typically, such high efficient TWTs are highly desirable for space applications in satellite transponder. The overall efficiency of the TWT is increased by increasing any of its constituent – electronic, circuit or collector. Collector efficiency enhancement is an easier and effective way of increasing the overall efficiency. Here, to increase the collector efficiency, optimization of the magnetic field profile in beam refocusing section (BRS) has been performed. The percentage magnetization of the three periodic permanent magnets (PPM) in the BRS section has been changed to maximize the collector efficiency. The corresponding collector potential optimizations have been performed using genetic algorithm and the results have been compared with the ones obtained by manual optimization.

20.4 - Design of Ka-Band High-Power TWT

- *Zhixin Yang, Qi Wang, Zugen Guo, Rujing Ji, Yubin Gong, Huarong Gong*
  University of Electronic Science and Technology of China

  A Ka-band traveling wave tube (TWT) with an output power above 5kw, an electronic efficiency above 10% in the bandwidth of 33-37GHz was designed. The structure of slow wave adopts folded waveguide. The folded waveguide TWT has a saturated gain of 43.5dB, peak power of 6.7kW and electronic efficiency of 10.54% at 35GHz. We also have designed the electronic optical system, simulation results show the electron gun voltage is 28Kv, and transmitted beam current is 2.54A.

Session 21:
Gyrotrons

Chair: Lawrence Ives

21.1 - Frequency Tuning and Spectrum Control in Sub-THz Gyrotrons - keynote

- *Mikhail Glyavin, Gregory Denisov, Alexey Fedotov, Andrey Fokin, Irina Zotova, Alexander Bogdashov*
  Insitute of Applied Physics RAS

  We present the results of recent IAP RAS investigations, which were aimed at controlling the radiation frequency and spectrum of sub-THz medium power gyrotrons. Different methods of extending the smooth frequency tuning band and providing high frequency stability in CW regimes are discussed. The development of gyrotrons with stated parameters are of interest for many modern applications, including DNP/NMR and RAD spectroscopy, direct measurements of positronium hyperfine structure, diagnostic of various media, etc.

21.2 - The Simulation and Design of a 0.68-THz Second Harmonic Gyrotron

- *Wei Sun*
  China Key System&Integrated Circuit Co. Ltd

- *Weihua Ge, Zhipeng Wang, sheng yu*
  Univesity of electronic science and technology of Chna

The gyrotron is one of the most promising sources to generate powerful radiation with high efficiency in THz band. Recently, a THz detection system is under development in the terahertz research center of UESTC. In order to satisfy the requirement of the source for the system, a 0.68 THz second harmonic gyrotron has been designed and simulated through the linear and nonlinear theories. The designed gyrotron is also tested experimentally in the center. The experiment results indicate that the measured output power is 2.75kW with the efficiency of 9.05%. The corresponding frequency is 0.679THz.

21.3 - Mechanical Design Study for Gyrotron E×B Drift Two-Stage Depressed Collector

- *Benjamin Ell, Ioannis Gr. Pagonakis, Chuanren Wu, David Albert, Gerd Gantenbein, Stefan Illy, Thorsten Kobarg, Tomasz Rzesnicki, Manfred Thumm, John Jelonnek*
  Karlsruhe Institute of Technology (KIT)

The key for a significant increase of the gyrotron efficiency is the development of an efficient multistage depressed collector (MDC) for the annular spent electron beam. During the past years, many different design approaches based on E×B drift concept have been theoretically investigated at KIT. The next step towards the experimental validation of such an MDC is the development of a prototype. The complexity of the mechanical design of the MDC is strongly dependent on the size of the electrodes, the manufacturing possibilities of individual parts, the electric field distribution, etc. Considering all those factors, an MDC system has been optimized in order to significantly reduce the manufacturing complexity of the prototype. As a result, a significant smaller and simpler conceptual design for the MDC system is presented.

21.4 - Secondary Electron Simulations of a Gyrotron Collector with Magnetic Sweeping and Voltage Depression

- *Stephen Cauffman, Monica Blank, Philipp Borchard, Kevin Felch*
  CPI

Megawatt-class gyrotrons are designed to distribute the residual electron beam energy across a large collecting surface, to keep power densities low enough to be dissipated without threatening long-term vacuum integrity. Because the incident beam is very narrow, various

techniques are used to lower the instantaneous and time-averaged power densities on the collector surface, while keeping the size of the collector within the limits of current fabrication capabilities. Gyrotron collector design typically focuses on optimizing the power deposition of the incident ("primary") beam. It is often assumed that the effects of secondary electron emission from the collector surface (whether due to reflection of primaries, or true secondary emission) will tend to further spread the power density profile. Such additional spreading can be beneficial if it lowers peak power densities, but can be detrimental if it deposits power in undesired locations or sends particles back toward the gyrotron's interaction region. Here, we simulate the effects of secondary/reflected electrons in the VGT-8115, a 110 GHz, 1.2 MW, 10-second gyrotron used for electron cyclotron heating and current drive in the DIII-D tokamak. We examine the ramifications of secondary emission under various operating conditions, such as variations in collector sweeping parameters and collector depression voltage, comparing power densities and particle trajectories with and without secondaries.

21.6 - An Improved Design for High-power Coaxial-cavity Gyrotron with Misaligned Insert

- *Shan Zhang, Qianzhong Xue*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy of Sciences

  The misalignment of insert would cause frequency shift, decrease in interaction efficiency and uneven ohmic loss distribution on the cavity walls which would affect the long pulse of gyrotron. The structure of gyrotron cavity has been optimized in our recent study to reduce the effect of misaligned insert. As the misaligned distance increases, the effects become larger. In this paper, the dependence of output characters on guiding center radius is investigated and an optimal guiding center radius is chosen to reduce the effect of misaligned insert.

Poster Sessions

Poster Session
High Power Microwaves

Chair: David Abe, DARPA

Co-Chair: Dev Palmer, Lockheed Martin Advanced Technology Labs

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P5.1 - Development of Composites for Nonlinear Transmission Lines

- *Travis D. Crawford, Andrew J. Fairbanks, Xiaojun Zhu, Julio A. Hernandez, Tyler N. Tallman, Allen L. Garner*
  Purdue University

Nonlinear transmission lines (NLTLs) offer a robust, solid state solution for generating high power microwaves (HPM). NLTLs use nonlinear dielectric and/or magnetic materials whose permittivity and permeability, vary with voltage and current, respectively, to modulate a delivered pulse and generate RF. Materials such as barium strontium titanite (BST) and nickel zinc ferrites (NZF) are used for their nonlinear dielectric and magnetic properties, respectively. This study examines the development of composites containing various volume loads of BST, NZF, or combined loadings to tune dielectric and magnetic properties. It was found that by increasing the volume fraction of BST, one can effectively increase the permittivity of a bulk sample. Similarly, by increasing the volume loading of NZF, a samples permeability can also be increased. These results are promising for the development of tunable NLTLs.

P5.2 - Predicting Effective Dielectric Properties of Composites for Nonlinear Transmission Lines Using Effective Medium Theories and CST Microwave Studios

- *Xiaojun Zhu, Andrew J. Fairbanks, Travis D. Crawford, Allen L. Garner*
  Purdue University

We present computational and theoretical assessments on the effective dielectric properties of the nonlinear composites comprised of ferroelectric ceramic inclusions (barium strontium titanate (BST)) and/or ferromagnetic inclusions (nickel zinc ferrite (NZF)) in a linear host to serve as materials for nonlinear transmission lines (NLTLs). We compare classical effective medium theories (EMTs) and computational models using CST Microwave Studio (CST MWS) to predict the dielectric and magnetic properties of the composites in the linear region to measurements. The composite models in CST MWS agree well with measurements and the Lichtenecker rule for NZF composites, while classical EMTs generally fail to estimate effective properties for the cases with high volume loadings and strong dielectric contrast.

P5.3 - Design of a Compact and High-Efficiency Metamaterial Extended Interaction Oscillator

- *Xin Wang, Hengyu Luo, Xuanming Zhang, Tao Tang, Zhanliang Wang, Huarong Gong, Yubin Gong, Zhaoyun Duan*
  University of Electronic Science and Technology of China

- *B.N. Basu*
  Supreme Knowledge Foundation Group of Institutions

In this paper, a highly efficient and compact metamaterial (MTM) extended interaction oscillator (MEIO) is designed and investigated. The power exchange function of the multi-gap of ? mode is discussed. Furthermore, a 5-gap MEIO with is designed and optimized, the diameter of the cavity is only 37 mm at S-band. The PIC simulation results show that the peak output power is about 10 MW, and electronic efficiency up to 48% at 2.866 GHz when the beam voltage and current are 130 kV, 80 A as well as the magnetic field is 0.2 T. It indicates that the proposed

MEIO can be used as MW-level microwave source with miniaturization and high efficiency for accelerators.

