Session 1. Modeling-I

April 29 (Monday) / 10:20 ~ 11:40 / Room 1

Session Chair: Dave Smithe (Tech-X Corporation, USA)

10:20 ~ 10:40

1.1 / [Keynote] Design and Simulation of W-band Second Harmonic Periodically Loaded Gyro-TWT Amplifier

Akash (Indian Institute of Technology, India), Thottappan (Indian Institute of Technology, India)

A W-band gyro-TWT amplifier using a periodic lossy dielectric disc loaded RF interaction structure operating in second harmonic TE_{02} mode is presented. The dielectric loaded linear section is used to suppress the potential BWOs. The present gyro-TWT is modeled in 3D particle-in-cell (PIC) tool to study its beam-wave interaction behavior. The simulation shows a peak power of 600kW in a second harmonic TE_{02} mode for the DC drive of 100kV, 25A. The electronic efficiency of the present amplifier is calculated as ~24% and the saturated gain is ~30dB. The -3dB bandwidth of the amplifier is 4.2GHz.

10:40 ~ 11:00

1.2 / DIMOHA: Traveling-wave tube simulations including band edge and multiple-carriers operations

Damien Minenna (Centre National d'E´tudes Spatiales / Aix-Marseille Université / Thales AVS, France), Yves Elskens (Aix-Marseille Université, France), Frédéric André (Thales AVS, France), Jérôme Puech (Centre National d'E´tudes Spatiales, France), Alexandre Poyé (Aix-Marseille Université, France), Fabrice Doveil (Aix-Marseille Université, France), Telma Pereira (Thales AVS, France)

A new kind of time domain simulation for travelingwave tube (TWT) is presented. The DIMOHA algorithm should be considered as an alternative to current particle-in-cell (PIC) and frequency approaches. To assess its validity, a comparison with a commercial Ku-band tapered helix TWT is performed. It shows an excellent agreement for the output power and the nonlinear phase shift at various frequencies. The algorithm is also tested near the band edge and for multitone simulations, both with success.

11:00 ~ 11:20

1.3 / Study on beam wave interaction and mode competition in a fusion gyrotron using 3-D EM PIC simulation

Ming-Chieh Lin (Hanyang University, Korea), David N. Smithe (Tech-X Corporation, USA)

3-D time-domain modeling of beam wave interaction in a fusion gyrotron is very challenging due to the open-end features of cavity structure and higher-order mode excitation employed to achieve high efficiency. In a previous project, namely GyroPIC, funded by DOE, several required capabilities or algorithms had been developed in a 3-D particlein-cell (PIC) simulation code in order to simulate the beam wave interaction in a high-order mode gyrotron. In past decades, it has been considered as an impossible mission to simulate a fusion gyrotron in 3-D using a PIC based method. The preliminary results showed that the 3-D electromagnetic (EM) PIC method could provide an alternative modeling tool for studying the gyrotron cavity interaction and mode competition for gaining more physics insight and further improving the efficiency. Upon finishing the code development, a research effort has been continued in recent years to study the beam wave interaction and mode competition using the well-developed 3-D EM PIC simulation.

11:20 ~ 11:40

1.4 / Large-scale parallel particle-in-cell code CHIPIC

Dagang Liu (University of Electronic Science and Technology, China), Huihui Wang (University of Electronic Science and Technology, China), Laqun Liu (University of Electronic Science and Technology, China), Mengjun Xie (University of Electronic Science and Technology, China)

A Large-scale Particle-in-cell (PIC) simulation code, CHIPIC, is introduced. This reports presents the parallel algorithm used in our code, and large-scale parallel particle-in-cell (PIC) simulations on MILO, RKA, TWT, and C-band MBK by making use of the Milky Way High Performance Computing platform.

Session 2. THz sources

April 29 (Monday) / 10:20 ~ 11:40 / Room 2

Session Chair: Joong Kim (Office of Naval Research, USA)

10:20 ~ 10:40

2.1 / Multi-Color Coherent Terahertz Smith-Purcell Radiation Based on Compound Grating

Juan-Feng Zhu (Peking University, Beijing), Chao-Hai Du (Peking University, Beijing), Lu-Yao Bao (Peking University, Beijing), Shi Pan (Peking University, Beijing), Hui-QI Bian (Peking University, Beijing), Fan-Hong Li (Peking University, Beijing), Pu-Kun Liu (Peking University, Beijing)

A multi-color coherent terahertz (THz) Smith-Purcell radiation based on compound grating is introduced in this paper. The periodically modulated depth in the compound grating is beneficial to decreasing the coupling strength of adjacent grooves and constructing a series of spoof surface plasmon (SPP) cavities. Owing to the weak coupling between two adjacent cavities, the multi-color coherent Smith-Purcell radiation in specific directions is induced by the excitation of free electron beam. This kind of Smith-Purcell radiation is promising for the development of THz radiation sources and THz communication.

10:40 ~ 11:00

2.2 / [Keynote] A 850GHz Folded Waveguide Based on Thin Dielectric

Lu Wang (Southeast University, China), Wenchen Xiang (Southeast University, China), Ningfeng Bai (Southeast University, China), Changsheng Shen (Southeast University, China), Xiaohan Sun (Southeast University, China), Pan Pan (Beijing Vacuum Electronics Institution, China), Jun Cai (Beijing Vacuum Electronics Institution, China), Jinjun Feng (Beijing Vacuum Electronics Institution, China)

We presents a folded waveguide based on thin dielectric (FWG-TD) for Terahertz traveling wave tube (TWT). Thin Dielectric layer helps to decrease phase velocity and improve the power capacity. The simulation results show that this FWG-TD has lower phase velocity compare to conventional folded waveguide, which decreases 15% at center frequency. Coupling structure of FWG-TD and grating filters are designed and simulated, which shows a good transmittance around 850GHz. Finally, PIC simulation show that the output power of this FWG-TD is 605mW, where the power gain is 20.8dB at 850GHz.

11:00 ~ 11:20

2.3 / Slow Wave Structure based on Defect Photonic Crystal Waveguide

Yang Xie (Nanjing University of Science and Technology, China), Wei Hong (Nanjing University of Science and Technology, China), Ningfeng Bai (Southeast University, China), Changsheng Shen

(Southeast University, China), Xiaohan Sun (Southeast University, China), Pan Pan (Beijing Vacuum Electronics Institution, China), Jun Cai (Beijing Vacuum Electronics Institution, China), Jinjun Feng (Beijing Vacuum Electronics Institution, China)

We present a defect photonic crystal waveguide (DPCW) as slow wave structure (SWS) for Terahertz (THz) TWT in this paper. The SWS is consists of photonic crystal waveguide and a defect unit in center. Due to strong confinement effect of electromagnetic, metallic PCW only needs four periods in transverse direction, which help to decrease the transverse size of SWS. The simulation results show that it has low phase velocity, 0.182c, and high pierce impedance, 47Ω, at 850GHz, which show the capability of DPCW as terahertz SWS with sufficient confinement and efficient interaction.

11:20 ~11:40

2.4 / Parallel multi-beam and its application in THz band

Kaichun Zhang (University of Electronic Science and Technology, China), Qlan Xu (University of Electronic Science and Technology, China), Neng Xiong (University of Electronic Science and Technology, China), Wangju Xu (University of Electronic Science and Technology, China)

A conception of parallel multi-beam is proposed for vacuum devices in THz band. This multi-beam, combined with the planar geometry of parallel pins circuit, can be applied in 300GHz-500GHz band. We have identified stable multi-beam formation and transport as the key enabling technology for this type of device. The convergence and control of this multi-beam is investigated by an elliptical solenoidal magnetic field. The dispersion of the slow-wave structure (SWS) is studied and compared with that of conventional corrugated waveguide SWS. Also, the interaction impedance in beam tunnel is calculated. The result shows that the structure has high interaction impedance suitable for this type of parallel multiple beams. To demonstrate these characteristics, two types of BWO at the central frequency of 340 GHz and 520GHz with 4-beam and the circuit of 3-row pins are studied by 3-D particle-in-cell simulation. Results indicate that this multi-beam combined with the planar geometry can lead to high-peak power output with low operation current of each beam and greater allowable total beam current.

Session 3. Klystrons

April 29 (Monday) / 10:20 ~ 12:20 / Room 3

Session Co-Chairs: Ming-Chieh Lin (Hanyang University, Korea)
Young-Soon Bae (National Fusion Research Institute, Korea)

10:20 ~ 10:40
3.1 / [Keynote] Simulation of High-Efficiency Klystrons with the COM and CSM bunching

Andrei Baikov (Moscow University, Russia), Olga Baikova (National Research Nuclear University, Russia)

The two types of high effective bunching in powerful klystrons are discussed. The first bunching type, named COM, is intended for standard klystron structure with first harmonic cavities only. The second bunching type, named CSM, is realized in klystron structures which includes cavities of second and third harmonics. Both bunching types allow to reach the klystron efficiency up to 90%.

10:40 ~ 11:00
3.2 / High Efficiency Klystrons for ESS

Chiara Marrelli (European Spallation Source, Sweden)

A high efficiency klystron making use of second and third harmonic cavity bunching method (Core Stabilization Method) has been developed. This tube would be able to produce up to 1.5 MW of pulsed RF power at 704.42 MHz, and it is compatible with the requirements for the klystrons for the medium and high beta part of the linac of the European Spallation Source.

11:00 ~ 11:20
3.3 / Design Study of High Efficiency CW Klystron for CEPC

O. Z. Xiao (Chinese Academy of Sciences, China), Z. S. Zhou (Chinese Academy of Sciences, China), Zaid-un-Nisa (Chinese Academy of Sciences, China), S. C. Wang (Chinese Academy of Sciences, China), G. X. Pei (Chinese Academy of Sciences, China), D. Dong (Chinese Academy of Sciences, China), S. Fukuda (High Energy Accelerator Research Organization, Japan)

In order to reduce energy consumption and operating cost for CEPC, the 650MHz/800kW high efficiency klystron has been regarded as a priority key technology to be researched and developed. In this paper, the recent progress of high efficiency CW klystron for CEPC is reviewed briefly. Then the RF section design study of the second stage of high efficiency klystron for CEPC is presented. Several computer codes have been used for klystron simulation. The simulation results with different codes are presented, which are in good agreement. The whole klystron simulation using 3D PIC solver in CST indicated that the klystron efficiency was

achieved up to 78% with asymmetry coaxial coupler.

11:20 ~ 11:40

3.4 / Klystron efficiency optimization based on a genetic algorithm

HAMEL Pierrick (IRFU CEA, France), PLOUIN Juliette (IRFU CEA, France), MARCHAND Claude (IRFU CEA, France), PEAUGER Franck (BE-RF-SRF CERN, Switzerland)

This paper presents a method based on a genetic algorithm optimization to design a high efficient klystron, operating in the X band. First, the genetic algorithm is used to optimize the bunching circuit and then to optimize the geometry of the output cavity. Finally the output cavity is integrated to the bunching circuit and the achieved efficiency is about 70%.

11:40 ~ 12:00

3.5 / Energy Efficient Klystron Operation at Saturation: Possibility due to Novel Modulator

Rutambhara Yogi (European Spallation Source, Sweden), Carlos Martins (European Spallation Source, Sweden)

The European Spallation Source (ESS) will be the world's most powerful pulsed neutron source by the end of the decade. The beam of protons will be accelerated by 155 amplifiers, out of which 126 are klystron amplifiers. Following the present state of art, the Low Level RF (LLRF) system will generate an input signal for the amplifier that drives the cavity to the field with an amplitude and phase that are within 0,1% and 0,1 degrees of the set value. To achieve this, ESS needs the LLRF overhead of 25%. As the differential gain of klystron at the saturation is nearly zero, the LLRF system needs to operate the klystron back-off from the saturation in the linear region by about 15-25 %. This leads to the two disadvantages: need for infrastructure with higher power capability and operation of the klystron in energy inefficient zone.

The present paper discusses the novel concept of operation of klystron at saturation and modulating the cathode high voltage delivered by the modulator to achieve modulation of the klystron RF output power. This avoids klystron operation in the linear region and will reduce the requirement on the amplifier power by 25% and at the same time increases the efficiency at the operating point by 15-20%. In the context of ESS operation, it will lead to energy savings of 7.5GW-hr per year. The energy saving leads to an operational cost saving of about 10 MEUR for 25 years. It will also minimize the wasted energy conversion into heat, thus minimizing the cooling and the ventilations costs.

12:00 ~ 12:20

3.6 / A miniaturized high-gain, high-efficiency metamaterial assited S-band extended interaction klystron

Xin Wang (University of Electronic Science and Technology of China, China), Zhaoyun Duan (University of Electronic Science and Technology of China, China), Fei Wang (University of Electronic Science and Technology of China, China), Shifeng Li (University of Electronic Science

and Technology of China, China), Shengkun Jiang (University of Electronic Science and Technology of China, China), Yubin Gong (University of Electronic Science and Technology of China, China), Baidyanath Basu (Supreme Knowledge Foundation Group of Institutions, India)

We proposed a miniaturized S-band extended interaction klystron (EIK) assisted by metamaterial. The interaction structure of the EIK consists of a cylindrical resonant cavity filled with a metamaterial (complementary electric split-ring resonator) array. The study based on CST Eigenmode Solver predicted that the transverse cavity dimension of the proposed metamaterial assisted EIK is 1/3-1/2 times smaller than that of its conventional counterparts, while the device delivers typically 122 kW power, 53.5 dB gain and 43.5% electronic efficiency with an input drive of 0.27 W for typical beam and magnetic field parameters. The proposed metamaterial assisted EIK has potential applications in radar, industrial heating, accelerator, and satellite communications.

Session 4. Gyrotrons

April 29 (Monday) / 13:30 ~ 15:10 / Room 1

Session Chair: EunMi Choi (Ulsan National Institute of Science and Technology, Korea)

13:30 ~ 13:50

4.1 / [Keynote] Developments of terahertz large-orbit highharmonic gyrotrons at IAP RAS

Ilya Bandurkin (Russian Academy of Sciences, Russia), Vladimir Bratman (Russian Academy of Sciences, Russia), Yuriy Kalynov (Russian Academy of Sciences, Russia), Vladimir Manuilov (Russian Academy of Sciences, Russia), Ivan Osharin (Russian Academy of Sciences, Russia), Andrei Savilov (Russian Academy of Sciences, Russia)

We describe high-harmonic gyrotrons with axisencircling electron beams developing on the basis of two experimental setups. The 30 keV / 0.7 A CW gyrotron is developed for the spectroscopy applications. Recently, selective operation at the second (0.267 THz) and at the third (0.394 THz) cyclotron harmonics were observed in a series of experiments. Quasi-regular cavities with periodic phase correctors are designed to improve the operation at the third harmonic, as well as to achieve the fourth-harmonic operation at frequencies of up to 0.65 THz. The pulsed 80 keV / 0.7 A gyrotron is aimed to provide high-power (hundreds Watts) microwave pulses at the third cyclotron harmonic at frequencies close to 1 THz. Recently, a sectioned cavity with a decreased diffractive Q-factor was experimentally tested at this setup. Now we study possibilities to increase the peak level of the output power up to the level of several kW in order to usethis gyrotron in plasma applications.