P5.4 - High Power Microwave Measurement Techniques at CEA-Gramat

- *Antoine Chauloux, Jean-Christophe Diot, Nicolas Ribière-Tharaud, Jérémy Pothée*
  CEA-Gramat

High power microwave (HPM) measurement remains a challenging application since it requires accurate sensors with high power handling. Electromagnetic (EM) fields can reach dramatically high magnitudes such as MV per meter. If no particular attention is paid when designing a sensor for HPM measurements, electrical breakdowns may appear. This leads to irreversible damages and non-accurate results. Through the HPM developments achieved at CEA-Gramat various techniques have raised for the diagnostic of EM fields patterns and microwave power levels delivered by relativistic sources. Three are here introduced: EM field measurement with in-situ calibration; a waveguide integrated coupler to determine output powers of microwave sources; a photothermal film to observe the EM field.

P5.5 - Enhancing the Intensity of High-Power Microwaves by Using a Cone Reflector

- *Sohail Mumtaz, Eun Ha Choi*
  Kwangwoon University

In this study, the collection of the microwaves was enhanced by using a cone reflector inside the drift tube. The inner diameter 13 cm of the reflector was selected for the experiment based on the simulation results. The power intensity of the microwave was 540 MW without reflector which is increased to 830 MW with reflector. The obtained results show that the collection of HPMs was increased up to 53 %. The dominant mode was found to be TM01.

P5.6 - Focusing the High-Power Microwave with a Ring-Shaped Zone Plate

- *Sohail Mumtaz, Eun Ha Choi*
  Kwangwoon University

We investigate an axial virtual cathode oscillator in our pulse power generator, chundoong (Max 600 kV, 88 kA, 60 ns). A ring-type zone plate was designed based on the dominant frequency of 3.50 GHz to focus the emitted high-power microwave at a desired focal point. The focal length of the zone plate was 18.8 cm for the dominant frequency. The maximum collected power without zone plate was measured to be 0.66 GW which enhanced significantly up to 1.22 GW at an optimized point by focusing the microwave with a zone plate.

P5.7 - Design Analysis of a Tunable Tapered Metallic Baffle TM_{01} to TE_{11} HPM Mode Converter

- *Vikram Kumar*
  Sri Venkateswara College of Engineering & Technology

- *Pradip Kumar Jain*
  National Institute of Technology Patna & IIT (BHU) Varanasi

Tapered metallic baffle mode converter for TM01 to TE11 mode has been presented. Using a triangular axially movable baffle, frequency tuning has been acheived. Conversion efficiency more than 98% at 2 GHz whereas more than 93% at 2.32 GHz, has been achieved and this enables to choose the mode converter frequency of operation accordingly. Mode converter RF beam stability has also been improved by adding a coaxial section at its output end. The proposed mode converter is an all metal structure, light in weight, higher in return loss, stable output beam and with frequency tunability feature; suitable for HPM system application.

P5.8 - Power Capabilities of Vircators: A Comparison between Simulations, Experiments, and Theory

- *Ernesto Neira, Felix Vega, Chaouki Kasmi, Fahad AlYafei*
  Technology and Innovation Institute

Maximum power that can be radiated by an Axially Extracted Vircators is calculated using a mathematical model. The established limits are compared against the results of experiments and simulations available in the literature.

P5.9 - Particle in Cell Simulation of Axial Vircator to Develop Second Virtual Cathode

- *Sohail Mumtaz, Eun Ha Choi*
  Kwangwoon University

In this study, a particle-in-cell simulation was carried out on an axial virtual cathode oscillator by using MAGIC. A second virtual cathode was formulated by using the escaping electrons as a wall charge accumulated at the floating zone plate inside the drift tube downstream region. The charge of a second virtual cathode interacts with electromagnetic wave generated from the conventional virtual cathode to amplify its magnitude and the output power increases from 152 MW to 650 MW.

P5.10 - Power and Efficiency Enhancement of the Reltron Using Dual RF Output Cavities

- *Garima Dubey, Manpuran Mahto, P. K. Jain*
  National Institute of Technology Patna

  In this paper, a dual RF output cavity based reltron is proposed to enhance the efficiency as well RF output power. It uses two RF output cavities of different quality factor. The quality factor of the first output cavity kept low whereas the quality factor of the second output cavity is kept higher. The output cavity with low quality factor extracts maximum RF output power whereas the second output cavity with has higher quality factor extracts remaining output power. With typically selected electrical parameters, the proposed reltron delivers ~ 270 MW output power with ~ 42.4% efficiency. The obtained results show the improvement in the device performance in terms of RF output power as well as efficiency as compared to the conventional reltron.

P5.11 - Design of the Quasi-Optical Transmission Line for Millimeter Wave Deep Drilling

- *Lina Wang, Xinjian Niu, Jianwei Liu, Qiao Liu, Shuang Chen*
  University of Electronic Science and Technology of China

- *Liwei Wang*
  Beijing Jiaotong University

  A 45GHz quasi-optical transmission line with three quasi-optical mirrors for millimeter wave deep drilling is designed and experimental tested. Based on the technique of Gaussian beam transformation, the proposed optical transmission line, which consists of three mirrors, is investigated and optimized by vector analysis of the fields on mirror surfaces. The synthesis method has been verified to transfer the electromagnetic wave from the MOU to the specified position of the sample to be heat. The numerical results show that the power transmission efficiency is over 95%. The experimental results demonstrate the output pattern at the position of rock is a good agreement with the desired fundamental Gaussian mode and the output power density of 1.65 kW/cm2 at the heated rock surface meets the preliminary requirements to melt the rock.

Poster Session
Microfab/THz

P6.2 - A Terahertz Phase Shifter Based on Liquid-Crystal Material

- *Jun Qing Wang, Jin Xin Shi, Shuang Chen*
  University of Electronic Science and Technology of China

  This paper introduces the design of a terahertz band phase shifter with SPPs structure and liquid crystal (LC) material. The phase shifter is composed of a carrier and a substrate, which are sandwiched with a metal surface grating and a liquid crystal dielectric layer. Its anisotropy will be changed under bias or no bias,thus the phase shift can be realized. We use nematic liquid

crystal materials with ??=?2.46, tan??=?0.02, ???=?3.26, and tan ??=?0.03. The substrate is composed of 50 um thick quartz plate. The thickness of liquid crystal layer is 80um. The phase shifter model which operating in 0.30THz-0.325THz at 40V can be continuously tuned up to 107° with an insertion loss is between - 1.2db and - 1.6dB and the return loss is below -30dB

P6.3 - Dynamical Tunable Ultra-Wide Band Absorber with Metal-Graphene Metamaterial

- *Renbin Zhong, Yilin Lv, Chen Han, Long Yang*
  University of electronic science and technology of China

- *Yiqing Wang*
  University of electronic science and technology of China

By construction metal-graphene metamaterial with simple gold strips parallel or side-by-side arranged on a monolayer graphene as molecular cells, multi-band and ultra-broad band absorber can be achieved at mid-infrared frequencies. The extremely absorption bandwidth up to 11.8THz can be obtained, the intensity exceeds 90% at the absorption peak. Independently tunable multi-band and ultra-wide band absorber is also explored by stacking molecular cells with two or three layers. The results will benefit the integrated micro-structure research with flexible tunability, and the multilayer structure has potential applications in tunable filtering, sensing, cloaking objects and other multispectral devices.

P6.4 - T-shape Vane Slow-Wave Structure for 220 GHz Sheet Beam Traveling-wave Tubes

- *Yiliang Xu, Shengkun Jiang, Merdan Wulam, Xin Wang, Zhanliang Wang, Yubin Gong, Zhaoyun Duan*
  University of Electronic Science and Technology of China

In this paper, a T-shape vane slow-wave structure (SWS) for 220 GHz sheet beam traveling-wave tube (TWT) is proposed. The high frequency characteristics and transmission characteristics of T-shape vane SWS are analyzed by using HFSS and CST. The results indicate that the interaction impedance has improved about 5% than rectangular vane at 220 GHz, and the reflection coefficient S11 is below -15 dB and the transmission coefficient S21 is greater than -5 dB at the frequency range from 213 GHz to 230 GHz.

P6.5 - Three-stage Depressed Collector for 220 GHz Sheet Beam Traveling-wave Tubes

- *Merdan Wulam, Shengkun Jiang, Yiliang Xu, Huarong Gong, Yubin Gong, Zhaoyun Duan*
  University of Electronic Science and Technology of China

In this paper, a three-stage depressed collector suitable for 220 GHz sheet beam slow-wave structure (SWS) is studied. The condition of spent sheet beam is analyzed by using the CST Particle Studio. The position distribution and velocity distribution of the sheet beam are also obtained. Based on the analysis of the sheet beam at the entrance of the collector and the characteristics of the sheet beam after the interaction of 220 GHz sheet beam traveling-wave tube (TWT), an efficient and low back streaming current three-stage depressed collector with the rectangular inlet and elliptical cavity shape is designed. The collector efficiency is 90% and the back streaming current is 1.6 mA, which is accounting for 1% of the sheet beam current are achieved. This article is believed to provide some guidance for the design of multistage depressed collector of G-band sheet beam TWT.

P6.6 - Study of a Terahertz TE17.4 Mode Transition

- *Ling GU*
  Southwest Minzu University

- *yinghui LIU, Qiao LIU*
  University of electronic science and technology of china

The taper as a transition matching device is widely used in electronic vacuum devices, it is required have high transmission efficiency, low reflection and structure matching well. In this paper, based on the gradual waveguide mode coupling theory, the radius of conical tapers with a gradual change from 9 mm to 10mm, the transmission mode is TE17.4 and the operating frequency is 420GHz. The optimal geometry parameters and operating parameters of several tapers of different profile curve be obtained by software optimization, and a comparison is done between these tapers. The study found that the taper using the new structure have high efficiency of the transmission, shorter length, wide bandwidth, and meets the application well.

P6.7 - Circuit Design and Simulation of a 0.85-THz Regenerative Feedback Oscillator

- *Tianyi Li, Pan Pan, Dong Li, Weisi Meng, Jun Cai, Jinjun Feng, Tiechang Yan*
  Beijing Vacuum Electronics Research Institute

A 0.85 THz regenerative feedback oscillator is proposed as a compact and frequency-tunable source. The circuit design and simulation is presented including both the folded waveguide slow wave structure and the feedback circuit. The bandwidth of the circuit is over 70 GHz and the output power is over 200 mW. The circuit is being fabricated using UV-LIGA micromachining process.

P6.8 - Studies on Millimeter-Band Low-Voltage Traveling-Wave Tubes with Planar Meander-Line Slow-Wave Structures

- *Andrei V Starodubov, Anton Pavlov, Viktor Galushka, Alexey Serdobintsev, Ilya Kozhevnikov*
  Saratov State University

- *Roman Torgashov, Andrey Rozhnev, Nikita M Ryskin*
  Saratov Branch, Institute of Radio Engineering and Electronics RAS

- *Dmitry A. Bessonov*
  Saratov State Technical University

- *Sergei Molchanov, Igor Bakhteev*
  Central Institute of Measurement Equipment, JSC CIME

- *Giacomo Ulisse, Viktor Krozer*
  Goethe University Frankfurt

  We present the results of studies aimed at development of compact, low-voltage traveling-wave tubes (TWTs) with meander-line slow wave structures (SWSs). W-band and D-band planar SWSs are designed, simulated, and fabricated. For the fabrication, we use the technology based on magnetron sputtering and laser ablation. Transmission and reflection losses of the developed SWSs were measured experimentally and evaluated numerically. The experimental results are in good agreement with the numerical ones. Small-signal and large-signal gain regimes of the TWT amplifiers with the meander-line SWSs are simulated by 1-D parametric frequency-domain code and verified by 3-D PIC simulation.

P6.9 - Concept and Design of the Terahertz Vacuum Electronic Amplifier Integrated on a Chip

- *Kaiwen Zhou, Bangrui Zhu, Weijie Wang, Yue Wang, Ding Li, Guo Liu, Jianxun Wang, Yong Luo*
  University of Electronic Science and Technology of China

- *Guoxiang Shu*
  Shenzhen University

  In this paper, the concept and design of the terahertz (THz) vacuum electronic amplifier (VEA) integrated on a chip is proposed. The THz VEA is driven by chip-scale cold cathodes and a cascade amplifier array (CAA). Based on the concept, an integrated travelling wave tube amplifier operating in the range of 200-500 GHz is designed. Particle-in-cell (PIC) simulation results show the integrated travelling wave tube produces a saturation output power of 2.76 W with a saturation gain of 23 dB at 400 GHz. The proposed concept paves a promising way for the VEA miniaturization and integration.

P6.10 - Design of G-band Folded Waveguide Traveling-wave Tube

- *Ping Han, Zugen Guo, Zhixin Yang, Rujing Ji, Ruifeng Zhang, Huarong Gong*
  University of Electronic Science and Technology of China

When it comes to the terahertz band, it is a challenging task to design traveling-wave tube. In this paper, the design of G-band folded waveguide traveling-wave tube (FWGTWT) is introduced in detail. The simulation results show that the folded waveguide circuit can produce over 27.5dB gain and over 15W output power within 10GHz bandwidth, when the beam current of the electron optical system (EOS) is 40 mA and the beam transmission rate is 100% with cathode voltage -19.25kV and the first anode -3kV.

P6.11 - The Smith-Purcell Radiation in the Grating-well Structure

- *Ping Zhang, Yilin Pan, Xiaosong Wang, Lang Wang, Yaxin Zhang, Lin Meng*
  University of Electronic Science and Technology of China

- *Amir Aimidula*
  Xinjiang University

- *Mingchun Tang*
  Chongqing University

The emergence of the fine micro-nano structure has advanced the development of traditional radiation. The periodical micro-nano structure can not only regulate the electromagnetic wave, but also have the potential to improve the intensity and directionality of radiation from moving electrons. We introduce the diaphragms in the grating structure to control the Smith-Purcell radiation intensity and directionality. Smith-Purcell can be seen as the radiation from the surface current, which is induced by the moving electrons. The simulation with the theory analysis shows that the diaphragms can not only enhance the intensity of the surface current, but also adjust the distribution of it. The changes of the radiation from the fine micro-nano structure demonstrated a more powerful way to control the radiation, and it is of significance in developing electron beam driven THz radiation source.

P6.12 - Research on New Grating Structure Based on 340GHz Super Smith-purcell Radiation

- *Guanyi Zhang, Zhenhua Wu, Jian Zhang, Min Hu, Renbin Zhong, Shenggang Liu*
  University of Electronic Science and Technology of China

In this paper, a new grating structure based on Smith-Purcell superradiation is studied. Smith-Purcell super-radiation is coherent Smith-Purcell radiation generated by free electrons swept over the surface of the grating. Its frequency is a multiple of the surface wave. In this paper, the structure and size of the grating were optimized through simulation. The terahertz wave at 340GHz was obtained under the electron beam of 15keV. Compared with the ordinary grating structure, it shortened the oscillation time and reduced the required current density. The

waveform is also more stable. The research in this paper is of great significance for the realization of compact, adjustable, high-frequency terahertz radiation sources.

P6.13 - THz Super-Radiant Smith-Purcell Radiation

- *Shaojie Chang, Min Hu, Zijie Xiong, Zhenhua Wu, Xiaoqiuyan Zhang, Kai Cui, Zhuocheng Zhang, Shenggang Liu*
  The Cooperative Innovation Center of Terahertz Science University of Electronic Science and Technology of China

We demonstrate a vacuum electronic device to realize terahertz super-radiant Smith-Purcell radiation. A flat grating structure was proposed and the dispersion relations was stimulating by CST. After optimization, the second space harmonic waves at 200GHz and the third space harmonic waves at 300GHz can be obtained at designed radiation angles with milliwatts output power. The experiment has been designed and is in progress. This work may be significant for realization of a miniature terahertz vacuum electronic radiation source.

P6.14 - Investigation on Smith-Purcell Radiation from Silicon Gratings

- *Zhaofu Chen, Xiaohan Sun*
  School of Electronic Science & Engineering, Southeast University

The Smith-Purcell radiation from silicon gratings is investigated, both theoretically and numerically. We use the waveguide-array theory, a simple but elegant analytical treatment, to solve the evanescent-to-propagating diffraction of silicon gratings. We show that the evanescent-to-propagating wave conversion efficiency of a silicon grating can be greatly improved when a high-Q resonance is obtained. The planar structure may enable a CMOS-compatible Terahertz source which is useful for many applications.