13:50 ~ 14:10

4.2 / Development of the Second Harmonic Dual Mode Gyrotron for OAM Beam Generation

Ashwini Sawant (Ulsan National Institute of Science and Technology, Korea), Ingeun Lee (Ulsan National Institute of Science and Technology, Korea), EunMi Choi (Ulsan National Institute of Science and Technology, Korea)

A novel scheme of orbital angular momentum (OAM) beam generation in radio frequency (RF) range using gyrotron is demonstrated. The gyrotron generates few kilowatts of power at 190 GHz frequency in a second harmonic mode-pair $TE_{8,3}/TE_{17,2}$ from 33/37 kV, 7A electron beam. It incorporates the two sinusoidal perturbations in the cylindrical cavity to eliminate the fundamental mode competition. These high-power OAM beams can be used for free space RF communication and RF beam plasma interaction.

14:10 ~ 14:30

4.3 / Mechanisms of Intense Pulses Generation in Gyrodevices

Irina Zotova (Institute of Applied Physics RAS, Russia), Alexey Fedotov (Institute of Applied Physics RAS, Russia), Alexander Sergeev (Institute of Applied Physics RAS, Russia), Vladimir Manuilov (N.Novgorod State University, Russia), Naum Ginzburg (Institute of Applied Physics RAS, Russia), Roman Rozental (Institute of Applied Physics RAS, Russia), Valdislav Zaslavsky (Institute of Applied Physics RAS, Russia), Valdimir Bratman (Institute of Applied Physics RAS, Russia)

We study theoretically and experimentally two mechanisms of generation of intense pulses trains under cyclotron resonance interaction of electromagnetic radiation with electron beams. The first mechanism is based on transformation of CW radiation into a train of SIT-solitons when an electron beam is initially rectilinear (absorbing). The second mechanism realizes in a gyrotron, operating with high excess of an electron current over the starting conditions. Results of corresponding Ka-band experiments are presented. Both mechanisms are of interest as methods of frequency-comb generation in microwave electronics.

14:30 ~ 14:50

4.4 / Second Harmonic 527 GHz Gyrotron for DNP-NMR

Sudheer Jawla (Massachusetts Institute of Technology, USA), Ivan Mastovsky (Massachusetts Institute of Technology, USA), Michael A. Shapiro (Massachusetts Institute of Technology, USA), Richard J. Temkin (Massachusetts Institute of Technology, USA)

We have built a frequency tunable 527 GHz gyrotron for an 800 MHz DNP-NMR spectrometer. The gyrotron is designed at the second harmonic ($\omega=2\omega_c$) of the electron cyclotron frequency. It produces ~10 W continuous microwave power at 527.12 GHz frequency using a diode type electron gun (V ~ 16.5 kV, I_b~110 mA). The gyrotron is tunable within ~ 0.5 GHz by combining voltage and magnetic field tuning. The gyrotron comprises an internal periscope assembly to internally convert a Gaussian beam to an HE11 mode in a 12 mm i.d. corrugated waveguide. The corrugated waveguide transmission line system is built including 3 m long 16 mm i.d. waveguide and a corrugated taper from 12 mm to 16 mm i.d. waveguide.

14:50 ~ 15:10

4.5 / Study of X-Ray Spectra Energy Distribution Excited by Spent Electrons in an X-Band Gyrotron Traveling Wave Tube

Yue Wang (University of Electronic Science and Technology of China, China), Guo Liu (University of Electronic Science and Technology of China, China), Wei Jiang (University of Electronic Science and Technology of China, China), Jianxun Wang (University of Electronic Science and Technology of China, China), Yong Luo (University of Electronic Science and Technology of China, China), Guoxiang Shu (Shenzhen University, China)

In this paper, theoretical and PIC simulation of the bremsstrahlung X-ray produced by an X-band gyrotron traveling tube (gyro-TWT) is analyzed with CST Particle Studio, which are used to investigate the X-ray spectra of the collector. X-rays flux spectral density and dose are obtained with theoretical Kramers law when the gyro-TWT operates with saturated output power of 136.9 kW at 9.6 GHz. Studying the X-ray spectra is of great importance for the X-ray protection of the gyro-TWT collector.

Session 5. TWTs-I

April 29 (Monday) / 13:30 ~ 14:50 / Room 2

Session Chair: Dave Abe (Naval Research Laboratory, USA)

13:30 ~ 13:50

5.1 / [Keynote] Development of a High Efficiency Coupled-cavity Traveling Wave Tube

Daxi Ji (Nanjing Sanle Group Co., Ltd, China), Ling Zhu (Nanjing Sanle Group Co., Ltd, China), Wanchao Huang (Nanjing Sanle Group Co., Ltd, China), Hang Tian (Nanjing Sanle Group Co., Ltd, China), Yun Chen (Nanjing Sanle Group Co., Ltd, China), Xirui Zhan (University of Electronic Science and Technology, China), Zhaoyun Duan (University of Electronic Science and Technology, China)

In this paper, an X-band air-cooled high efficiency traveling wave tube with coupled-cavity slow-wave structure and four-stage depressed collector was developed. The experimental results show that its average output power can reach more than 850 W and total efficiency is over 40% in the operating band (800 MHz). The X-band air-cooled high efficiency coupled-cavity traveling wave tube has met the requirements of airborne environment.

13:50 ~ 14:10

5.2 / Development of Miniaturized Linearized Channel Amplifier for Ku-Band LCTWTA

Bin ZHOU (China Academy of Space Technology (Xi'an), China), Yan FANG (China Academy of Space Technology (Xi'an), China), Bin HE (China Academy of Space Technology (Xi'an) , China), Weibo HUANG (China Academy of Space Technology (Xi'an) , China), Depeng BAI (China Academy of Space Technology (Xi'an) , China)

In this paper, a miniaturized Linearized Channel Amplifier (LCAMP) is designed to reduce nonlinearity of traveling wave tube amplifier (TWTA), and realize channel gain setting and output power setting. LCAMP include the channel amplifier, linearizer and DC circuit. The each part is manufactured by advanced technology to realize low mass and small volume. The frequency band covers the typical Ku-band from 12.25 GHz to 12.75 GHz. This LCAMP has been manufactured and integrated into the Ku-band Linearized Traveling Wave Tube Amplifier (LCTWTA) to improve the linearity of TWTA, which will be in orbit.

14:10 ~ 14:30

5.3 / Highly Integrated Control Technology of Flexible LTWTA for Space Application

Bin He (China Academy of Space Technology (Xi'an) , China), Junping Li (China Academy of Space Technology (Xi'an) , China), Bin Zhou (China Academy of Space Technology (Xi'an) , China), Weibo Huang (China Academy of Space Technology (Xi'an) , China), Depeng Bai (China

Academy of Space Technology (Xi'an), China), Yukai Zhou (China Academy of Space Technology (Xi'an), China)

A highly integrated control technology for Flexible Linearized Travelling Wave Tube Amplifier (LTWTA) is proposed in this paper. This control technology has flexible and complete functions to achieve accuracy control effects, especially for the power adjustment range, which could be up to 3dB with 64 steps. Control module is optimized to fit response of TWT and to ensure drive security across the full flexible range. Moreover, the System In Package (SIP) circuit is designed to integrate nearly twenty chips and hundreds of resistors and capacitors, this distinct integrated package in control module realizes the miniaturization of the LTWTA product.

14:30 ~ 14:50

5.4 / 160W L-band High Efficiency Space TWT

Yiqun Liu (NANJING SANLE GROUP CO., LTD, China), Hongxia Cheng (NANJING SANLE GROUP CO., LTD, China), Xiaoran Zhang (NANJING SANLE GROUP CO., LTD, China), Xiaoyu Dong (NANJING SANLE GROUP CO., LTD, China), Yulu Hu (University of Electronic Science and Technology of China, China), Tao Huang (University of Electronic Science and Technology of China, China)

NanJing SanLe Group CO., LTD has recently developed a high efficiency L-band TWT for space communication and navigation systems. The TWT is space qualified and can get a stable output power of 160W at efficiencies exceeding 68% with the bandwidth. And the nonlinear characteristics also meet industrial requirements. This paper gives the main technical characteristics of the TWT and the main performances (industrial batch) with the bandwidth in L frequency range.

Session 6. MBKs

April 29 (Monday) / 13:30 ~ 15:10 / Room 3

Session Chair: Sung-Ju Park (Pohang Accelerator Laboratory, Korea)

13:30 ~ 13:50

6.1 / Thermal simulation of a Multiple Beam Electron gun for Ku-Band Klystron

Ayan Kumar Bandyopadhyay (CSIR-CEERI, India), Raktim Guha (CSIR-CEERI, India), Debasish Pal (CSIR-CEERI, India), Atmakuru Nagaraju (CSIR-CEERI, India), Rajendra Sharma (CSIR-CEERI, India)

This article reports thermal analysis of a multiple beam electron gun for a Ku band multiple beam klystron. Thermal analysis of the electron gun has been carried out to estimate temperature distribution at different parts of the electron gun including each individual emission button. It is necessary to have uniform temperature distribution among the emission buttons to ensure uniform electron emission. The electrode and support structure and joints have been optimized to minimize thermal drain in hot condition. Estimation of the thermal deformations in the cathode geometry and the operating power have also been done.

13:50 ~ 14:10

6.2 / On filter system tuning of wideband multibeam klystron with high-mode double-gap output cavity

Anatoly Galdetskiy (JSC “RPC “Istok” named after Shokin”, Russia), Nikita Golovanov (JSC “RPC “Istok” named after Shokin”, Russia), Serguey Scherbakov (JSC “RPC “Istok” named after Shokin”, Russia)

A new tuning technique for klystron output filter system is considered. It is based on comparison of partial frequencies of 3D model and optimized LC prototype of output cavity system. The use of double-gap active cavity and tripletuned filter system makes possible significant increasing of bandwidth. The results of simulation and tuning of output filter system for multibeam X-band klystron with double-gap active cavity operating on third mode are presented.

14:10 ~ 14:30

6.3 / Simulation of collector induced voltage in high-power multiple-beam klystron

Alexander N. Darmaev (JSC "RPE "Toriy". Russia), Dmitry A. Komarov (JSC "RPE "Toriy", Russia), Yury N. Paramonov (JSC "RPE "Toriy", Russia), Denis A. Kalashnikov (JSC "RPE "Toriy", Russia)

The paper deals with the effect of external electrical circuits on the conditions in high-power multiple-beam klystron collectors. A mathematical model describing the induced voltage on the

collector of the O-type devices with allowance for external electrical circuits taking into account the electric field distribution is presented. The possibility of reducing the collector induced voltage when using external capacitive elements and new collector design is shown.

14:30 ~ 14:50

6.4 / S-Band Wideband Multi-Beam Klystron with Reversed Permanent Magnet Focusing and High Average Power

Li Ye (Beijing Vacuum Electronics Research Institute, China), Li Dong-feng (Beijing Vacuum Electronic Research Institute, China), Yang Lu-xuan (Beijing Vacuum Electronic Research Institute, China), Zuo Haibo (Beijing Vacuum Electronic Research Institute, China), Wang Zi-wei (Beijing Vacuum Electronic Research Institute, China)

This paper presents a new developed S-Band Wideband High-Power Multi-Beam Klystron (MBK) . The tube is focused by reversed permanent magnet with a relative wideband over 13.6%.The average output power is over 20kW and the weight is only 34kg,which is easy for equipment dismantling and assembling. This MBK index is the highest in china at present.

14:50 ~ 15:10

6.5 / [Keynote] 6 kW L-band pulsed MBK with broad frequency band of 15%

Igor Guzilov (JSC, Vacuum device's basic technologies, Russia)

L-band MBK with frequency band of 15% and output power of 6kW that employs the new technology of decreasing cavity sizes was designed at VDBT. Two samples of MBK were fabricated and successively tested. The diameter of MBK is no more than a half of wavelength.

Session 7. HPM and Relativistic devices

April 29 (Monday) / 16:30 ~ 18:10 / Room 1

Session Chair: Edl Schamiloglu (University of New Mexico, USA)

16:30 ~ 16:50

7.1 / [Keynote] Preliminary experimental investigations into an oversized coaxial relativistic klystron amplifier at Ka band

Shifeng Li (University of Electronic Science and Technology of China / China Academy of Engineering Physics, China), Zhaoyun Duan (University of Electronic Science and Technology of China, China), Hua Huang (China Academy of Engineering Physics, China), B. N. Basu (Indian Institute of Technology (BHV), India), Zhiwei Dang (University of Electronic Science and Technology of China / China Academy of Engineering Physics, China), Yu Bai (China Academy of Engineering Physics, China), Zhanliang Wang (University of Electronic Science and Technology of China, China), Yubin Gong (University of Electronic Science and Technology of China, China)

Preliminary experimental results on an oversized high-power coaxial relativistic klystron amplifier (OCRKA) at Ka band were presented. The measured values on the cold-test setup agreed with those predicted by simulation. An annular intense relativistic electron beam (IREB) was produced by an explosive emission cathode in a diode with beam transmission greater than 88%. The device output power of ~100 kW was demonstrated, using a 517 kV, 4.9 kA IREB. Larger output power could have been obtained with improved input coupler of lower values of insertion loss.

16:50 ~ 17:10

7.2 / Enhancing the power of high power microwaves by using zone plate and investigations for the position of virtual cathode inside the drift tube

Sohail Mumtaz (Kwangwoon University, Korea), Jun Sup Lim (Kwangwoon University, Korea), Bhagirath Ghimire (Kwangwoon University, Korea), Suk Woo Lee (Kwangwoon University, Korea), Jin Joo Choi (Kwangwoon University, Korea), Eun Ha Choi (Kwangwoon University, Korea)

We have investigated the axial-typed vircator in our pulsed power generator, “Chundoong” (Max 600kV, 88kA, and 60ns), and simulated the vircator using the 3-D particle-in-cell simulation code called “MAGIC.” We try to find out the position of the virtual cathode (VC) inside the drift tube and enhance the power of microwaves by focusing them at the focus point using the ring-typed zone plate with a focal length of 18.8cm. The dominant frequency is obtained as 3.5GHz measured by fast Fourier transform, which is in good agreement with simulation frequency. It is found that the mean position of the VC is almost the same as the A-K gap distance of 10mm, in which the virtual cathode oscillates from 7.9mm to 12.1mm

behind the meshed anode, as verified by the simulation results. The maximum output power without the zone plate is obtained as 0.66GW with the efficiency of 27%, which is maximized up to 1.22GW with the efficiency of 51% at the focus point by using the zone plate. The microwave emission mode from the vircator is the TM01 mode based on the simulation results.