P6.15 - The Radiation of Two Dimension Dipole Oscillations in Subwavelength Hole Array

- *Xiaosong Wang, Ping Zhang, Deqiang Zhao, Yilin Pan, Liangjie Bi, Yin Yong, Bin Wang, Hailong Li, Xuesong Yuan, Lin Meng*
  University of Electronic Science and Technology of China

Smith-Purcell radiation is a kind of moving dipole oscillation radiation. In the subwavelength hole array, there are two-dimension dipole oscillations to happen when the e-beam is moving through the holes in a beam channel. It leads to the Smith-Purcell radiation energy enhanced, compared to one dipole oscillation in electron beam moving above period occurred metal surface. In addition, the dipole oscillation radiation takes place inside the hole, so the hole also plays a role to resonant the radiation so that the Smith-Purcell radiation has a good direction.

Therefore, the radiation of two-dimension dipole oscillations in subwavelength hole array form a kind of Smith-Purcell radiation with intensity enhanced and the radiation direction tuned. It has potential to develop the vacuum electrons device based on Smith-Purcell radiation, such as Orotron, on-table THz free electron laser.

P6.16 - 1 THz Trapezoidal Staggered Grating Traveling Wave Tube

- *Ruichao Yang, Jin Xu, Pengcheng Yin, Shuanzhu Fang, Gangxiong Wu, Xia Lei, Qian Li, Xuebin Jiang, Jinjing Luo, Lingna Yue, Hairong Yin, Guoqing Zhao, Wei Yang, Wenxiang Wang, Yanyu Wei*
  University of Electronic Science & Technology of China

- *Tianjun Ma, WenXn Liu*
  Institute of Electronics, Chinese Academy of Science

In this paper, the high frequency characteristics of Trapezoidal Staggered Grating Slow-wave Structure for 1THz Traveling Wave Tube has been studied. The transmission structure has been simulated, the reflection coefficient is less than -20dB in the frequency of 1015GHz to 1055GHz and the loss of the structure is over 58dB. The PIC simulation shows that the saturation output power is 405mW at the frequency of 1030GHz, and the corresponding gain is 19.08dB.

P6.17 - Thermal Cavity Calculation of 38-GHz Extended Interaction Oscillator

- *Jie Qing, Hua Zhen Wu, Hui Ying Liu*
  the Cooperative Innovation Center of Terahertz Science University of Electronic Science and Technology of China

Abstract: In this article, a cavity with a frequency of 38GHz is designed—a high frequency structure of 38GHz extended interaction oscillator. Through numerical calculation and computer simulation, the results of particle simulation is shown in this article. When the voltage is 20.4kV, the current is 1.35A, and the longitudinal magnetic field is 0.3t, the average output power is 9.3kW, and the energy conversion efficiency is 33.8%?This research is of great significance for the development of millimeter wave vacuum devices.

P6.18 - Influence of Self-Heating on Thermal Noise in Substrate-Biased Trigate-Junctionless-Transistor

- *Deepti Gola, Pramod Kumar Tiwari*
  Department of Electrical Engineering Indian Institute of Technology (IIT) Patna Bihta,

- *Balraj Singh*
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  This paper presents an insight into self-heating effect on thermal noise for trigate-junctionless-field-effect-transistor (TG-JL-FET). The channel thermal noise is correlated with the local device temperature which increases due to self-heat generation in a device. Low thermal conductivity of SiO2, used as buried oxide and gate oxide, is the main culprit causing self-heat in substrate-on-insulator based devices, like TG-JL-FET. Thus, it is shown in this paper that thermal noise behavior in TG-JL-FET deteriorates due to boost in lattice and electron temperature caused by self-heating. The three-dimensional TCAD based device simulator from Synopsys has been used to carry out the simulations for both self-heating and thermal noise in TG-JL-FET.

Poster Session
Modeling

P7.1 - Design and Modeling of a Microwave Plasma Enhanced Chemical Vapor Deposition System at 2.45 GHz

- *Yilang Jiang, Kaviya Aranganadin, Ming-Chieh Lin*
  Hanyang University

- *Hua-Yi Hsu*
  National Taipei University of Technology

  Solid thin films developed by a microwave plasma-enhanced chemical vapor deposition (MPECVD) system have excellent electrical properties, good substrate adhesion, and excellent step coverage. Due to these advantages, MPECVD films have been widely used in very large-scale integrated circuit technology, optoelectronic devices, MEMS and other fields. The MPECVD method is one of the promising candidates for synthetic CNTs due to low temperature and large area growth. Recently, this technique has gained popularity in graphene and diamond film fabrication. This paper discusses the design of an MPECVD chamber operated at 2.45 GHz of frequency using a finite element method (FEM) simulation. The design consists of a coaxial waveguide and a cylindrical chamber at the center connected using 4 identical slots in each direction. For the magnetic coupling, slots placed at the bottom of the central cavity. TM011 mode in the inner chamber is employed to generate the plasma at 2.45GHz. In addition, we discussed the effect of input power and gas pressure on plasma density in detail.

P7.2 - Thermal and Structural Analysis of Multi-stage Depressed Collector for G-band Traveling Wave Tubes

- *Yue Ou, WenXin Liu, LongLong Yang, Zhengyuan Zhao*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy of Science

  Multi-stage depressed collector (MDC) is used as an essential efficiency enhancement technique in traveling wave tubes (TWT), two-third of the total power consumption of TWT is dissipated in the collector. In this paper, thermal and defor-mation analysis of MDC in G-band are implemented by using ANSYS. Temperature distribution of the MDC at given power supply are fully simulated, meanwhile maximum defor-mations in MDC at different ambient temperature are carefully compared with. The simulated prediction is in agreement with the experimental results.

P7.3 - A Simulation Method to Determine the Assembly Distance between Cathode and Heater of Electron Gun

- *Jingyuan Che, Xiaofang Zhu, Yulu Hu, Quan Hu, Bin Li, Tao Huang, Xiaolin Jin, Li Xu*
  University of Electronic Science and Techology of China

  The assembly distance between cathode and heater has significant influence on the performance of electron gun of traveling wave tubes. This paper presents a simulation method to accurately determine this assembly distance. The simulation method uses ANSYS to simulate the working state of electron gun, and transfers the thermally deformed cathode and heater models into CST through the ANSYS geometry processing module SpaceClaim. Use the contact judgment function of CST to gradually move the heater to contact the cathode to measure the distance between cathode and heater. Adjust the model on the basis of measuring results and continue simulation process until the assembly distance which satisfies the assembly tolerance rate is obtained. This method can accurately measure the distance between cathode and heater after deformation, avoid damage of electron gun under working condition and effectively guide the assembly process of electron gun.

P7.4 - A Steady-State Theoretical Model Applicable to Solving Klystron Beam-Wave Interaction

- *Guang Luo, Yulu Hu, Xiaofang Zhu, Quan Hu, Tao Huang, Bin Li, Li Xu, Xiaolin Jin*
  University of Electronic Science and Technology of China

  This paper proposes a steady-state theoretical model for the klystron beam-wave interaction and develops the relevant code. First, the electron beam channel and the resonant cavity are expanded in a mode, and the equations satisfying the voltage and current of the electron beam channel and the resonant cavity in the steady state are derived, and then the corresponding field distribution is obtained for solving the electron motion equation. Taking an X-band klystron simulation design as an example, the calculation ability and effect of the program are tested. The results are comparable to the 3D PIC software, and the calculation efficiency is greatly

improved. The preliminary design and parameter optimization of the beam-wave interaction system.

P7.5 - Prototyping a Broadband Waveguide Circulator Centered at 2.45 GHz Using 3D Printing

- *Shijun Mi , Kaviya Aranganadin, Ming-Chieh Lin*
  Hanyang University

- *Hua-Yi Hsu*
  National Taipei University of Technology

The ferrite waveguide circulator available on the market nowadays has a rigid housing made up of metal and connected with several mechanical joints. The parts are assembled by molding, brazing, metallization, silver, or conventional soldering. These traditional techniques usually increase the production cost of one unit. The testing of these devices and the corresponding fine-tuning for the desired frequency and bandwidth lead to further increase of the cost and time. Hence, we propose to use the 3D printing technology to prototype the ferrite waveguide circulator. The metal circulators commonly used in the industry are generally more expensive. Therefore, the experimental prototype of a WR340 ferrite waveguide circulator can be built using a cost-effective 3D printing technology for validating the design, comparing with its simulation results. The said circulator has a simple structure; hence by using the Lego method, the unit can be quickly produced and assembled. This paper presents how to 3D print a circulator housing, which is then metal coated. the ferrite discs are then fixed at the chamfer center enclosed by the magnets on both sides to complete the magnetic circuit. The circulator developed by this additive manufacturing is expected to have a bandwidth of 150 MHZ or higher with a transmission of 93% operated at 2.45GHz frequency.

P7.6 - Self-Consistent Modeling of Waveguide Circulator under Realistic Magnetic Field for Industrial Applications

- *Kaviya Aranganadin, Ming-Chieh Lin*
  Hanyang University

- *Hua-Yi Hsu*
  National Taipei University of Technology

An RF waveguide circulator is a ferromagnetic passive device with three or four ports, which is used to protect other RF components from excessive signal reflection. The previous studies on the design and development of the circulators deal with achieving broad bandwidth and high transmission efficiency using finite element method (FEM) simulations with a homogenous applied bias field. This work takes a step further and presents a novel self-consistent approach to modeling a ferrite waveguide circulator by solving electromagnetic and magnetostatic solutions simultaneously. The comparison between the homogenous and the non-homogenous

field models shows the importance of coupling a magnetic circuit to an electromagnetic simulation. The more realistic circulator design presented here still has a broad bandwidth of 180 MHz, insertion loss less than 0.24 dB, reflection, and isolation better than 20 dB operated at the center frequency of 2.45 GHz. It can be used to replace an industrial waveguide circulator, which has only a 50 MHz bandwidth. Hence, by increasing the bandwidth of a circulator one can reduce the number of units for a dual-frequency magnetrons operating concurrently at 2,430 and 2,480 MHz. with a working power of 3 kW each employed in the microwave plasma system.

P7.7 - Simulation and Design of 1-THz Backward Wave Oscillator

- *Peipeng Wang, Zhenhua Wu, Min Hu, Jian Zhang, Guanyi Zhang, Shenggang Liu*
  UESTC

A single grating rectangular waveguide is used as the slow-wave structures (SWS) of 0.978THz BWO. The dispersion characteristics of single grating structure are studied by Matlab simulation, and the structure parameters of grating are obtained. On this basis, three-dimensional electromagnetic simulation software Magic was used to build the structure model for simulation. Finally, under the condition of 1KV voltage and 100A/cm2 banded electron injection input, the electromagnetic wave with output frequency of 0.978THz and power of 3.9mW can be obtained with an efficiency of 0.65%.

P7.8 - Particle-In-Cell Simulations of Beam-wave Interacion for Sub-Terahertz Folded Waveguide Traveling Wave Tubes

- *Zhengyuan Zhao, WenXin Liu, Yue Ou, LongLong Yang*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy of Science

In this paper, we modelled a sub-Terahertz at the frequency of 0.108THz folded waveguide traveling-tube (FWTWT) by utilizing a 3-D particle-in-cell (PIC) in CST STUDIO SUITE, and we investigated the beam and electromagnetic field of 108GHz FWTWT. The process of the interaction for FWTWT are presented, including working voltage, the structural parameters, working frequency. The radiation power and gain of the FWTWT at 108GHz is 42.32W and 26.26dB. The output of the FWTWT changes only 1.2dB across the 7Ghz bandwidth ranging from 103Ghz to 110GHz, which is useful in many fields, such as communications, electronic countermeasures, radar.

P7.9 - Research on Internal Temperature Prediction of Slow Wave Structure Based on Experimental Data

- *Xingqun Zhao, Xiaoting Ying, Xiaohan Sun*
  Southeast University

At present, there are many researches on the thermal characteristics of traveling wave tube, but few researches and discussions on the measurement of its internal temperature field are involved. Moreover, it is difficult to monitor the internal temperature of traveling wave tube. In related research, an RBF neural network model based on ANSYS slow wave structure simulation data has been proposed. Data outside the slow wave structure is input into the model to calculate its internal thermal characteristics. On this basis, a simplified model of slow wave structure was designed in this study. The real data outside the model tube measured by the infrared temperature measurement system was input into the inversion model to get the internal temperature, and the error is small compared with the real internal temperature.

P7.10 - Simulation Exploration of Assembly Process and Key Parameters of TWT

- *Xiaofang Zhu, Jingyuan Che, Yulu Hu, Quan Hu, Bin Li, Tao Huang, Xiaolin Jin, Li Xu*
  University of Electronic Science and Technology of China

Assembly process and key parameters have important effects on performance of traveling wave tubes. In this paper, simulation exploration on Graphite heat extrusion process and the cathode-heater assembly distance of electron gun are introduced, which have been carried out during the last two years and is to be used to guide the assembly process in TWT. More simulation exploration in processing are still in progress.

P7.11 - Kinetic Analysis of Two-Dimensional Cyclotron Maser with Single Gratings

- *Xiaofei Li, Qianzhong Xue, Yidong Xiang*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy of Sciences

- *Ding Zhao*
  Aerospace Information Research Institute, Chinese Academy of Sciences

In this paper, the TE mode dispersion relation of the two dimensional sheet beam cyclotron maser with single gratings is obtained by the kinetic method. By numerical calculations, the effects of the structure parameters and the beam state on the growth rate are analyzed. As the high-order mode in the two dimensional single grating waveguide, the TE mode has the value to be investigated and the method is meaningful in the practice.

P7.12 - Fast Optimization Design Method of Periodic Permanent Magnet Focusing System for TWT

- *Shilong Zhu, Quan Hu, Yulu Hu, Xiaofang Zhu, Tao Huang, Bin Li, Li Xu, Xiaolin Jin*
  University of Electronic Science and Technology of China

This paper proposes a fast optimization design method for the traveling wave tube (TWT) periodic permanent magnet focusing (PPM) system. Based on the target system value distribution using MTSS software, a magnetic system that satisfies the requirements is quickly designed, and the accurate single-loop value of each magnetic steel is obtained. The actual magnetic system processed according to the single-loop value is more in line with the design requirements, which is conducive to the assembly and commissioning of higher frequency millimeter wave and terahertz electric vacuum devices.

P7.13 - Dispersion Relation of Embed Beam-Wave Interaction for Planar Grating Structure Terahertz Radiation Source

- *LongLong Yang, WenXin Liu, Zhengyuan Zhao, Yue Ou*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy of Science

In vacuum electronic devices region, high power, compact, portable and miniaturized terahertz radiation source has always been the research goal. The core of vacuum electronic device is slow wave structure, which determines the beam wave interaction efficiency and output power. For the classical slow wave structure of rectangular grating, the field matching method is used to analyze the slow wave structure of rectangular grating with holes in the middle, and then the dispersion equation is obtained. For the field treatment in the trough, the higher term is retained, which is expressed as the sum of an infinite standing wave.

P7.14 - Small Signal Analysis of Open Planar Tape Helix SWS with Straight-Edge Rectangular and Cylindrical

- *G. Naveen Babu , A. An Belin Felicsona*
  Shiv Nadar University

Dispersion characteristics of a Planar Tape Helix (PTH) slow-wave structure (SWS) composed of the planar helix with rectangular and cylindrical straight-edge connections are performed. The PTH consists of a set of parallel conducting lines in the transverse and the longitudinal directions. A numerical study was conducted to analyze and compare the dispersion characteristics of the open PTH-SWS for rectangular and cylindrical straight-edge connections using 3-D simulation tool CST microwave studio (CST-MWS). The derived dispersion equation without any apriori assumption about the current density is numerically computed and the computed dispersion characteristics are compared with the simulated results obtained using Eigenmode solver of the CST. For the PTH-SWS considered, the phase velocity, dispersion characteristics and the intrinsic impedances are determined for both straight edge and cylindrical edge connections. The outcome of the present numerical study exhibits results of rectangular straight edge type PTH for use in millimeter-wave frequency ranges and cylindrical straight edge type PTH, for use in C and X band frequency range. The results of this work will lead to development of millimeter-wave PTH SWS that can be fabricated.