17:10 ~ 17:30

7.3 / Recent Advances in Relativistic MDOs

Edl Schamiloglu (University of New Mexico, USA), Mikhail Fuks (University of New Mexico, USA), Dmitrii Andreev (University of New Mexico, USA), Artem Kuskov (University of New Mexico, USA)

The relativistic magnetron is the most compact and efficient high-power microwave (HPM) source. It has been researched since Bekefi's pioneering work in 1975 at MIT. The performance of the relativistic magnetron did not dramatically improve until the 2000s when new cathode concepts were introduced independently by researchers at the University of Michigan and at the University of New Mexico. These advances demonstrably decreased the time for onset of oscillations and increased the efficiency. All of these earlier works involved relativistic magnetrons with radial extraction. Researchers at the University of New Mexico then revisited the magnetron with diffraction output and most recently have shown in particle-in-cellsimulations that its efficiency can exceed 90% when powered by a virtual cathode and leakage current is suppressed using a magnetic mirror. This paper summarizes our most recent advances.

17:30 ~ 17:50

7.4 / Novel Schemes of High-Power Relativistic Vircators

Semen Kurkin (University of Saratov, Russia), Artem Badarin (University of Saratov, Russia), Alexey Rak (Belarusian State University, Belarus), Alexey Koronovskii (Saratov State University, Russia), Alexander Hramov (University of Saratov, Russia)

The following novel schemes of relativistic generators with virtual cathode were proposed and investigated in terms of enhancing output power, efficiency and generation frequency: multibeam vircator; vircator with elliptical resonator; vircator with photonic crystal. The carried-out analysis and obtained results have shown efficiency of the proposed vircator schemes.

17:50 ~ 18:10

7.5 / High-power THz Wave Generation through Coherent Cherenkov Radiation based on a Plasma Dielectric Wake-field Accelerator using Relativistic Annular Electron Beam

Sun-Hong Min (Korea Institute of Radiological and Medical Sciences, Korea), Ohjoon Kwon (Institute for Basic Science Center for Axion and Precision Physics Research, Korea), Matlabjon Sattorov (Seoul National University / Seoul-Teracom, Inc., Korea), Seontae Kim (Seoul National University, Korea), Dongpyo Hong (Seoul National University, Korea), Chawon Park (Korea Institute of Radiological and Medical Sciences, Korea), Ilsung Cho (Korea Institute of Radiological and Medical Sciences, Korea), Bong Hwan Hong (Korea Institute of Radiological and Medical

Sciences, Korea), In Su Jung (Korea Institute of Radiological and Medical Sciences, Korea), Won Taek Hwang (Korea Institute of Radiological and Medical Sciences, Korea), Gun-Sik Park (Seoul National University, Korea)

Generally, as the operating frequency of the electromagnetic wave increases, the maximum output becomes smaller and the wavelength of the wave becomes smaller, so that the size of the circuit cannot but be reduced. Particularly, fabrication of a circuit with a high-power terahertz (THz) wave frequency band of kW or more is limited due to the problem of circuit size on the order of μm to mm. In order to overcome these limitations, this paper proposes a source design technique of 0.1THz-0.3GW levels with a cylindrical shape with a diameter of about 2.4cm. Modeling and computational simulation were performed to optimize the design of high power electromagnetic sources based on the Cherenkov radiation generation technology using the principle of plasma wake-field acceleration with ponderomotive force and artificial dielectrics. An effective design guideline has been proposed to facilitate the fabrication of large-power terahertz wave vacuum devices of large diameter that are less restricted in circuit size through objective verification.

Session 8. Millimeter-wave TWTs-I

April 29 (Monday) / 16:30 ~ 17:50 / Room 2

Session Chair: Zhaoyun Duan (University of Electronic Science and Technology of China, China)

16:30 ~ 16:50

8.1 / Fabrication and measurements of a planar slow wave structure operating in V-band

Giacomo Ulisse (Goethe University Frankfurt, Germany), Viktor Krozer (Goethe University Frankfurt, Germany), Nikita Ryskin (Institute of Radio Engineering and Electronics RAS / Saratov State University, Russia), Andrey Starodubov (Institute of Radio Engineering and Electronics RAS / Saratov State University, Russia), Alexey Serdobintsev (Saratov State University, Russia), Viktor Galushka (Saratov State University, Russia), Mikhail Samarskiy (Institute of Radio Engineering and Electronics RAS, Russia), Anton Pavlov (Saratov State University, Russia)

A traveling wave tube amplifier (TWTa) operating in V-band (62-65 GHz) was designed considering a planar slow wave structure (SWS). Particle in cell simulations were performed to calculate the gain and the output power of the TWT. The simulated TWT showed a maximum gain of 36 dB at 64 GHz and an output power of 16 W. The planar SWS was then fabricated with a laser machining technique. Sparameters measurements of the SWS showed excellent matching and low losses in the operating frequency band.

16:50 ~ 17:10

8.2 / 71 – 76 GHz Folded Waveguide TWT for Satellite Communications

C.W. Robertson (University of Strathclyde, UK), A.W. Cross (University of Strathclyde, UK), C. Gilmour (TMD Technologies LTD, UK), D. Dyson (TMD Technologies LTD, UK), P. G. Huggard (STFC Rutherford Appleton Laboratory, UK), F. Cahill (STFC Rutherford Appleton Laboratory, UK), M. Beardsley (STFC Rutherford Appleton Laboratory, UK), R. Dionisio (ESA ESTEC, NL), Kevin Ronald (University of Strathclyde, UK)

A high frequency folded waveguide travelling wave tube (TWT) has been designed to test this delay line technology. Envisaged applications of the technology are in satellite communications. PIC 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. Simulations of the return loss of the vacuum windows yield values lower than -30 dB cross the frequency band of interest.

17:10 ~ 17:30

8.3 / 80 to 100 Watts TWT in Q-band for Space Downlink Communication

Frédéric André (Thales AVS / MIS, France), Justin Demory (Thales AVS / MIS, France), Jean

Gastaud (Thales AVS / MIS, France), Wolfgang Dürr (Thales Germany / MIS, Germany), Dawid Kupidura (Thales Germany / MIS, Germany), Natanael Ayllon (ESA, The Netherlands), Roberto Dionisio (ESA, The Netherlands), Jérôme Puech (CNES, France)

The first breadboard results for the development of a new TWT in Q-band with 80 to 100W of saturated power are presented. Two technologies for the delay have been tested at TWT level. They have successfully reached the targetted performances in terms of power, efficiency and oscillation margins. More than 100W of saturated power has been reached with both technologies in broadband operation covering the full band of 5 GHz allocated around 40 GHz. These results give strong confidence on the feasibility of this commercial product.

17:30 ~ 17:50

8.4 / A Novel Beam Forming Electrode for Sheet Beam Electron Gun

Shaomeng Wang (Nanyang Technological University, Singapore), Sheel Aditya (Nanyang Technological University, Singapore), Yuanjin Zheng (Nanyang Technological University, Singapore)

A novel beam focusing electrode (BFE) is proposed for an electron gun to form a sheet electron beam. The proposed BFE is in the shape of an elliptical ring and is defined by the parameters of height and the lengths of the major and minor axis. The BFE is suitable for microfabrication and can be designed to form a sheet electron beam from either a rectangular cathode or circular cathode. A thermionic electron gun with a circular-cylindrical cathode is then designed based on the proposed BFE. CST particle studio is used to determine the electron beam trajectory and to achieve a sheet electron beam with beam current of 20 mA, voltage of 4000 V, and cross-section size of 0.75 mm×0.15 mm. The fabrication and assembly of the thermionic electron gun are also briefly described.

Session 9. Systems / Power supply

April 29 (Monday) / 16:30 ~ 17:50 / Room 3

Session Chair: Michael Kempkes (Diversified Technologies, Inc., USA)

16:30 ~ 16:50

9.1 / [Keynote] Development of a Solid State Pulsed Power Supply IGBT Modulator for Gyrotron TWT

Youlei Pu (University of Electronic Science and Technology of China, China), Zewei Wu (University of Electronic Science and Technology of China, China), Junqian Jin (University of Electronic Science and Technology of China, China), guo liu (University of Electronic Science and Technology of China, China), wei jiang (University of Electronic Science and Technology of China, China), zhigang lu (University of Electronic Science and Technology of China, China), Yong luo (University of Electronic Science and Technology of China, China)

This paper describes the development of a solid state pulsed power supply (SSPPS) IGBT Switch for high power millimeter wave gyrotron. The modulator is made up of seriesconnected insulated gate bipolar transistor (SC-IGBT). Finally, the developed IGBT Modulator can output the pulse with the maximum repetition rate is 10-kHz and the pulse width from 5us to DC, the amplitude of the output can be adjusted from 0 to 60 kV.

16:50 ~ 17:10

9.2 / Integrated Klystron Test Stand

Marcel P.J. Gaudreau P.E. (Diversified Technologies, Inc., USA), Luan Jashari (Diversified Technologies, Inc., USA), Michael Kempkes (Diversified Technologies, Inc., USA), Rebecca Simpson (Diversified Technologies, Inc., USA)

Diversified Technologies, Inc. (DTI) recently delivered an Integrated Klystron Test Stand for klystrons under development at the Naval Research Laboratory (NRL) and Communication and Power Industries, Inc. (CPI). The test stand provides an HV beam and depressed collector power supplies, mod-anode modulator, controls, and circuit /klystron protection. The Integrated Klystron Test Stand simplifies and speeds the ability of the user to safely and efficiently test and exercise the klystron over the full range of its capabilities.

17:10 ~ 17:30

9.3 / HV Solid State Series Switch 18kV/50A: Technology Demonstrator for ESS Spoke RF Power Station

Rutambhara Yogi (European Spallation Source, Sweden), Carlos Martins (European Spallation Source, Sweden), Petro Pohorilo (European Spallation Source, Sweden), Matthew Bergstrom

(European Spallation Source, Sweden)

The European Spallation Source (ESS) will be the world's most powerful pulsed neutron source by the end of the decade, which will accelerate a beam of protons with a beam current 62.5 mA to 2 GeV. The beam pulse width is 2.86 ms long and pulse repetition frequency is 14 Hz. The acceleration will be provided by 155 cavities, out of which 97 % of the cavities are superconducting. The first section of the ESS superconducting linac is Spoke linac consisting of 26 spoke cavities resonant at 352 MHz.

The maximum power requirement for ESS spoke RF power station is 400kW. It will be achieved by combining the output of two tetrode TH595 amplifiers. The two tetrodes are powered by a single anode power supply. Instead of standard crow-bar protection, a single series switch will be used to protect the two tetrodes. Such series switch was developed for ESS.

The present paper discusses the selection of series switch over the crow-bar and the first test results of the technology demonstrator HV series switch.

17:30 ~ 17:50

9.4 / Ku-Band Dual TWTs Pulsed MPM for Space Application

Weibo Huang (China Academy of Space Technology (Xi'an), China), Hui Li (China Academy of Space Technology (Xi'an), China), Qianwen Chen (China Academy of Space Technology (Xi'an), China), Bin Zhou (China Academy of Space Technology (Xi'an), China), Bib He (China Academy of Space Technology (Xi'an), China), Depeng Bai (China Academy of Space Technology (Xi'an), China)

The advances to MPM is introduced. A compact Microwave Power Module (MPM) for Space application is presented which consists of an electronic power conditioner (EPC), two solid-state power amplifiers (SSPA) and two short travelling wave tubes (TWT). The EPC and SSPA are assembled together with these two TWTs in one housing. The MPM weight less than 7kg is capable of providing output power over 500W with 45% efficiency in 15% duty cycle. The Phase Coherence of it is less than 5degree.

Session 10. Modeling-II

April 30 (Tuesday) / 10:20 ~ 12:00 / Room 1

Session Chair: Khanh Nguyen (Beam Wave Research, Inc., USA)

10:20 ~ 10:40

10.1 / [Keynote] Elastostatics in Beam Optics Analyzer

Thuc Bui (Calabazas Creek Research Inc., USA), David Marsden (Calabazas Creek Research Inc., USA), R. Lawrence Ives (Calabazas Creek Research Inc., USA)

Beam Optics Analyzer has the new capability to perform stress analysis making it a truly multiphysics computational tool. Finite element formulation of elastostatics will be described, and thermal stress analysis from radiation and electrons heating a triode control grid will be presented.

10:40 ~ 11:00

10.2 / Simulation of a Double-gap Coupled Cavity Based on Finite Element Method

Hangxin Liu (University of Electronic Science and Technology of China, China), Li Xu (University of Electronic Science and Technology of China, China), Xiaofang Zhu (University of Electronic Science and Technology of China, China), Zhonghai Yang (University of Electronic Science and Technology of China, China), Bin Li (University of Electronic Science and Technology of China, China)

In Extended Interaction Klystrons (EIK), multiple interaction gaps within one cavity is used to increase the impedance of the cavity eigenmode, decrease the voltage between each gap, and enhance the power capability of the cavity. It is significant to project numerical simulation method used in the analysis of cavities with multiple coupled gaps. In this paper, using the finite element method, a simulator named High Frequency Circuit Simulator for Cavity (HFCS-C) was developed and used for design and analysis of multi-gap coupled cavity. To validate HFCS-C, numerical results for a double-gap coupled cavity structure are compared with HFSS in detail.

11:00 ~ 11:20

10.3 / Optimization of the Cut-cell Mesh-Generating Code for Simulation of Vacuum Electronic Devices

Wenjin Cai (University of Electronic Science and Technology of China, China), Xiaolin Jin (University of Electronic Science and Technology of China, China), Xiaoliang Gu (University of Electronic Science and Technology of China, China), Tao Huang (University of Electronic Science and Technology of China, China), Bin Li (University of Electronic Science and

Technology of China, China)

A cut-cell mesh-generating code was developed and optimized to simulate vacuum electronic devices. This code can provide the needed Cut-cell mesh when simulating vacuum devices by conformal Finite Differential Time Domain (FDTD) method. This article was focused on the efficiency improvement of the Cut-cell mesh-generation code. The test results show that the meshing efficiency is greatly improved while maintaining the certain computational accuracy.