Poster Session
Cathodes/Materials/Electron Guns

P8.1 - Quantitative Analysis of Single-Surface Dielectric Multipactor Susceptibility with Dual Carrier Frequencies

- *Shu Lin*
  Xi'an Jiaotong University & Michigan State University

- *Yongdong Li*
  Xi'an Jiaotong University

- *Asif Iqbal, John Verboncoeur, Peng Zhang*
  Michigan State University

This paper presents quantitative threshold analysis of multipactor breakdown on single dielectric surface initiated with an radio-frequency signal consisting of two carrier frequencies. The statistical modeling of multi-carrier multipactor on a dielectric is conducted for multipactor susceptibility chart and threshold analysis. On that basis, the effect of the relative phase and strength, and the frequency difference of two carrier frequencies on multipactor threshold are analyzed to achieve performance optimization. The results indicate that additional carrier frequency may increase power transmission capacity of high-power dielectric window.

P8.2 - Thermionic Emission of a Novel $Y_2Hf_2O_7$ Ceramic Cathode Applied in High-Power Magnetron Tubes

- *Shikai Qi, Zeng Wei , Liu Li*
  Institute of Electronics Engineering, Jiujiang University

- *Xiaoxia Wang , Xingqi Wang*
  Institute of Electronics, Chinese Academy of Sciences

- *Mingwei Hu*
  School of Physics and Optoelectronics Engineering, Xidian University

In order to enhance output power and prolong lifetime of the high-power magnetron tubes, a novel Y2Hf2O7 Ceramic cathode had been developed. The thermionic emission and lifetime characteristics of the 2Hf2O7 cathode had been measured. The results show that the cathode can provide 0.15A/cm2, 3.5A/cm2 current density for the space charge limitation at 1300 degrees Cbr, 1600 degrees Cbr respectively under 300V anode voltage. The lifetime of the cathode is more than 4100 h with an initial load of 0.5A/cm2 at 1400 degrees Cbr.

P8.3 - Design of a Planar Sheet-Beam Magnetron Injection Gun

- *Yidong Xiang, Qianzhong Xue, Xiaofei Li*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy Sciences

- *Ding Zhao*
  Aerospace Information Research Institute, Chinese Academy of Sciences

A planar sheet-beam magnetron injection gun for the 94GHz sheet beam metallic grating waveguide amplifier based on combined resonance has been designed in this paper. The planar sheet-beam magnetron injection gun has two anodes which can optimize velocity ratio and transverse velocity spread conveniently. The electron beam produced by the planar sheet-beam magnetron injection gun can operate at accelerating voltage 34kV and current 1.7A. The guiding center of the electron beam at the region of interaction is 0.525mm and the magnetic field at interaction region is 2.8T. The simulation result of Opera indicate that the velocity ratio is 1.16 and transverse velocity spread is 3.5%.

P8.4 - Theory on AC Contact Resistance

- *Foivos Antoulinakis, Yue Ying Lau Lau*
  University of Michigan

Electrical contact is an important issue to high power microwave sources, pulsed power systems, field emitters, thin film devices and integrated circuits, and interconnects, etc. Contact resistance, and the enhanced ohmic heating that results, have been treated mostly under steady state (DC) condition. In this paper, we consider the AC contact resistance for a simple geometry, namely, that of two semi-infinite slab conductors of different thicknesses joint at z = 0. The conductivity of the two slabs may assume different values. In the DC case, this model was solved exactly. We have constructed an exact solution under AC condition, and we have shown that in the limit of zero frequency, our AC solution reduces to the DC case. New features that accompanies AC condition, such as the resistive skin effect, inductive, and capacitive effects, as well as radiation losses will be explored. Scaling laws for resistance as a function of frequency will be constructed for a several cases.

P8.5 - Design a Sheet-Beam Electron Gun for Ka-Band EIO

- *Jian Zhang, Zhenhua Wu, Jie Qing, Jielong Li, Bo Wang, Renbin Zhong, Min Hu, Shenggang Liu*
  University of Electronic Science and Technology of China

Based on the basic theory of electronic motion, this article has made a preliminary study on the design of a strip injection electron gun, and according to the requirements of the project, a belt

with 20.4kv, 1A, and the current density of the cathode emission surface is 50A / cm2 The electron beam injection gun will be used in the research of Ka-band extended interaction oscillator. The particle beam injection software CST is used to perform 3D modeling and simulation of the electron beam gun. Instability, so according to the required magnetic field size and structure size requirements, the PCM magnetic system is designed, which can finally make the electron beam stable transmission 50mm.

P8.6 - Electron Emission of the Thermionic Cathode Impregnated with Pure Ba_2ScAlO_5 Phase

- *Qiang Zheng, Zhenghu Huang, Ran Yan, Yong Luo, Hao Fu*
  University of Electronic Science and Technology of China

We report on a new type of dispenser cathode impregnated with single phase Ba2ScAlO5 solid-solution powders made from liquid-phase co-precipitation technique. The dc emission test results reveal that the divergent current density Jdivs are 6.7 and 5.0 A·cm-2 occurring at 950 and 900 ?B, respectively, for the cathode with Ba1.5Ca0.5ScAlO5 active salt. Excellent low-temperature emission makes this sort of cathode promising for the application in millimeter-wave and high-power microwave devices.

P8.7 - Inverse Magnetron Injection Gun for 170GHz Gyrotron

- *Chao Tang, Hui Wang, Zhiyuan Jin, Xinjian Niu, Yinhui Liu, Jianwei Liu*
  University of Electronic Science and Technology of China

A key part of the research on the gyrotron is the research and design of the electron gun. As the source of the gyrotron, the electron gun converts the electrical energy of the power source into the kinetic energy of the electronic movement, and provides a stable electron beam for the gyrotron. The quality of the electron beam will directly affect the performance of the entire gyrotron. The effect of tube energy conversion, which determines the overall performance of the gyrotron. According to the operating parameters of the 170GHz electron gun, an inverse magnetron injection gun (IMIG) is designed in this paper. Under the condition that the acceleration voltage of the electron beam is 75KV and the current of the electron beam is 45A, it is obtained that the center radius of the electron beam guide is about 7.6mm, and the lateral-vertical speed ratio is 1.3. The transverse velocity dispersion is 3.6% and the longitudinal velocity dispersion is 5.6%, which meets the requirements of beam-wave interaction.

P8.8 - Experimental Studying of CNT Field-Emission Array with Double Insulator

- *Anton Burtsev*
  Kotel'nikov Institute of Radio Engineering and Electronics RAS, Saratov Branchnd Electronics RAS

- *Igor Navrotsky, Kirill Shumikhin*
  Kotel'nikov Institute of Radio Engineering and Electronics RAS, Saratov Branch

We present the results of experimental investigations of cathode-gate structure containing carbon nanotubes (CNTs). The structure prepared by using photolithographic process on a silicon substrate with reactive ion etching process of metal gate and double silicon dioxide layer and PE-CVD method for the growth of the CNT arrays. Experimental specimens of field emission cathode-gate matrix based on a vertical-aligned CNT with a 2 μm diameter of cell of and microstructure pitch of 7 μm have been fabricated. The electron gun employing the cathode–gate structure with diameter of 0.8 mm has an emitting current up to 14 mA.

P8.9 - Simulated Comparison of Two Anode Types of Coaxial Electron Gun for 170GHz Gyrotron

- *Kai Wang, Qianzhong Xue*
  Aerospace Information Research Institute, Chinese Academy of Sciences & University of Chinese Academy of Sciences

The simulated comparison of two anode types of coaxial electron gun has been presented in this paper. The calculated results simulated by CST code indicate the electron gun could generate great quality electron beam both in two anode types. No reflected electron occurs and the laminar beam is obtained. The transverse velocity spread for single-anode gun and double-anode gun are 3.79% and 1.92% with the identical velocity ratio 1.3.

P8.10 - Distribution of Desorption Products on Interior Surfaces of Scandate Cathode Test Vehicle

- *Mujan N. Seif, Sydney Kolnsberg, Thomas John Balk, Matthew J. Beck*
  University of Kentucky

- *Bernard K. Vancil*
  E Beam, Inc.