11:20 ~ 11:40

10.4 / Backward-Wave Oscillator with Distributed Power Extraction Based on Exceptional Point of Degeneracy and Gain and Radiation-Loss Balance

Tarek Mealy (University of California, USA), Ahmed F. Abdelshafy (University of California, USA), Filippo Capolino (University of California, USA)

We propose a new design paradigm for power efficient backward-wave oscillators (BWOs). Conventional BWOs exhibit small starting current and limited power efficiency. We introduce the concept of distributed radiation loss in a hot slow wave structure (SWS) working at an exceptional point of degeneracy (EPD) to achieve high power extraction from the electron beam aiming at high power efficiency. We show how the simultaneous presence of distributed radiation loss and distributed gain arising from the electron beam can be exploited to realize an EPD. In principle this new condition guarantees full synchronization between the electromagnetic (EM) guide mode and the charge wave for any amount of beam current and power extracted. We show how radiating EM modes (viadistributed apertures) with backward propagation in the SWS and interacting with the charge wave are engineered to exhibit a second order EPD. We also show that including distributed radiation-losses in the design results in having high threshold current which implies higher power generation.

11:40 ~ 12:00

10.5 / Self-Similar Analysis of Short Pulse Amplification and Generation in Cherenkov-type Devices

Alena Rostuntsova (Saratov State University, Russia), Nikita M. Ryskin (Institute of Radio Engineering and Electronics RAS, Russia), Naum S. Ginzburg (Institute of Applied Physics RAS, Russia)

The equations describing the interaction of an electron beam with an electromagnetic wave in Cherenkovtype vacuum tube devices allow a self-similar solution describing amplification and compression of short electromagnetic pulses. In this paper, we discuss the main features of the self-similar solutions and present the results of detailed numerical simulations, which confirm the theoretical analysis.

Session 11. TWTs-II

April 30 (Tuesday) / 10:20 ~ 11:40 / Room 2

Session Chair: R. K. Sharma (Central Electronic Engineering Research Institute, India)

10:20 ~ 10:40

11.1 / [Keynote] Two-Beam Ku-Band Oscillator-Amplifier Using a Planar Helix Slow-Wave Structure

Ajith Kumar M. M (Nanyang Technological University, Singapore), Sheel Aditya (Nanyang Technological University, Singapore)

A novel two-beam oscillator-amplifier based on planar helix slow-wave structure with straight-edge connections is presented. The device combines the operation of both oscillator and amplifier in a single slow-wave structure. The simulation results show that the operating frequency of the oscillator-amplifier tunes from 14.1 GHz to 19.1 GHz when the beam voltage for backward-wave synchronization varies from 3 KV to 8 KV. The output performance of the oscillatoramplifier is compared with that of the conventional backward wave oscillator (BWO) using the same slow-wave structure. The comparison shows that the oscillator-amplifier gives an efficiency improvement of at least two times compared to that of the conventional BWO. Significantly, the oscillator-amplifier preserves the size as well as the tuneable bandwidth of the conventional BWO.

10:40 ~ 11:00

11.2 / Group Delay Distortion Optimization for a L-band Helix TWT with a Positive-Tapered Pitch Segment

Wenkai Deng (University of Electronic Science and Technology of China, China), Yulu Hu (University of Electronic Science and Technology of China, China), Quan Hu (University of Electronic Science and Technology of China, China), Xiaofang Zhu (University of Electronic Science and Technology of China, China), Bin Li (University of Electronic Science and Technology of China, China)

Group delay is an important parameter to evaluate the performance of space traveling wave tubes. In this paper, a positive-tapered pitch profile is introduced in the input segment and the length of the second segment is slightly adjusted to optimize the group delay performance of a L-band space TWT. Using this method, the group delay is finally successfully reduced to less than 1ns without loss of gain. The optimization is fulfilled in Microwave Tube Simulator Suite.

11:00 ~ 11:20

11.3 / Tape-Helix Analysis of Shielded Planar Helix Slow-Wave Structure

Ajith Kumar M. M (Nanyang Technological University, Singapore), Sheel Aditya (Nanyang Technological University, Singapore)

An analysis using tape-helix approximation to determine the dispersion characteristics and interaction impedance of planar helix slow-wave structure with straight edge connections shielded by a metal enclosure is presented. The complexity of the analysis is reduced by incorporating the characteristic equation of an infinitely wide planar helix inside a metal enclosure with the effective dielectric constant methods. The results from this analysis are compared with those from the CST microwave studio. The comparison shows that the results from the presented tape-helix analysis are accurate in the frequency range far from cutoff.

11:20 ~ 11:40

11.4 / A Simulation Method of Graphite Heat Extrusion Process for High-Frequency Structure of Helix TWTs

Jingyuan Che (University of Electronic Science and Technology of China, China), Xiaofang Zhu (University of Electronic Science and Technology of China, China), Yulu Hu (University of Electronic Science and Technology of China, China), Quan Hu (University of Electronic Science and Technology of China, China), Bin Li (University of Electronic Science and Technology of China, China)

A simulation method of Graphite Heat Extrusion Process for high-frequency structure of helix STWT is proposed in this paper. The Graphite Heat Extrusion Process includes both the heating and the cooling process which cannot be simulated in a whole simulation, so we simulate them respectively in ANSYS Workbench. The model after heating is somewhat damaged and need to be repaired in ANSYS Workbench. The effects of the deformation on electrical characteristics of the high-frequency structure can be analyzed with Microwave Tube Simulator Suite (MTSS). Using this method, the working parameters of the Graphite Heat Extrusion Process can be evaluated, as well the performance of the manufactured high-frequency structure can be observed.

Session 12. Thermionic cathodes

April 30 (Tuesday) / 10:20 ~ 12:20 / Room 3

Session Chair: Jun Chen (Sun Yat-sen University, China)

10:20 ~ 10:40

12.1 / [Keynote] Space Qualification of M- and MMC-type Cathodes at High Current Density

Christof Dietrich (Thales Germany / MIS, Germany), Jean-Michel Roquais (Thales AVS / MIS, France), Justin Demory (Thales AVS / MIS, France), Frédéric André (Thales AVS / MIS, France)

The need for higher current densities in combination with a long lifetime in recent TWT development, in particular in Q-band, drives a permanent improvement of cathode technology, models and operating conditions at Thales. Building on the very positive on-orbit experience with the M-type cathode up to 2.5 A/cm^2 we show in this presentation that this cathode can safely operate at 4 A/cm^2 for a space mission with a lifetime exceeding 15 years provided that its operating temperature is adequately adjusted. In parallel Thales is pursuing the development of an improved MM-type cathode doped with chromium (so-called MMC-type) targetting a qualification at 5 A/cm^2. We update on the latest results.

10:40 ~ 11:00

12.2 / Thermally Assisted Photoemission of CeB_6 at High Temperatures

Konstantin Torgasin (Kyoto University, Japan), Kenichi Morita (Kwawsaki Heavy Industry, Ltd., Japan), Heishun Zen (Kyoto University, Japan), Kai Masuda (Kyoto University, Japan), Toshiteru Kii (Kyoto University, Japan), Kazunobu Nagasaki (Kyoto University, Japan), Hideaki Ohgaki (Kyoto University, Japan)

Photocurrent of CeB_6 was measured over wide range of temperature. The photocurrent at high temperature exceeds the value expected by the Fowler-DuBridge theory. A transmission coefficient was introduced to the photoemission equation in order to account for electron escape probability. The fitting of measured data reveals that the transmission coefficient can not explain the rise in photocurrent at high temperatures for different photonenergies.

11:00 ~ 11:20

12.3 / Study on the thermal effect of photon-induced electron emission enhancement

Yanxiao Guo (Southeast University, China), Hehong Fan (Southeast University, China), Hang Du (Southeast University, China), Xiaohan Sun (Southeast University, China), Zhengqiang Bao (Nanjing Sanle Group Co. Ltd, China), Tian Liang (Nanjing Sanle Group Co. Ltd, China), Wenjing Hu (Nanjing Sanle Group Co. Ltd, China)

In order to investigate the thermal effect of photon-induced enhancement of electron emission, emissions from a diode with coated Ba-W cathode under different temperature & voltage conditions, and under certain irradiation of ultraviolet light were detected. The measured results were compared with theoretical results of thermo-optical-emission. Experiments showed that, the measured photon-induced enhancement of electron emission, as well as the quantum efficiency, remained almost the same at low values within a large temperature range, but increased dramatically from temperatures 100K-400K below the normal cathode operation temperature, with the maximum quantum efficiency reached 6.0×10^{-2} at 1290K. Furthermore, apparent peaks appeared on tested ΔI-Va curves near knee-voltage points, which demonstrated different tendencies than theoretical estimated results.

11:20 ~ 11:40

12.4 / The work function of the Ammonium Perrhenate Impregnated W Matrix Ba-W Cathode

Wang Xiaoxia (Chinese Academy of Sciences, China), Xiaoqian Chen (Chinese Academy of Sciences, China), Shuai Zhang (Chinese Academy of Sciences, China), YUN li (Chinese Academy of Sciences, China), Qi Zhang (Chinese Academy of Sciences, China)

In this paper we mainly describes the research progress in a kind of ammonium perrhenate impregnated W matrix Ba-W cathode, which includes the work function measuring and the lifetime testing of the cathode. The work function measuring results shows that the initial practice work function of the cathode is 1.75eV. After 41571h lifetime at a temperature of 1000º Cbr ~ 1010º Cbrand a dc load of 3.0 A/cm^2, the practice work function increase to 1.84eV.

11:40 ~ 12:00

12.5 / Statistical Model of Non-Uniform Emission from Polycrystalline Tungsten Cathodes

Dongzheng Chen (University of Wisconsin-Madison, USA), Ryan Jacobs (University of Wisconsin-Madison, USA), Vasilios Vlahos (L3 Technologies, USA), Dane Morgan (University of Wisconsin-Madison, USA), John Booske (University of Wisconsin-Madison, USA)

We have constructed a model capturing the statistical nature of non-uniform thermionic electron emission from polycrystalline W cathodes. This model incorporates the proportion of different crystallographic emitting surfaces from commercial cathode samples via electron backscatter diffraction (EBSD), the effects of surface roughness from optical interferometry measurements, and surface-specific work function values calculated using density functional theory (DFT). Using this model, we aim to calculate 2D emission maps and the corresponding Miram curves for real cathodes. This model provides a pathway to understanding the complex physics of emission from inhomogeneous cathode surfaces, which is a key issue for the commercial production and use of impregnated cathodes in vacuum electronic devices.

12:00 ~ 12:20

12.6 / LaB_6 cathode workfunction and operating temperature

Victor Katsap (NuFlare Technology America, Inc., USA), Chising Lai (NuFlare Technology America, Inc., USA)

LaB_6 cathode is the emitter of choice in electron beam lithography tools. We have devised and implemented simple, robust technique for evaluating LaB_6 cathode workfunction (WF), and studied workfunction-operating temperature relationship.

Session 13. Fusion gyrotrons

April 30 (Tuesday) / 13:30 ~ 15:10 / Room 1

Session Chair: John Jelonnek (Karlsruhe Institute of Technology, Germany)

13:30 ~ 13:50

13.1 / [Keynote] Development of Megawatt Gyrotrons in IAP/GYCOM

G. Denisov (Institute of Applied Physics Russian Academy of Sciences, Russia), A. Litvak (Institute of Applied Physics Russian Academy of Sciences, Russia), E. Sokolov (GYCOM Ltd, Russia), A. Chirkov (Institute of Applied Physics Russian Academy of Sciences, Russia), A. Eremeev (Institute of Applied Physics Russian Academy of Sciences, Russia), E. Tai (GYCOM Ltd, Russia), E. Soluyanova (GYCOM Ltd, Russia), V. Myasnikov (GYCOM Ltd, Russia), L. Popov (GYCOM Ltd, Russia)

A brief summary of current developments in Russia of megawatt power gyrotrons is presented. The gyrotron developed are applied in experiments at several modern tokamaks. New demands to gyrotron parameters and possible ways to reach them are discussed.

13:50 ~ 14:10

13.2 / From W7-X Towards ITER and Beyond: 2019 Status on EU Fusion Gyrotron Developments

John Jelonnek (IHM / IHE, Gremany), Gaetano Aiello (IAM-AWP, Germany), Ferran Albajar (Fusion for Energy, Spain), Stefano Alberti (Swiss Plasma Center, EPFL, Switzerland), Konstantinos A. Avramidis (IHM, Gremany), Andrea Bertinetti (Politecnico Di Torino, Italy), Philippe T. Brücker (IHM, Gremany), Alex Bruschi (National Research Council of Italy, Italy), Ioannis Chelis (National and Kapodistrian University of Athens, Greece), Jérémie Dubray (Swiss Plasma Center, EPFL, Switzerland), Francesco Fanale (National Research Council of Italy, Italy), Damien Fasel (Politecnico Di Torino, Italy), Thomas Franke (EUROfusion Consortium, Germany), Gerd Gantenbein (IHM, Gremany), Saul Garavaglia (National Research Council of Italy, Italy), Jérémy Genoud (Swiss Plasma Center, EPFL, Switzerland), Gustavo Granucci (National Research Council of Italy, Italy), Jean-Philippe Hogge (Swiss Plasma Center, EPFL, Switzerland), Stefan Illy (IHM, Gremany), Zisis C. Ioannidis (IHM, Gremany), Jianbo Jin (IHM, Gremany), Heinrich Laqua (Max-Planck-Institut für Plasmaphysik, Germany), George P. Latsas (National and Kapodistrian University of Athens, Greece), Alberto Leggieri (Microwave & Imaging Solution, THALES, France), Francois Legrand (Microwave & Imaging Solution, THALES, France), Rodolphe Marchesin (Microwave & Imaging Solution, THALES, France), Alexander Marek (IHM, Gremany), Blaise Marlétaz (Swiss Plasma Center, EPFL, Switzerland), Martin Obermaier (IHM, Gremany), Ioannis Gr. Pagonakis (IHM, Gremany), Dimitrios V. Peponis (National and Kapodistrian University of Athens, Greece), Sebastian Ruess (IHM / IHE, Gremany), Tobias Ruess (IHM, Gremany), Tomasz Rzesnicki (IHM, Gremany), Paco Sanchez (Fusion for Energy, Spain), Laura Savoldi (Politecnico Di Torino, Italy), T. Scherer (IAM-AWP, Germany), D. Strauss (IAM-AWP, Germany), Philippe

Thouvenin (Microwave & Imaging Solution, THALES, France), Manfred Thumm (IHM / IHE, Gremany), Ioannis Tigelis (National and Kapodistrian University of Athens, Greece), Minh-Quang Tran (Swiss Plasma Center, EPFL, Switzerland), Fabian Wilde (Max-Planck-Institut für Plasmaphysik, Germany), Chuanren Wu (IHM, Germany), Anastasios Zisis (National and Kapodistrian University of Athens, Greece)

In Europe, the research and development with main focus on achieving robust industrial designs of series gyrotrons for electron cyclotron heating and current drive of today' nuclear fusion experiments and towards a future DEMOnstration fusion power plant is constantly progressing. The R&D is following two different paths. Both are complementing each other: Firstly, it is the adaption of the physical design and basic mechanical construction of the reliably operating 140 GHz, 1 MW CW (spec.: 920 kW, 1800 s) gyrotron of the stellarator Wendelstein 7-X (W7-X), Greifswald, Germany. With regards to time and costs it is the target to perform reliable developments of fusion gyrotrons with advanced specifications for today' plasma fusion experiments. Main focus is on the development of the first EU 170 GHz, 1 MW CW (3600 s) gyrotron for the installation in ITER, Cadarache, France. Another adaption is the dualfrequency 126/84 GHz 1 MW (2 s) gyrotron upgrade for the medium size TCV tokamak, Lausanne, Switzerland. Finally, it is the upgrade of the W7-X gyrotron design towards an RF output power per unit of up to 1.5 MW and possible dualfrequency operation by keeping the basic mechanical construction. Additional to the proven design it allows to fit the new 1.5 MW gyrotron into the already existing infrastructure and to reuse existing W7-X gyrotron auxiliaries, e. g. the highpower voltage supply (HV PS) and the superconducting (SC) magnet. The second R&D path is defined by the complementary approach with regards to development risks towards a future gyrotron which shall fulfil the significant more advanced specifications of a future EU DEMO. The starting point is the 2 MW EU/KIT coaxial-cavity gyrotron design. Main requirements are an RF output power of 2 MW CW at above 200 GHz, multiple operating frequencies, frequency step-tunability and a total efficiency above 60 %.

14:10 ~ 14:30

13.3 / Study of 140GHz and 170GHz gyrotrons for fusion plasma ECRH

Bentian Liu (Beijing Vacuum Electronics Research Institute, China), Jinjun Feng (Beijing Vacuum Electronics Research Institute, China), Yichi Zhang (Beijing Vacuum Electronics Research Institute, China), Yang Zhang (Beijing Vacuum Electronics Research Institute, China), Bo Chen (Beijing Vacuum Electronics Research Institute, China)

The development of 140GHz and 170GHz MW gyrotron research in BVERI are given in this paper. There are three versions of the 140GHz MW gyrotrons which have been designed and fabricated in BVERI. All of the 140GHz gyrotron have been tested and the experimental results have been enhanced to output power of 500KW with Gaussian beam. Using the techniques achieved in the study on the 140GHz gyrotorns, the 170GHz gyrotron has been designed with the sing-depressed collector and quasi-optical mode converter.

14:30 ~ 14:50

13.4 / Manufacturing and Test of the 1 MW Long-Pulse 84/126 GHz Dual-Frequency Gyrotron for TCV

Rodolphe Marchesin (Microwave Imaging Solution, THALES, France), Stefano Alberti (Swiss Plasma Center, EPFL, Switzerland), Konstantinos A. Avramidis (Karlsruhe Institute of Technology, Germany), Andrea Bertinetti (Politecnico Di Torino, Italy), Jérémie Dubray (Swiss Plasma Center, EPFL, Switzerland), Damien Fasel (Swiss Plasma Center, EPFL, Switzerland), Gerd Gantenbein (Karlsruhe Institute of Technology, Germany), Jérémy Genoud (Swiss Plasma Center, EPFL, Switzerland), Jean-Philippe Hogge (Swiss Plasma Center, EPFL, Switzerland), John Jelonnek (Karlsruhe Institute of Technology, Germany), Jianbo Jin (Karlsruhe Institute of Technology, Germany), Stefan Illy (Karlsruhe Institute of Technology, Germany), Francois Legrand (Microwave Imaging Solution, THALES, France), Blaise Marlétaz (Swiss Plasma Center, EPFL, Switzerland), Alberto Leggieri (Microwave Imaging Solution, THALES, France), Laura Savoldi (Politecnico Di Torino, Italy), Philippe Thouvenin (Microwave Imaging Solution, THALES, France), Ioannis Gr. Pagonakis (Karlsruhe Institute of Technology, Germany), Minh-Quang Tran (Swiss Plasma Center, EPFL, Switzerland), Manfred Thumm (Karlsruhe Institute of Technology, Germany)

An 1 MW long-pulse (2s), 84/126 GHz dual-frequency gyrotron has been produced by THALES MSI, France responding to the needs for upgrading the ECH system of the TCV tokamak. The initial tests of the prototype carried out at EPFL, Switzerland, have verified a stable operation at both frequencies in short-pulse operation (TRF≤10ms) with measured output powers in excess of 0.9 MW at 84GHz and 1.0 MW at 126 GHz.

14:50 ~ 15:10

13.5 / Megawatt Power-Level G-band Planar Gyrotrons with Transverse Energy Extraction

Naum Ginzburg (Institute of Applied Physics RAS / Nizhny Novgorod State University, Russia), Vladislav Zaslavsky (Institute of Applied Physics RAS / Nizhny Novgorod State University, Russia), Alexander Sergeev (Institute of Applied Physics RAS, Russia), Irina Zotova (Institute of Applied Physics RAS, Russia)

Modern controlled-fusion facilities are equipped with electron-cyclotron plasma fusion systems based on gyrotron complexes, in which the maximum continuous-wave radiation power has been achieved at a megawatt power level in the millimeter wavelength range. At the same time, a higher frequency of microwave sources is required for novel compact fusion reactors with strong magnetic fields. For example, the DEMO reactor project, which is intensely discussed at present, requires development of shorter-wave megawatt continuouswave sources having a frequency of 220-60 GHz. As such sources, we suggest gyrotrons of planar geometry of interaction space with a sheet electron beam and transverse energy extraction. An advantage of this scheme in comparison with conventional cylindrical geometry is the possibility to ensure effective mode selection over the open transverse coordinate in combination with radiation outcoupling that leads to a substantial reduction of Ohmic losses. In this paper we perform theoretical analysis and numerical simulation of two G-band planar gyrotrons operating at the

first harmonic of the cyclotron frequency. First, 140 GHz planar gyrotron driven by a sheet helical electron beam with an energy of 50 keV and beam current of 30 A is studied. The project of this oscillator is under development at Institute of Applied Physics RAS currently. Finally, simulations of 260 GHz megawatt power planar gyrotron for DEMO project are considered.

Session 14. D/G-band TWTs

April 30 (Tuesday) / 13:30 ~ 15:10 / Room 2

Session Chair: Nikita Ryskin (Institute of Applied Physics, Russian Academy of Sciences, Russia)

13:30 ~ 13:50

14.1 / [Keynote] System Development and Perfomance Evaluation of a 0.272 THz Pulsed Folded Waveguide Traveling Wave Tube Oscillator

Ingeun Lee (Ulsan National Institute of Science and Technology, Korea), Wonjin Choi (Ulsan National Institute of Science and Technology, Korea), Ashwini Sawant (Ulsan National Institute of Science and Technology, Korea), Mun Seok Choe (Ulsan National Institute of Science and Technology, Korea), Jinwoo Shin (Agency of Defese Development, Korea), EunMi Choi (Ulsan National Institute of Science and Technology, Korea)

We present recent experimental results of a 0.272 THz energy-recirculating folded-waveguide traveling wave tube oscillator, developed in Ulsan National Institute of Science and Technology (UNIST), South Korea. Main components of the device were designed, fabricated, and evaluated individually. The 11 kV and 92 mA electron-beam from the scandate cathode is guided by a solenoidal magnet system and the electron transmission rate is monitored. The generated signal from the device is analyzed by a developed plasmonic THz detector and a heterodyne system. The details will be provided in the paper.

13:50 ~ 14:10

14.2 / Design of D-band Double Corrugated Waveguide TWT for Wireless Communications

Rupa Basu (Lancaster University, UK), Laxma R. Billa (Lancaster University, UK), Jeevan M. Rao (Lancaster University, UK), Rosa Letizia (Lancaster University, UK), Claudio Paoloni (Lancaster University, UK)

The European Commission Horizon 2020 ULTRAWAVE, “Ultra capacity wireless layer beyond 100 GHz based on millimeter wave Traveling Wave Tubes”, aims to exploit portions of two frequency bands in the millimetre wave spectrum, the D-band (141 -148.5 GHz) and the G-band (275 - 305 GHz) for creating a very high capacity layer. Due to the high atmosphere and rain attenuation, high transmission power is needed to provide a useful transmission range. Traveling Wave Tubes are the only devices that can provide the multi-Watt transmission power above 100 GHz. In this paper, the design of the Double Corrugated Waveguide (DCW), as slow wave structure, for a novel D-band TWT, for wireless communications, will be described.

14:10 ~ 14:30

14.3 / The Electron Optical System for 0.34-THz Folded Waveguide Traveling Wave Tube

Peng Hu (China Academy of Engineering Physics, China), Wenqiang Lei (China Academy of Engineering Physics, China), Yi Jiang (China Academy of Engineering Physics, China), Yinhu Huang (China Academy of Engineering Physics, China), Rui Song (China Academy of Engineering Physics, China), Hongbin Chen (China Academy of Engineering Physics, China)

The electron optical system (EOS) for a 0.34-THz folded waveguide traveling wave tube is designed and tested, the electron gun of this EOS is a pierce triode electron gun, the focusing magnetic system is a periodic permanent magnet (PPM) system. In the test of beam transmission tube, the emission current achieves 24.5 mA, the transmission ratio achieves 92%, and the duty cycles achieve 50% with forced cooling.

14:30 ~ 14:50

14.4 / Studies on sub-THz Sheet-Beam TWT with Staggered Grating Slow-Wave Structure

Anton A. Burtsev (RPE "Almaz" Saratov, Russia), Igor Navrotsky (RPE "Almaz" Saratov, Russia), Nikita M. Ryskin (V.A. Kotel'nikov Institute of Radio Engineering and Electronics RAS Saratov, Russia), Aleksei V. Danilushkin (RPE "Almaz" Saratov, Russia), Andrey E. Ploskih (Saratov State University, Russia), Vladimir N. Titov (Saint Petersburg Electrotechnical University, Russia)

Design and simulation of a sub-THz traveling-wave tube amplifier with a grating slow-wave structure (SWS) is discussed. A Pierce-type electron gun with a converging sheet electron beam emitted from a cylindrical curved cathode is designed. Beam focusing by the uniform and reversal magnetic field is compared. The results of gain and output power calculations are presented.

14:50 ~ 15:10

14.5 / Design and Analysis of a High-gain High-power cascaded 220GHz FWGTWT

Xiaochuan Zou (Chinese Academy of Science, China), Qianzhong Xue (Chinese Academy of Science, China), Xuewei Wang (Chinese Academy of Science, China)

A high-gain high-power cascaded foldedwaveguide (FWG) traveling-wave tube (TWT) is designed. By analyzing dispersion and coupling impedance, some main structural dimensions are determined. An external attenuator with sever is designed to suppress reflection and how to load it is also discussed. The slow-wave structure and the focusing system of the electron optics system are optimized. Finally, the output power may reach 100.8W at 220GHz within a practical focusing magnetic field of 0.517T. The gain is 32.3dB. And the -3dB bandwidth is about 8GHz.

Session 15. Magnetrons and CFA

April 30 (Tuesday) / 13:30 ~ 15:10 / Room 3

Session Chair: Jung-Il Kim (Korea Electrotechnology Research Institute, Korea)

13:30 ~ 13:50

15.1 / [Keynote] A Study of Harmonic Locking Between Oscillators in a Dual Frequency Magnetron

Drew A. Packard (University of Michigan, USA), Geoffrey B. Greening (CPI, USA), Nicholas M. Jordan (University of Michigan, USA), Steven C. Exelby (University of Michigan, USA), Y.Y. Lau (University of Michigan, USA), Ronald M. Gilgenbach (University of Michigan, USA), Brad W. Hoff (Air Force Research Lab, USA), Jason F. Hammond (Air Force Research Lab, USA)

The Harmonic Recirculating Planar Magnetron (HRPM) is a crossed field microwave source capable of oscillating at high power, potentially at four different frequencies from L-Band to S-Band. In a previous experiment, the two oscillators of the Multi-Frequency Recirculating Planar Magnetron (MFRPM) exhibited harmonic frequency locking, where one oscillator at S-Band locked to the second harmonic of the other oscillator's L-Band resonant frequency. The HRPM has been designed to experimentally test the harmonic frequency locking concept.

13:50 ~ 14:10

15.2 / Experiments on a Recirculating Planar Crossed-Field Amplifier

Steven C. Exelby (University of Michigan, USA), Geoffrey B. Greening (University of Michigan, USA), Nicholas M. Jordan (University of Michigan, USA), Drew A. Packard (University of Michigan, USA), Yue Ying Lau (University of Michigan, USA), Ronald M. Gilgenbach (University of Michigan, USA), Brad W. Hoff (Air Force Research Laboratory, USA), David Simon (Air Force Research Laboratory, USA)

The Recirculating Planar Crossed-Field Amplifier (RPCFA) has demonstrated amplification in excess of 10 dB of a ~30 kW RF signal, with 15% bandwidth. The RPCFA is the amplifying adaptation of the Recirculating Planar Magnetron (RPM) also developed at the University of Michigan. Ansys HFSS and the particle-in-cell code MAGIC were used to design a prototype. The prototype RPCFA was constructed and demonstrated transmission characteristics similar to those predicted by simulation. Sustained amplification for pulses 100's of nanoseconds in length have been observed with peak amplification as high as 16dB and greater than 1 MW of output power. The RPCFA is shown to be unsaturated at the 10's of kW RF drive at which it has been tested, suggesting higher input drive power may lead to even greater output power. The range of amplifiable frequencies implied by the transmission band is verified experimentally. The lower limit for RF drive power that can be amplified is found to be approximately 100 W. Sources of irreproducibility of microwave gain are being investigated. Injection of higher drive power up to

1 MW is planned.

14:10 ~ 14:30

15.3 / Novel Cold Cathode Design for mm-wave (THz) Spatial Harmonic Magnetrons

Rajendra Kumar Verma (CSIR-Central Electronics Engineering Research Institute, India), Shivendra Maurya (CSIR-Central Electronics Engineering Research Institute, India), Rajendra Kumar Sharma (CSIR-Central Electronics Engineering Research Institute, India)

Cathode Emission for effective electron cloud/ plasma expansion is one of the prime physical mechanism influencing the performance of a magnetron with reference to efficiency and power levels. It essentially requires enhanced secondary electron emission by cold cathodes in mm/sub-mm wave (THz) spatial harmonic magnetrons (SHMs). The manuscript presents a novel cold cathode design named as interdigitated thermally assisted - secondary electron emission (T-SEE) cathode. CST-Particle Studio (CST-PIC) simulations of SHM with the proposed novel configuration cold cathode has resulted in 3kW power enhancement with 3.46% efficiency enhancement with reference to the conventional cold SEE cathode used in SHMs.