Scandate cathodes have shown a higher emitted current density than any of its predecessors, which is hypothesized to stem from chemical complexes on the W matrix surface. Therefore, it is crucial to examine the cathodes' desorption behavior to understand how surface chemistry evolves during cathode lifetime. In this work, the distribution of desorption products of scandate cathode activation and operation mapped with XPS and EDX are reported. The compositional studies were conducted on the interior of the glass envelope wherein the cathodes were activated and operated, as well as the anode resting directly atop the cathodes. The results from the glass envelope indicate that Ca is expelled from the surface during pre-activation, not activation. Results from the anode yield insight into the composition and volume of material expelled throughout cathode activation and operation. Lastly, within the detection limits of XPS and EDX, no appreciable Sc was found on the anode nor the glass envelope, suggesting it is not evaporating in great amounts at any stage of cathode lifetime.

P8.11 - Miniaturized Metamaterial-based Sheet Beam Radiation Sources

- *Xuanming Zhang, Hengyu Luo, Xin Wang, Tao Tang , Zhanliang Wang, Huarong Gong, Yubin Gong, Zhaoyun Duan*
  University of Electronic Science and Technology of China

In this paper, we investigate the transmission and reflection characteristics of metamaterial based slow-wave structure with two waveguide couplers. The beam-wave interaction simulation of the radiation source is also presented here. The simulation results show that this device operating at 2.83 GHz has a pass band near 3 GHz, has efficiency of 26.7% and its peak output power is 61.6 kW for a beam voltage of 38.5 kV and a beam current of 6 A. The transverse dimensions of the metamaterial-based slow-wave structure is approximately 1/7 of the corresponding free space operating wavelength, which proves its added advantage of miniaturization.

P8.12 - The Design and Simulation of a Double-Anode Magnetron Gun for a 0.68-THz Second Harmonic

- *qiuling mou, Wenbo Zeng*
  Sichuan Institute of Solid State Circuits, China Electronics Technology Group Corp

- *Zhipeng Wang, sheng yu*
  Univesity of electronic science and technology of Chna

In this paper, in order to satisfy the requirement of the electron beam source in a 0.68 THz second harmonic gyrotron, a double-anode MIG (magnetic injection gun) is simulated and designed through PIC code. In our design, the structure of main anode is modified so that the distribution of electric field is more uniformed around the area between the cathode and main anode. Through optimization, the satisfactory results are obtained that the transverse velocity spread is 2.3%, the cathode-anode voltage is 40kv, the beam current is 1A and the velocity ratio is 1.3. The sensitivity analysis of the different parameters is also made, which is helpful to improve the performance of the MIG

P8.13 - Microwave Sintering of W-Ir Matrix for Improved Emission Performance of Cathode

- *Junyan Gao, Yunfei Yang, Shilei Li, Peng Hu, Jinshu Wang*
  Beijing University of Technology

Microstructural control of matrix is a critical way to improve the emission properties of cathode. In this work, microwave sintering strategy was developed to fabricate W-Ir alloy matrix with uniform grain size. The maximum of zero-field current density was measured to be 17.30 A/cm2 at 1050 ?b, which is superior to M type cathode coated with Ir and Ir- Re-W films.

P8.14 - Environments Adaptability and Failure Analysis of Nanoscale Vacuum Channel Transistors

- *Xinghui Li, Panyang Han, Yunzhu Xie, Ting Du, Jun Cai, Jinjun Feng*
  Beijing Vacuum Electronics Research Institute

Metal-emitter-based nanoscale vacuum channel transistors with vertical surround-gate configuration were fabricated by using thin-film deposition and focus ion beam etching. Adaptability testing in different vacuum environments and failure analysis of the transistors were carried out to make the basis for stability enhancement and component performance improvement.

P8.15 - A Novel Tunable PCM Focusing System for a 220 GHz Sheet Beam Electron Gun

- *Shengkun Jiang, Merdan Wulam, Yiliang Xu, Tao Tang, Zhanliang Wang, Huarong Gong, Yubin Gong, Zhaoyun Duan*
  University of Electronic Science and Technology of China

The transport of sheet beam is one of the major difficulties in the development of terahertz sheet beam devices due to the electron gun and magnetic focusing system, both of which are required extremely high assembly precision. In this paper, a 220 GHz sheet beam electron gun has briefly introduced and a novel tunable periodic cusped magnet (NTPCM) system for focusing sheet beam has been investigated. The beam current of the designed single anode sheet beam electron gun is 0.13 A at 22 kV beam voltage, and the sheet beam size at beam waist is around 0.5 mm × 0.1 mm. Furthermore, the simulation results show that the sheet beam with current density greater than 260 A/cm2 can achieve a transport distance of more than 90 mm through this NTPCM.

P8.16 - Digital Light Processing of Alumina Ceramics for Vacuum Electron Devices

- *Wang Bofeng*
  Institute of Electronics, Chinese Academy of Sciences, Beijing 100190, China

Alumina were fabricated by digital light processing (DLP) with alumina powders. Alumina surface morphology, microstructure and properties were studied by scanning electron microscopy and performance test system of electron gun assembly, respectively. The results indicate that DLP alumina has the characteristics of high density and conductivity. The heat transfer in electron gun assembly includes heat conduction and heat radiation. The heat transfer mode of DLP alumina was heat conduction and heat radiation, indicating high heating efficiency, compared to that of the alumina(heat conduction) by the existing technology.

P8.17 - Effect of Electron Irradiation on Properties of RTV560 Silicon Rubber

- *Guangjiang Yuan, Wei Song, Mingyang Zhu, Guoxing Miao*
  Institute of Electronics, Chinese Academy of Sciences

- *Ruiqi Li, Jiuchun Yan*
  Harbin Institute of Technology

High voltage terminals are enclosed with RTV560 silicone rubber. Space travelling wave tubes are exposed in irradiation environment. As one organic elastomer, silicone rubber is degraded by the radiation. In the paper, effect of electron irradiation on properties of RTV560 silicone rubber was investigation. The used electrons have an energy range 10~100 keV, and the irradiation fluence ranges from 1.0×106 rad to 1.0×107 rad. At last, roughness, hardness, DTA and TGA were measured and analyzed for all samples.

P8.18 - Deposition of Tungsten Nanoparticles for Potential Use in Dispenser Cathodes

- *Huanhuan Bai, Matthew J. Beck, Thomas John Balk*
  University of Kentucky

Dispenser cathodes have attracted attention in both industrial and academic research for a long time, due to their application as high-brightness electron sources. Since most modern cathodes utilize tungsten as the base material, it is useful to investigate how novel forms of tungsten can influence a cathode. In the present study, nanoscale tungsten particles were generated by physical vapor deposition and deposited onto substrates, to gauge the effectiveness of generating a tungsten coating that can enhance electron emission. These nanoparticles were characterized by scanning and transmission electron microscopy. The tungsten particles formed a continuous nanoporous structure, along with discrete larger particles on the substrate.

P8.19 - Processing and Surface Analysis Capabilities of the Cathode Characterization Chamber

- *Kerry Baker, T. John Balk*
  University of Kentucky

At the University of Kentucky, we have the ability to process and characterize cathodes in our Cathode Characterization Chamber (CCC). This chamber has key capabilities that allow us to characterize cathode pellets at various stages of heating and activation. The chamber is equipped with a heater, pyrometer, residual gas analyzer (RGA), Kelvin probe, ambient pressure photoemission spectroscopy (APS), surface photovoltage spectroscopy (SPS), and contact potential difference (CPD) modes. These tools allow us to heat the sample under vacuum, measure species that desorb, and measure the work function of the sample. We are able to replicate the heating cycle applied to cathodes in order to activate them. This ability allows us to

compare various cathode types before, during, and after activation. Using the CCC, we will gain a greater understanding of what parameters influence scandate cathode surfaces.

P8.20 - Quantifying Work Function Using Kelvin Probe Systems

- *Antonio M. Mántica, T. John Balk*
  University of Kentucky

Quantifying the work function of materials is a major component of research dedicated to developing in vacuo electrical devices with high current density at low operating temperatures. These devices are regularly composites of more than one material and understanding the roles that the individual components play in determining the overall work function is at the frontier of this research. The work function characterization technique outlined here is analysis using a Kelvin Probe System, which yields the opportunity to quantify a material's work function through measuring contact potential difference (CPD) or through photovoltage spectroscopy (SPV). In this paper, these separate techniques are outlined and experimental data is given for W and Ba, two elements of interest in device development.