14:30 ~ 14:50

15.4 / A Novel Phase-locking Structure Applied to Millimeter-wave Magnetrons

Tianqi Hu (University of Electronic Science and Technology of China, China), Minsheng Song (University of Electronic Science and Technology of China, China), Yong Yon (University of Electronic Science and Technology of China, China), Bin Wang (University of Electronic Science and Technology of China, China), Hailong Li (University of Electronic Science and Technology of China, China), Lin Meng (University of Electronic Science and Technology of China, China)

A novel phase-locking structure of millimeterwave magnetrons is studied. The phases of multiple magnetrons can be locked by using this phase-locking structure. This phase-locking structure utilizes impedance transformation can be applied to continuous-wave magnetrons or pulse-wave magnetrons, generating multiple high-power in-phase outputs for power synthesis, etc. The purpose of this structure is to use less than 10 dB microwave power in the magnetrons for coupling to achieve phase locking, while most of the power can be effectively output. The structure has been studied by the resonant system of Ka-band rising-sun magnetrons.

14:50 ~ 15:10

15.5 / Tuning Characteristics Analysis of a Ka-band Coaxial Magnetron

Minsheng Song (University of Electronic Science and Technology of China, China), Tianqi Hu (University of Electronic Science and Technology of China, China), Yin Yong (University of Electronic Science and Technology of China, China), Lin Meng (University of Electronic Science and Technology of China, China), Hailong Li (University of Electronic Science and Technology of China, China), Bin Wang (University of Electronic Science and Technology of China, China)

In this paper, tuning characteristics of a Ka-band coaxial magnetron has been studied. The initial parameters of the coaxial cavity have been analyzed theoretically and verified by CST MW Studio. This paper summarizes some methods to optimize the parameters of coaxial cavity. Moreover, the characteristics of asymmetrical tuning is quantified by R/Q, quality-factor, the percentage of stored energy in coaxial cavity, as well as resonant frequency. It is simulated by CST MW Studio. Cold test is ongoing to verify the simulations.

Session 16. FELs / BWOs / Cherenkov devices

April 30 (Tuesday) / 16:30 ~ 17:50 / Room 1

Session Chair: Young Uk Jeong (Korea Atomic Energy Research Institute, Korea)

16:30 ~ 16:50

16.1 / [Keynote] Enhanced radiation using Cerenkov effect in Fano metamaterial

Seontae Kim (Seoul National University, Korea), Dongpyo Hong (Seoul National University, Korea), Matlabjon Sattorov (Seoul-Teracom, Inc. / Advanced Institutes of Convergence Technology, Korea), Muhammad Mohsin Hossain (Seoul National University, Korea), Sun-Hong Min (Korea Institute of Radiological and Medical Sciences, Korea), Gun-Sik Park (Seoul National University, Korea)

The Fano metamaterial provides a way of trapping and releasing electromagnetic waves in microwave and terahertz regime. We show that, by utilizing the electromagnetic properties, the efficiency of radiation power from the Cerenkov effect in our recently proposed metallic metamaterial is much larger than the one from the ordinary Cerenkov and Smith Purcell effects. The optimization of the efficiency was numerically conducted by manipulating the quality(Q) factor of the trapped Cerenkov light. The proposed metamaterial is suitable for developing compact and highly efficient free electron lasers.

16:50 ~ 17:10

16.2 / Realization of ultra-stable hard X-ray Free Electron Laser

H.-S. Kang (Pohang Accelerator Laboratory, S. Korea)

The use of electron-beam-based alignment incorporating undulator radiation spectrum analysis has allowed reliable operation of PAL-XFEL with unprecedented stability in terms of orbit, energy, and timing. A timing jitter of smaller than 20 fs for the FEL photon beam, a transverse position jitter of smaller than 10% of the photon beam size, and a variation of FEL intensity of smaller than 5% are consistently achieved due to the use of state-of-the-art design of the electron linear accelerator and the 3-BC lattice less vulnerable to RF jitters. The low timing jitter of the electron beam makes it possible to observe Bi(111) phonon dynamics without the need for timing-jitter correction, indicating that PAL-XFEL will be an extremely useful tool for hard X-ray time-resolved experiments.

17:10 ~ 17:30

16.3 / RF-Undulators and Powering Sources towards Compact Efficient Compton FEL-scattrons

Nikolai Yu. Peskov (Russian Academy of Sciences, Russia), Edward B. Abubakirov (Russian Academy of Sciences, Russia), Ilya V. Bandurkin (Russian Academy of Sciences, Russia), Andrey

N. Denisenko (Russian Academy of Sciences, Russia), Naum S. Ginzburg (Russian Academy of Sciences, Russia), Sergey V. Kuzikov (Russian Academy of Sciences, Russia), Andrey V. Savilov (Russian Academy of Sciences, Russia), Alexander A. Vikharev (Russian Academy of Sciences, Russia), Vladislav Yu. Zaslavsky (Russian Academy of Sciences, Russia)

Conception of Compton-type FELs operating up to X-ray band is under development currently at IAP RAS (N.Novgorod). This concept is aimed at reducing energy of a driving relativistic electron beam and thereby increasing efficiency of the electron-wave interaction in FEL, as well as achieving relative compactness of the generator. The basis of this concept is RF-undulators of a new type - the so-called "flying" undulators. Present paper is devoted to the results of current research of these RF-undulators, their simulations and "cold" tests in the Ka-band. For powering RF-undulators spatially-extended narrow-band Cerenkov masers are developed in the specified frequency range. In order to achieve the required sub-gigawatt power level of the pumping wave in a strongly oversized oscillator, we exploit the original idea of using two-dimensional distributed feedback implemented in the 2D doubly-periodical slow-wave structures. The design parameters of Ka-band surface-wave oscillator intended for powering RF-undulators, results of its simulation and initial experimental studies are presented.

17:30 ~ 17:50

16.4 / Development of a High-power Terahertz Free Electron Laser Using a Microtron accelerator and an Electro-magnetic Planar Undulator

Sangyoon Bae (Korea Atomic Energy Research Institute / Chungnam National University, Korea), Sergey Miginsky (Korea Atomic Energy Research Institute, Korea), Taesik Yoon (Korea Atomic Energy Research Institute / Chungnam National University, Korea), Boris A. Gudkov (Korea Atomic Energy Research Institute, Korea), Kyu-Ha Jang (Korea Atomic Energy Research Institute, Korea), Kitae Lee (Korea Atomic Energy Research Institute, Korea), Min Yong Jeon (Chungnam National University, Korea), Young Uk Jeong (Korea Atomic Energy Research Institute, Korea)

A high-power terahetz FEL is under development at KAERI. We developed a compact microtron to accelerate electrons up to 5 MeV with the energy spread of about 0.4%. An electro-magnetic planar undulator was designed and fabricated to cover the FEL's lasing wavelength range of 350~650 μm. The magnetic field strength in the gap of the undulator is changeable from 0.76 to 1.18 T by varying the coil current of the undulator from 1.4 to 2.4 kA. The undulator provides horizontal focusing force to keep the low energy electrons passing a specially-designed narrow waveguide.

Session 17. Millimeter-wave TWTs-II

April 30 (Tuesday) / 16:30 ~ 17:50 / Room 2

Session Chair: John Booske (University of Wisconsin, USA)

16:30 ~ 16:50

17.1 / Design and Experiment of An E-band Folded Waveguide Traveling Wave Tube

Rujing Ji (University of Electronic Science and Technology of China, China), Zhixin Yang (University of Electronic Science and Technology of China, China), Zugen Guo (University of Electronic Science and Technology of China, China), Qi Wang (University of Electronic Science and Technology of China, China), Ping Han (University of Electronic Science and Technology of China, China), Huarong Gong (University of Electronic Science and Technology of China, China)

An E-band folded waveguide traveling wave tube (FWGTWT) was designed, fabricated and tested. Experimental result shows that the prototype tube covers the bandwidth of 83-86GHz with the output power of above 30W, meanwhile, the peak power is 35W in 85.5GHz. The maximum electron efficiency is up to 3.3%. The tube is tested when the electron gun voltage is 17kV and the beam current is 62mA.

16:50 ~ 17:10

17.2 / Investigation on W-Band 100W Three-section Ridge-Loaded Folded Waveguide TWT

Fei Li (IECAS, China), Liu Xiao (IECAS, China), Jiandong Zhao (IECAS, China), Yuhui Sun (IECAS, China), Tianjun Ma (IECAS, China), Linlin Cao (IECAS, China), Jian Wang (IECAS, China), Hongxia Yi (IECAS, China), Xinwen Shang (IECAS, China), Mingguang Huang (IECAS, China)

A W-band 100W three-section folded waveguide traveling wave tube (TWT) is investigated by numerical simulation and fabrication experiments. The results show that the ridge-loaded folded waveguide circuit achieves higher coupling impedance than conventional folded waveguide circuit with dispersion characteristics almost unchanged. Three-section structure can not only increase gain and gain flatness of TWT, but also save cost by removing attenuator and improve machining straightness of each section ridge-loaded folded waveguide assembly by shortening length of it.

17:10 ~ 17:30

17.3 / Simulations of a W-Band Circular TWT

K. Nusrat Islam (University of New Mexico, USA), Edl Schamiloglu (University of New Mexico, USA), Andrey D. Andreev (University of New Mexico, USA), Frank Krawczyk (Los Alamos National Laboratory, USA), Bruce Carlsten (Los Alamos National Laboratory, USA)

We are exploring the amplification of W-band electromagnetic radiation using a dielectric-loaded traveling wave tube (TWT) by employing several particle-in-cell (PIC) codes. We are seeking to replicate recent results obtained by a Naval Research Laboratory's (NRL's) dielectric-loaded TWT design [1] consisting of a solid circular electron beam (26 kV, 100mA and 0.185 mm beam radius) surrounded with dielectric material, ε_r=13.5, and coupled to a TM_{01} electromagnetic wave at a frequency of 94 GHz. NRL used a finite-difference-time domain (FDTD) formulation in a 2-D cylindrical coordinate system to perform the dielectric-loaded TWT simulations. In our work, we have opted for PIC simulations comparing three different software tools-a 3-D Cartesian coordinate system 'FDTD-PIC method-based MAGIC', 'CST Electromagnetic and Multiphysics Simulation Studio Suite', and 'Improved Concurrent Electromagnetic Particle-In-Cell (ICEPIC)'. This paper summarizes our results from these studies.

17:30 ~ 17:50

17.4 / Investigation of a Sheet Beam RF Structure with Bragg Reflector for W band Amplifier

Richards Joe Stanislaus (CSIR-Central Electronics Engineering Research Institute, India), Anirban Bera (CSIR-Central Electronics Engineering Research Institute, India), Rajendra Kumar Sharma (CSIR-Central Electronics Engineering Research Institute, India)

A W Band staggered double vane (SDV) loaded traveling wave tube amplifier (TWTA) with two sections separated by a lossy dielectric loaded rectangular wave guide is studied in this paper. The dispersion characteristics and transient analysis of the slow wave structure are analyzed in Computer Simulation Technology Microwave studio (CST MWS) and High Frequency Software Simulator (HFSS). In this amplifier, we propose to use Bragg reflectors on both sides of the slow wave structure (SWS), at the windows for the sheet beam at the electron gun and collector ends; this increases the impedance bandwidth of the RF structure. The attenuator section is comprised of a rectangular waveguide loaded on either side with single lossy dielectric material spanning over 5.5 pitches. The loss profile of the attenuator and loss magnitude is optimized to provide a 20dB loss in separating the input and output sections. A bandwidth of 15GHz ranging from 90-105GHz is obtained through the analysis. In the PIC simulations, a sheet beam of 50mA current is fed with an operating voltage of 18.3kV. The TWTA yields 20dB gain in the 90-105GHz range.

Session 18. Components

April 30 (Tuesday) / 16:30 ~ 17:50 / Room 3

Session Chair: Seong-Tae Han (Korea Electrotechnology Research Institute, Korea)

16:30 ~ 16:50

18.1 / Output coupler for a THz gyro-amplifier

Craig R. Donaldson (University of Strathclyde, UK), Liang Zhang (University of Strathclyde, UK), Wenlong He (Shenzhen University, China)

This paper presents the design and simulation results of an output coupler for a gyro-amplifier operating at THz frequencies. The combination of a smoothly profiled horn and multilayer microwave window allow for the almost total conversion of the TE_{11} mode to the Gaussian-like HE_{11} mode while forming a vacuum tight seal with very low reflections. This assembly operates over the 360-384 GHz frequency range.

16:50 ~ 17:10

18.2 / Rectangular- versus Sine-Corrugated Waveguide Polarizers for Ka-band Gyro-TWT

Alexey Kosogor (Rostov-on-Don Research Institute of Radio Communication, Russia), Yuri Tikhov (Rostov-on-Don Research Institute of Radio Communication, Russia)

This paper presents a comparison of two kinds of waveguide polarizers for use in Ka-band Gyro-TWT. It is shown that in competition versus conventional polarizer having rectangular corrugation, a sine-corrugation is not necessarily a prerequisite for superior high-power handling or enhanced circular polarization purity over broadband frequency range.

17:10 ~ 17:30

18.3 / Design and Multipactor Analysis of a High Power RF Window

Mohit Kumar Joshi (IIT, India), Tapeshwar Tiwari (IIT, India), Ratnajit Bhattacharjee (IIT, India)

This paper presents the design of a high power RF window for X-band megawatt class pulsed coaxial magnetron. In this proposed design, overmoded cavity, with TE_{012} like mode (mixed with TE_{312}) is considered instead of conventional pillbox cavity. Frequency domain simulation is carried out in CST and return loss, insertion loss, VSWR are obtained as 51.52 dB, 0.07 dB, and 1.005, respectively at 9.3 GHz. Mixed mode operation makes the bandwidth broad, and 40.8 MHz bandwidth is achieved for VSWR less than 1.05. Multipactor and RF breakdown limit the power handling capacity of high power microwave devices and components. Knowledge of multipactor threshold is required for the proper operation of devices. The multipactor analysis of the proposed RF window is carried out in SPARK3D to determine multipactor threshold. Vaughan

model is used for the Secondary Electron Yield (SEY) characterization of materials. Multipactor threshold of the proposed RF window is determined as 16 MW. This makes the RF window suitable for the operation up to 16 MW peak power at 9.3 GHz.