P8.21 - Stability Improvement of Electron Gun for Millimeter Wave TWTs by Immersed Flow Focusing System

- *Ruofan Wang, Jin Xu, Lingna Yue, Hairong Yin, Guoqing Zhao , Wenxiang Wang, Y. B. Gong, Yanyu Wei*
  University of Electronic Science and Technology of China

- *J. J. Feng*
  Beijing Vacuum Electronics Research Institute

This paper introduces a high-stability electron optical system for millimeter wave traveling wave tubes. Firstly, a circular electronic injection Pierce electron gun is designed. The electron channel radius is 0.2mm, the current is 90mA. Then the immersed flow method was used to design a ppm focusing system with a magnetic field period of 7.3 mm and a peak value of 4900 Gauss. The stability of the immersed flow electron gun is compared with the gun under a conventional ppm magnetic field in consideration of thermal deformation and assembly errors.

P8.22 - Analytical Solution for Space Charge Limited Current Emission from a Sharp Tip Using Variational Methods

- *N. R. Sree Harsha, Allen L. Garner*
  Purdue University

In this paper, we shall present an analytical solution for current density from a sharp tip in the tip-to-plate configuration, with an applied dc voltage bias, using the methods of variational calculus. We shall also show that when the radius of the tip tends to infinity, we get back the current density formula for the classical Child-Langmuir (CL) law for a flat surface. The local current density near the tip is found to be much higher than the current density in the classical CL configuration. The results seem to be in agreement with the recent numerical simulations of the current density near a sharp tip.

P8.23 - Impregnated Cathode Thermionic Analysis using X-Ray Photoelectron Spectroscopy

- *Claudio C Motta*
  University of Sao Paulo

- *Gabriel G. J. Sousa, Glauco P Zanella*
  Fundacao PATRIA

In this paper an improvement of experimental apparatus existing and developed for a complete characterization of impregnated thermionic cathodes in terms of surface chemistry is obtained by inclusion of an x-ray source for photoelectron spectroscopy analysis. Now in the ultra high vacuum chamber of the apparatus, there are not only a hemispherical electron analyzer, an electron gun for Auger spectroscopy and, an ion gun but also an x-ray source for XPS spectroscopy.

P8.24 - 3D-Design of Magnetron Injection Gun for 42GHz Second Harmonic Gyrotron

- *Alok Mishra, Om Ranjan, A. Bera*
  CSIR-Central Electronics Engineering Research Institute

- *M. V. Kartikeyan*
  Indian Institute of Technology, Roorkee

This paper presents the 3D design simulation of MIG for 42GHz, 100kW second harmonic Gyrotron operating at TE0, 3 mode. Initially, the analytical design approach was opted using design trade-off equations and then the 3D simulation has been performed by using CST Particle Studio. The beam parameters, velocity ratio, and velocity spread was obtained 1.35, 3.3% respectively.

P8.25 - Design and Simulation of Magnetron Injection Guns for a 0.5 THz Frequency-Tunable Gyrotron

- *Jie Huang, Tao Song, Wei Wang, Diwei Liu*
  University of Electronic Science and Technology of China

The design and simulation of magnetron injection guns (MIGs) for 0.5 THz broadband continuously frequency-tunable gyrotron with the principle of multi-mode switching and axial mode transition via electrical tuning and magnetic tuning have been presented in this paper. Moreover, the variation of the electron beam quality including the velocity spread and the pitch factor with respect to the operating magnetic field B0 and the operating voltage V0 has also been studied.

P8.26 - Application of Electrodynamic Admittances in the TWT Theory

- *Yuriy Nikitich Pchelnikov*
  retired

An electrodynamic method of the TWTs' analysis with application of the "admittance tensor" and its projections on the boundaries between regions of slow-wave structures is demonstrated on the example of the sheath helix with finite surface conductivities along the helix turns and in the perpendicular to them direction. The replacement of the sheath helix by a two-dimensional "conductivity tensor" allowed deriving a general dispersion equation connecting the electrodynamic admittances in the adjacent to the helix regions. The application of the electrodynamic admittances of the electric and magnetic types, represented by the scalar projections of the admittance tensor on the boundary surfaces, decreases twice the number of the boundary conditions, that significantly simplifies the derivation of the dispersion equations in the presence of the electron beam and complex boundary conditions.

P8.27 - Novel Sawtooth Structure Loading to Mitigate Mode Competition in a 346 GHz Backward Wave Oscillator

- *Christián Hurd, Yuan Zheng*
  University of California Davis

- *Neville C. Luhmann, Jr.*
  University of California

A novel approach to mitigate mode competition and improve stability in a 346 GHz Backward Wave Oscillator (BWO) by loading a copper sawtooth slow wave structure (SWS) is proposed. The effects of mode competition, and the sawtooth structure loading effects are discussed. CST simulation has been used to verify the analysis and test of the stability of those circuits.

P8.28 - Cold Test Design of the Open Resonant Cavity in a High-Order Mode Gyrotron

- *Menglong Jiao, Zheng Wen, Chen Yang, Zhixian Li*
  Institute of Electrics, Chinese Academy of Sciences & University of Chinese Academy of Sciences

- *Jirun Luo, Wei Guo, Min Zhu*
  University of Chinese Academy of Sciences

- *Yu Fan*

A design of the cold test for frequency, Q-factor and electric field distribution of high-order mode resonator of gyrotron with a computer control is presented. The designed results show that the difference between maximum and minimum of electric filed can clearly be distinguished, which can be applied to the measurement of the electric field pattern on crossed section.

P8.29 - Circuit Design and Simulation of a 0.85 THz Regenerative Feedback Oscillator

- *Tianyi Li, Pan Pan, Dong Li, Weisi Meng, Jun Cai, Jinjun Feng, Tiechang Yan*
  Beijing Vacuum Electronics Research Institute

A 0.85 THz regenerative feedback oscillator is proposed as a compact and frequency-tunable source. The circuit design and simulation is presented including both the folded waveguide slow wave structure and the feedback circuit. The bandwidth of the circuit is over 70 GHz and the output power is over 200 mW. The circuit is being fabricated using UV-LIGA micromachining process.

P8.30 - Simulation of Non-Periodic Folded Waveguide Slow-Wave Structure

- *Duo Xu, Wei Shao, Hexin Wang, Tenglong He, Ningjie Shi, Zhigang Lu, Huarong Gong, Zhanliang Wang, Zhaoyun Duan, Yubin Gong*
  University of Electronic Science and Technology of China

This paper proposed a novel slow wave structure (SWS) named non -periodic folded waveguide (NPFW) SWS. The novel NPFW has the ability to suppress the backward wave oscillation and can achieve a high-gain one-stage traveling wave tube (TWT). A W-band NPFW-TWT was built and simulated in this paper to verify the performance of the novel NPFW-SWS. The simulation results show that the maximal output power and gain are 105W and 27.6dB in the designed one-stage NPFW-TWT.

P8.31 - Simulation and Analysis of the $TE_{28,8}$ Mode Excitation in an Open Resonant Cavity of Gyrotron

- *Zhixian Li, Menglong Jiao, Chen Yang, Zheng Wen, Jirun Luo*
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A mode generator consisting of an open resonant cavity and a quasi-parabolic mirror for the TE28,8 mode excitation was presented. The excitation condition of the TE28,8 mode was discussed and the obtained electric field distribution was analyzed and compared with the ideal TE28,8 mode according to its scalar and vector correlativity.

P8.32 - Operation Condition of GW Class Magnetron with Diffraction Output in Particle-in-Cell Simulation

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  National Penghu University of Science and Technology

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  Oriental Institute of Technology

Particle-In-Cell (PIC) simulations were performed to study the GW operation condition of an A6 Magnetron with Diffraction Output (MDO) with transparent cathodes. The input waveform is a -500 KV pulse of 100 ns pulse width. The results show the GW class output power appears after 30 ns at 0.36 T external magnetic field, which is within theoretical prediction of conventional Buneman–Hartree (B-H) condition, but is very sensitive to magnetic field strength. The actual energy efficiency maybe lower than expected.

P8.33 - Design of a G-Band EIK Three-Stage Depressed Collector

- *Le Li, Qi Wu, Jin Xu, Lingna Yue, Hairong Yin, G. Q. Zhao, H. R. Gong, W. X. Wang, Z. G. Lu, Y. B. Gong, Yanyu Wei*
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- *Yong Zhong, J. J. Feng*
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- *Dazhi Li*
  Neubrex.Ltd.

In this paper, the method of directly exporting the particle data from the CST interaction results to the collector is used to effectively improve the accuracy of the collector design. A three-stage

depressed collector for 220GHz extended interaction klystron was designed with an efficiency of 90% and a reflow rate of zero.