17:30 ~ 17:50

18.4 / A Novel terahertz Wave Microstructure Phase Shifter Loaded in Rectangular Waveguide

Zongjun Shi (University of Electronic Science and Technology of China, China), Yujie Guo (University of Electronic Science and Technology of China, China), Yihong Zhou (University of Electronic Science and Technology of China, China), Xinjin Shi (University of Electronic Science and Technology of China, China), Ziqiang Yang (University of Electronic Science and Technology of China, China), Feng Lan (University of Electronic Science and Technology of China, China)

This paper proposes a novel, compact and wide phase shift range tunable phase shifter operating in 0.3THz-0.325THz, which is loaded in WR-3 band rectangular waveguide and controlled by electricity. The phase shifter comprises of three phase shift units that are mounted in the H plane cuts of the rectangular waveguide. The phase shifter units based on quartz substrate are designed to be a symmetrical structure for both increasing volume of phase shift and reducing the insertion loss. Each unit is adopted microstripe line as secondary transmission line coupling with primary transmission line inside rectangular waveguide via gold probe to introduce extra parallel impedance into main transmission line. Furthermore, diodes are loaded with secondary transmission line for electric steering so that the phase shifter with total three phase shift units is capable to realize four discrete phase shifts. Simulation results show the phase shift ranges from 0 to 180 degrees with the step of 60 degrees. Its insertion loss is better than -1.5dB, and the return loss is below -10dB. A prototype has been fabricated and measured by using the terahertz vector network analyzer. In static test, the maximum phase shift is up to 260 degrees. For the dynamic test of the three shifting units, the maximum phase shift is about 90 degrees at 0.31THz.

Session 19. EIKs / EIOs / Oscillators

May 1 (Wednesday) / 10:00 ~ 12:00 / Room 1

Session Chair: Young-Min Shin (Communications and Power Industries, USA)

10:00 ~ 10:20

19.1 / [Keynote] Development of a High Power Ka-Band Extended Interaction Klystron

Ding Zhao (Chinese Academy of Sciences, China), Gaofeng Liu (Chinese Academy of Sciences, China), Wei Gu (Chinese Academy of Sciences, China), Tongli Ma (Chinese Academy of Sciences, China), Qianzhong Xue (Chinese Academy of Sciences, China), Zhiqiang Zhang (Chinese Academy of Sciences, China)

After completing the designs of the electron gun with large compression ratio, the stable electron optics system with high transmission, and the efficient beam-wave interaction circuit, using a permanent magnetic uniform field focusing, we have successfully built a high power Ka-band extended interaction klystron with excellent performance. The working voltage and current are about 25.5 kV and 3.1 A, respectively. The measured DC beam transmission is over 97%, and in the most adverse state of high frequency operation, the transportation can still keep the value of over 90%. In the condition of non-equal excitation, the device demonstrates the bandwidth of 435 MHz corresponding to the output power of 10 kW or more. The duty cycle is over 3%. Near the optimal working point, the klystron clearly shows its potential, which means that the maximum output power exceeds 20 kW with the gain 44 dB and the efficiency 25% in the bandwidth of 60 MHz.

10:20 ~ 10:40

19.2 / Oversized W-band 2D Periodic Lattice Oscillator

A. W. Cross (University of Strathclyde, UK), A. J. MacLachlan (University of Strathclyde, UK), C. W. Robertson (University of Strathclyde, UK), L. Zhang (University of Strathclyde, UK), C. R. Donaldson (University of Strathclyde, UK), H. Yin (University of Strathclyde, UK), A.D.R Phelps (University of Strathclyde, UK), K. Ronald (University of Strathclyde, UK)

To mitigate the conventional scaling of slow-wave vacuum electronic oscillators, in which the maximum output power reduces as the frequency increases, an oversized cylindrical structure is driven by an annular electron beam. To enhance mode selectivity a two dimensional (2D) periodic lattice structure (PSL) is used. The 2D PSL consists of shallow periodic cosinusoidal perturbations in both the azimuthal and axial directions on the inner wall of a cylindrical waveguide. Analytical theory and numerical PIC simulations have been used to design the W-band oscillator that has been constructed. The ratio of the diameter of the cylindrical cross-section of the structure to the operating wavelength is ~5. The performance of this oscillator is being measured and compared with the predictions of the numerical simulations.

10:40 ~ 11:00

19.3 / Design and Fabrication of G-band Extended Interaction Klystron with Unequal-length Slots

Renjie Li (Beihang University, China), Shasha Li (Beihang University, China), Cunjun Ruan (Beihang University, China), Huafeng Zhang (Beihang University, China)

A G-band rectangular beam extended interaction klystron (EIK) with unequal-length slots structure is proposed. The unequal-length slots structure has great influence on the high-frequency features. The length ratio of long-slot with short slot will seriously affect the effective characteristic impedance and mode separation. Compromised length ratio is selected considering the mode competition and beam-wave interaction efficiency. Based on the design of high-frequency structure, we established a completed beam-wave interaction model. With PIC simulation, we obtained 400 W peak output power and 800 MHz bandwidth, with efficiency of 8.0%. We fabricated the high-frequency structure by CNC machining method, and the surface roughness and fabrication error are 0.40 μm and 10 μm, respectively. Measurement of S_{11} indicated that the amplitudes of measured and simulated are close, but the frequency is shift about 1 GHz. The frequency shift is resulted from the large fabrication error. Our design beam-wave interaction model preliminarily showed potential in performance improvement of terahertz EIK.

11:00 ~ 11:20

19.4 / Development of Ka-band Extended-Interaction Klystron

Haiping Feng (Beijing Vacuum Electronics Research Institute, China), Fujiang Sun (Beijing Vacuum Electronics Research Institute, China), Dongfeng Li (Beijing Vacuum Electronics Research Institute, China)

This paper presents the design and the results for a Ka-band Extended-Interaction Klystron working at 2π mode. The electron gun, the permanent magnetic focusing system, the extended-interaction technology performance are calculated by computer simulation. After testing Klystron, the peak output power is over 10KW, average power is over 500W ,gain is over 30dB and bandwidth is over 300MHz.

11:20 ~ 11:40

19.5 / The Primary Research of 140GHz EIO

Bo Wang (University of Electronic Science and Technology of China, China), Zhenhua Wu (University of Electronic Science and Technology of China, China) Chuanhong Xiao (University of Electronic Science and Technology of China, China), Jie Qing (University of Electronic Science and Technology of China, China), Jielong Li (University of Electronic Science and Technology of China, China), Min Hu (University of Electronic Science and Technology of China, China), Renbin Zhong (University of Electronic Science and Technology of China, China), Shenggang Liu (University of Electronic Science and Technology of China, China)

In this paper, a preliminary study of the structure of EIO is based on the EIO of the same aperture. The influence of the length of the coupling hole and the relative opening size on the EIO structure of the 2π operating point was studied by computer simulation. The dispersion curves and Q values of the 140 GHz EIO in TM_{11} and TM_{31} modes are analyzed. After obtaining the optimal aperture length, the aperture of the EIO interval is shortened to increase the bandwidth.

11:40 ~ 12:00

19.6 / Design of a Low Aspect Ratio Electron Gun for a 220 GHz Sheet Electron Beam EIK

Zhang Huafeng (Beihang University, China), Ruan Cunjun (Beihang University, China)

Taking the unit width electron beam based on the Pierce-type electron gun at the cathode surface as the object of study, we give the formula of designing the aspect ratio and the normalized range of the sheet beam electron gun. The main parameters of the electron gun is U = 16.5 kV, I = 0.30 A and the waist size is 0.30 mm × 0.13 mm, which can be used in the research of the 220 GHz extended interaction klystron (EIK). Through the modeling and analysis in the 3D software CST, it is found that the smaller the size of the anode hole, the higher the height of the electron beam waist and the larger the electron beam width ratio, and the smaller the distortion of the narrow side. Using the compression ratio formula and the range formula, it is convenient to calculate the key parameters of the electron gun. Therefore, our study provides an effective method for the design of the Pierce-type sheet beam gun.

Session 20. G-band TWTs

May 1 (Wednesday) / 10:00 ~ 11:20 / Room 2

Session Chair: Jinjung Feng (Beijing Vacuum Electronics Research Institute, China)

10:00 ~ 10:20

20.1 / [Keynote] A G-band wideband CW folded waveguide TWT

Lei Wenqiang (China Academy of Engineer Physics, China), Hu Peng (China Academy of Engineer Physics, China), Huang Yinhu (China Academy of Engineer Physics, China), Jiang Yi (China Academy of Engineer Physics, China), Song Rui (China Academy of Engineer Physics, China), Chen Hongbin (China Academy of Engineer Physics, China)

Institute of Applied Electronics has developed a wideband continuous waves (CW) folded waveguide Traveling Wave Tube (FWTWT) amplifier operating at G-band. The design and fabrication on CW FWTWT was presented, including electronic-optical system, folded waveguide slow wave structure (FWSWS) and input/output (I/O) windows system. By the measurement, the amplifier produced the maximum output power 18W at frequency 216GHz with 10GHz -3dB bandwidth at CW work. The maximum gain is 28.2dB.

10:20 ~ 10:40

20.2 / Dispersion Measurements of 220 GHz FWSs

Sudhamani HS (Ministry of Defence, India), SUM Reddy (Ministry of Defence, India), Jyothi Balakrishnan (Bangalore University, India)

In this paper, the fabrication of Folded Waveguide Structures operating at 220 GHz using micro machining method is briefly described. Dispersion measurements have been carried out and the results presented. The comparison with the simulations shows that they are closely matching within 0.5%. Simulated experiment is carried out to determine the interaction impedance and found to match within 10% in the passband.

10:40 ~ 11:00

20.3 / Study of an Airborne 220 GHz Traveling Wave Tube Amplifier

Pan Pan (Beijing Vacuum Electronics Research Institute, China), Ye Tang (Beijing Vacuum Electronics Research Institute, China), Yinxing Chen (Beijing Vacuum Electronics Research Institute, China), Jinjun Feng (Beijing Vacuum Electronics Research Institute, China)

An airborne 220 GHz traveling wave tube (TWT) amplifier with output power of 10 W and bandwidth of 5 GHz is being developed. The design of the TWT and the test of a TWT prototype are presented.

11:00 ~ 11:20

20.4 / Loss Measurements of 220 GHz FWSs

Sudhamani HS (Defence Research and Development Organization Bangalore, India), SUM Reddy (Defence Research and Development Organization Bangalore, India), Jyothi Balakrishnan (Bangalore University, India)

In the present work, the fabrication of folded waveguide structures operating at 220 GHz is presented. The structure is fabricated using three different materials brass aluminium and OFHC copper and their surface characteristics are compared. The FWS was fabricated using different micromachining methods. Cold test measurements have been carried out for estimating the losses.

Session 21. Field emssion / Cold cathodes / Scandate cathodes

May 1 (Wednesday) / 10:00 ~ 11:40 / Room 3

Session Chair: Kyu Chang Park (Kyung Hee University, Korea)

10:00 ~ 10:20

21.1 / Quality and Performance of Commercial Nanocomposite Scandate Tungsten Material

Michelle Gonzalez (University of California, USA), Neville C. Luhmann Jr. (University of California, USA), Diana Gamzina (SLAC National Accelerator Laboratory, USA), Colin McElroy (Vacuum Process Engineering Inc., USA), Carl Schalansky (Vacuum Process Engineering Inc., USA)

Nano-composite scandate tungsten cathodes have been demonstrated to have superior performance to other thermionic cathodes by researchers worldwide. Focus on quality and its relationship to emission performance is essential for transferring this transformational material technology to commercial applications. Metrics for evaluation of powder quality, sintered pellet quality, and emission performance have been established and are employed for manufacture of commercially viable large batch scale production process.

10:20 ~ 10:40

21.2 / High-Performance Scandate Cathode

Daniel E. Bugaris (Engi-Mat Co., USA), Claudia Goggin (Engi-Mat Co., USA), Xiaomeng Zhang (University of Kentucky, USA), John Balk (University of Kentucky, USA), Daniel Busbaher (a 3M Company, USA), Jack Tucek (Northrop Grumman Corporation, USA)

Scandate cathodes have long attracted attention due to their higher emission current density, apparent low work function, and anticipated improved longevity compared to conventional cathodes. However, scandate cathodes have not been applied as extensively as their potential would imply. In this study, the compositional homogeneity of a scandia/tungsten composite powder was investigated by scanning electron microscopy, X-ray energy dispersive spectroscopy, and X-ray photoelectron spectroscopy. From these techniques, a sample providing the optimal coverage of tungsten by scandia particles was then chosen. A cathode fabricated from this sample displayed a greater than 200°C decrease (improvement) in knee temperature versus the standard M-type cathode.

10:40 ~ 11:00

21.3 / Exact Analytical Solution for Ultrafast Electron Emission Due to Two-Color Laser Fields

Yi Luo (Michigan State University, USA), Peng Zhang (Michigan State University, USA)

This paper presents an analytical model for ultrafast electron emission from a metal surface illuminated by two-color continuous laser fields. The exact solution is valid for arbitrary fundamental and harmonic laser frequencies, laser intensities, phase difference between the two lasers, metal work function and Fermi level. We found two-color laser fields can strongly modulate the emission current up to 99%. Our results are in excellent agreement with recent experiments.

11:00 ~ 11:20

21.4 / Alignment of Carbon Nanotubes inside the Fibers Through Interfacial Interaction of Nanoparticles for Using as Cathode for Field Emission

Muhammad Mohsin Hossain (Seoul National University, Korea), Dongpyo Hong (Seoul National University, Korea), Matlabjon Sattorov (Seoul-Teracom, Inc. / Advanced Institutes of Convergence Technology, Korea), Seontae Kim (Seoul National University, Korea), Gun-Sik Park (Seoul National University, Korea)

Alignment of carbon nanotubes (CNTs) inside the CNT fiber is very important for the fast electron movement through CNTs. We utilized nanoparticles, such as ZnO for the alignment of CNTs and described how semiconducting ZnO can act as an alignment agent in carbon nanotubes (CNTs) fibers. Due to the alignment of CNTs through the ZnO nanoparticles linking groups, the CNTs inside the fibers were equally distributed by the attraction of bonding forces into sheet-like bunches, such that any applied mechanical breaking load was equally distributed to each CNT inside the fiber, making them mechanically robust against breaking loads. Although semi conductive ZnO nanoparticles were used here, the electrical conductivity of the aligned CNT fiber was comparable to bare CNT fibers, suggesting that the total electron movement through the CNTs inside the aligned CNT fiber is not disrupted by the insulating behavior of ZnO nanoparticles. Due to the high electrical, mechanical, and thermal properties of CNT fiber, it is a good candidate as field emitter. For using CNT fiber as cathode for sheet beam, CNT fiber further was converted to the sheet structure, which are more important for getting sheet.

11:20 ~ 11:40

21.5 / Fabrication of high current carbon nanotube based cold cathode emitters and applications

Hye In Lee (KyngHee University, Korea), Jung Su Kang (KyngHee University, Korea), Kyu Chang Park (KyngHee University, Korea)

We developed high current electron emission carbon nanotube cold cathode electron sources for high power vacuum devices. To develop high power devices with electron beam, electron emission current is most important. More than 100 mA electron emission current achieved with the optimized CNT fabrication process and its structure. The electron emission current limited by the conductivity of CNT emitters, the higher conducting emitters show higher electron emission current. Detail on the fabrication process and performance of electron beam would be presented.

Session 22. Gyro-devices

May 1 (Wednesday) / 13:30 ~ 15:10 / Room 1

Session Chair: Jagadishwar Sirigiri (Bridge12 Technologies, Inc., USA)

13:30 ~ 13:50

22.1 / Development of a THz Broadband Mini-Gyrotron

Chao-Hai Du (Peking University, China), Shi Pan (Peking University, China), Zi-Chao Gao (Peking University, China), Hui-Qi Bian (Peking University, China), Pu-Kun Liu (Peking University, China)

We are currently investigating about demonstrating gyrotron with the capability of super broadband operation in THz band. A strong-field pulse magnet is applied to provide a time-varying magnetic field, and the cyclotron frequency of the electron beam in the cavity changes accordingly. The electron beam efficiently excites a backward wave in a specially designed pre-bunching cavity. A broadband quasi optical converter and a Brewster window are installed in the tube to radiate out the broadband power. Theoretical study reveals that the gyrotron is potential to radiate peak power about 1 kW around 0.33 THz and a frequency tuning range about 10 GHz in each pulse. Further study predicts that when high-order whispering gallery modes are employed as the operation modes, this broadband mini-gyrotron is capable of sequentially jumping from one mode to another and finally radiates power covering the range of 350 GHz – 410 GHz.

13:50 ~ 14:10

22.2 / Experiments on W-band High-Gain Helical-Waveguide Gyro-TWT

S. V. Samsonov (Russian Academy of Sciences, Russia), A.A. Bogdashov (Russian Academy of Sciences, Russia), G. G. Denisov (Russian Academy of Sciences, Russia), I. G. Gachev (Russian Academy of Sciences, Russia)

Design, simulation results and first experimental results are presented for a W-band gyro-TWT using helically corrugated waveguides in its microwave circuit. The specific of this gyro-TWT is a sectioning (2 helical-waveguide sections separated by a sub-cutoff drift channel) which enables its operation at the second cyclotron harmonic with a high gain (45-50 dB) and high stability to the spurious oscillations. Using an available superconducting magnet with B-field of 1.9 T the tube was designed to be powered by a 40-kV 0.7-A electron beam with a pitch-factor of 1.3. The 3D PIC simulations predict the maximum output power of 3 kW at about 95 GHz and 1-kW-level bandwidth of 7.2 GHz when driving by a 100-mW input signal.

14:10 ~14:30

22.3 / Characteristic measurements of a wideband gyro TWA operating in W-band

Wenlong He (Shenzhen University, China), Liang Zhang (University of Strathclyde, UK), Craig R. Donaldson (University of Strathclyde, UK), Kevin Ronald (University of Strathclyde, UK), Alan D.R. Phelps (University of Strathclyde, UK), Adrian W. Cross (University of Strathclyde, UK), Peter Cain (Keysight Technologies UK Ltd, UK)

Following on from the successful operation of a broadband, high-power gyrotron traveling wave amplifier (gyro-TWA) in W-band, experiments were carried out to demonstrate the versatility of the gyro-TWA and investigate its tuning characteristics. When operating at a lower voltage of 40kV, 30 dB gain was achieved for a 1 GHz bandwidth frequency-swept input signal.

14:30 ~ 14:50

22.4 / Development of Ultrashort Pulse Generators based on Helical Gyro-TWT with Saturable Cyclotron Resonance Absorber in the Feedback Loop

Naum Ginzburg (Institute of Applied Physics RAS / Nizhny Novgorod State University, Russia), Grigory Denisov (Institute of Applied Physics RAS, Russia), Michael Vilkov (Institute of Applied Physics RAS, Russia), Alexander Sergeev (Institute of Applied Physics RAS, Russia), Sergey Samsonov (Institute of Applied Physics RAS, Russia), Irina Zotova (Institute of Applied Physics RAS, Russia), Alexander Bogdashov (Institute of Applied Physics RAS, Russia), Alexander Marek (Karlsruhe Institute of Technology, Germany), John Jelonnek (Karlsruhe Institute of Technology, Germany)

Presently, Ka-band ultrashort pulse (USP) generator is under development at Institute of Applied Physics RAS. Based on a time-domain model and direct PIC simulations we demonstrate that a periodic train of ultrashort microwave pulses can be generated in an electron oscillator consisting of a helically corrugated gyro-TWT and a saturable absorber based on cyclotron resonance interaction of radiation with an initially rectilinear electron beam. The gyro-TWT operates at the second cyclotron harmonic while in the absorber interaction at the fundamental harmonic should be realized. According to simulations with parameters of existing Ka-band gyro-TWT, the peak power of generated pulses with a duration of 200 ps and repletion frequency 1 GHz is about 400 kW.

14:50 ~ 15:10

22.5 / Design of a Broad-band Circular Waveguide TE°_{21} Mode Generator for Cold Test of Gyro-TWT

Yong Xu (University of Electronic Science and Technology of China, China), Hao Li (University of Electronic Science and Technology of China, China), Tinghui Peng (University of Electronic Science and Technology of China, China), Miao Sun (University of Electronic Science and Technology of China, China), Yong Luo (University of Electronic Science and Technology of China, China), Guo Liu (University of Electronic Science and Technology of China, China),

Jianxun Wang (University of Electronic Science and Technology of China, China), Wei Jiang (University of Electronic Science and Technology of China, China), Zewei Wu (University of Electronic Science and Technology of China, China), Hongfu Li (University of Electronic Science and Technology of China, China)

In this paper, the design of a broadband circular waveguide $TE^{\bigcirc}_{21}$ mode generator for gyro-TWT cold test is presented. The proposed mode generator is constituted by a rectangular waveguide $TE^{\square}_{10}$ to rectangular waveguide $TE^{\square}_{20}$ mode converter, a rectangular waveguide $TE^{\square}_{20}$ to crossing waveguide TE^{+}_{22} mode converter and the converter from TE^{+}_{22} to TE^{o}_{21} mode. The linear gradient structure is adopted in each convert for easy fabricating. Simulation results reveal that the S_{21} parameter of the proposed $TE^{\bigcirc}_{21}$ mode converter is better than -0.037dB and the S_{11} parameter is below -28dB in whole Q-band. Cold test shows that the designed generator realizes high conversion efficiency (>96.6%) in whole Q-band.

Session 23. Fabrication techniques / Materials

May 1 (Wednesday) / 13:30 ~ 15:10 / Room 2

Session Chair: Colin Joye (Naval Research Laboratory, USA)

13:30 ~ 13:50

23.1 / [Keynote] Copper Reconsidered: Material Innovations to Transform Vacuum Electronics

Diana Gamzina (SLAC National Accelerator Laboratory, USA), Michael Kozina (SLAC National Accelerator Laboratory, USA), Apurva Mehta (SLAC National Accelerator Laboratory, USA), Emilio A. Nanni (SLAC National Accelerator Laboratory, USA), Sami Tantawi (SLAC National Accelerator Laboratory, USA), Paul B. Welander (SLAC National Accelerator Laboratory, USA), Timothy Horn (North Carolina State University, USA), Christopher Ledford (North Carolina State University, USA)

Copper is critical to the manufacturing of vacuum electronic devices due to its high electrical and thermal conductivities. It enables high RF performance while maintaining low thermal losses. Copper is also responsible for some of the challenges: RF power output is often limited by the strength of copper and RF breakdown is induced by copper transformation at the vacuum surface. Recent advances in understanding of RF interaction with copper offer insight into its limitations and how they may be mitigated. Emerging manufacturing technologies, such as electron beam melting of copper, can be employed to achieve a stronger copper state in the RF structures, opening opportunities for higher power and more compact vacuum electronics. As copper focused additive manufacturing evolves, strengthening mechanisms can be incorporated into the material to produce desired material properties locally, further enhancing performance capabilities of vacuum devices.

13:50 ~ 14:10

23.2 / Characterization of W-band Serpentine Waveguide TWT Circuits

Reginald L. Jaynes (U.S. Naval Research Laboratory, USA), Alan M. Cook (U.S. Naval Research Laboratory, USA), Colin D. Joye (U.S. Naval Research Laboratory, USA), Edward L. Wright (Beam Wave Research, Inc., USA), Dean E. Pershing (Beam Wave Research, Inc., USA), Khanh T. Nguyen (Beam Wave Research, Inc., USA)

We present experimental characterization of W band serpentine waveguide TWT circuits fabricated by CNC micro-endmill machining. Cold test measurements of S-parameters demonstrate excellent agreement with simulation and precise fabrication repeatability between multiple circuits. The circuit wavelength dispersion was measured in both W- and D-band waveguide bands, covering an octave in frequency, showing agreement with simulation from 85-170 GHz. We discuss details of the fabricated circuits and cold test results.

14:10 ~ 14:30

23.3 / Research on high thermal conductivity and low loss tangent aluminum nitride ceramics

Yang Yan-ling (Beijing Vacuum Electronics Research Institute, China), Lu Yan-ping (Beijing Vacuum Electronics Research Institute, China)

In this paper, a high thermal conductivity and low loss tangent AlN ceramics was prepared. The developed AlN has a dielectric constant of 8.42, the loss tangent of 5×10^{-4} (35GHz), thermal conductivity at room temperature is 186 W/(m·K). The developed AlN ceramic can not only meet the requirements of the microwave window, but also can be applied to be collector and clamp-pole in the microwave tube.

14:30 ~ 14:50

23.4 / Secondary electron emission of (Mg-Zn-O)/(MgO-Au) bilayer composite film deposited by sputtering

Jie Li (Xi'an Jiaotong University, China), Wenbo Hu (Xi'an Jiaotong University, China), Qiang Wei (Xi'an Jiaotong University, China), Shengli Wu (Xi'an Jiaotong University, China), Yongdong Li (Xi'an Jiaotong University, China), Huiqing Fan (Northwestern Polytechnical University, China)

(Mg-Zn-O)/(MgO-Au) bilayer composite film was proposed, and the influence of Zn-doping concentration on the surface morphology, electronic structure and electron-induced secondary electron emission (SEE) performance of this composite film was investigated. The investigation results show that the Zn doping with a low concentration in the MgO surface layer brings about the enlargement of grain size and the reductions of both bandgap and work function of MgO, which leads to the superior SEE performance owned by (Mg-Zn-O)/(MgO-Au) composite film.

14:50 ~ 15:10

23.5 / Circuit Fabrication Methods for Millimeter-Wave Vacuum Electronics

Colin D. Joye (U.S. Naval Research Laboratory, USA), Alan M. Cook (U.S. Naval Research Laboratory, USA), Reginald L. Jaynes (U.S. Naval Research Laboratory, USA), B. Spence Albright (U.S. Naval Research Laboratory, USA), John R. Lowe (U.S. Naval Research Laboratory, USA), John C. Rodgers (U.S. Naval Research Laboratory, USA), Jeffrey P. Calame (U.S. Naval Research Laboratory, USA), Scooter D. Johnson (U.S. Naval Research Laboratory, USA)

We report on fabrication techniques for creating vacuum electron (VE) circuits from 30 GHz to 300 GHz. For devices up to 300 GHz, micro-CNC machining appears suitable.

Session 24. Applications

May 1 (Wednesday) / 13:30 ~ 15:10 / Room 3

Session Chair: Heung-Sik Kang (Pohang Accelerator Laboratory, Korea)

13:30 ~ 13:50
24.1 / [Keynote] Injection-Locked CW Magnetron for a wirelessly-powered TV

Bo Yang (Kyoto University, Japan), Tomohiko Mitani (Kyoto University, Japan), Naoki Shinohara (Kyoto University, Japan)

It is shown a wireless power transfer system that transmitted microwave drove the power and video signal of a TV which worked as a wirelessly-powered TV. At the transmitter, we modulated a video signal on a 2.45 GHz sine wave via frequency modulation, a 2.45 GHz injection-locked magnetron could amplify the frequency modulation signal. Utilizing injection locking method, we injected the modulated signal to a 2.45 GHz magnetron and the magnetron amplified this modulation signal. At the receiver, we rectified the microwave energy to the power source and demodulated this microwave to the video signal of the TV. The wireless power transfer distance was 3.5 meters. At the aid of the transmitted microwave, we successfully rectified 48 W DC power and demodulated the video signal.

13:50 ~ 14:10
24.2 / Active Electronically Scanned Array Based on TWT

Suiming Zhou (Beijing Vacuum Electronic Research Institute, China), Baoliang Hao (Beijing Vacuum Electronic Research Institute, China), Jianyong Kou (Beijing Vacuum Electronic Research Institute, China)

Active electronically scanned array (AESA) radar is one of the future radar tendencies. Travelling wave tubes (TWTs) were applied as key parts in lots of AESA radars in last century. At the end of last century lots of solid-state power-amplifier AESA radars were developed, but these AESA radars were limited in actual combats. In the last decade with the TWT technical breakthroughs, such as miniaturization, high efficiency, high consistency and high reliability, TWT could be undertaken as the power amplifier in AESA radar, which makes the radar's maneuverability higher and its cost lower. Maybe TWT would be the optimal choice of power device in the development of AESA radar.

14:10 ~ 14:30
24.3 / X-band Linear Accelerator for Radiotherapy

Y. S. Lee (Korea Electrotechnology Research Institute, Korea), G. J. Kim (Korea Electrotechnology Research Institute, Korea), S. H. Kim (Korea Electrotechnology Research Institute, Korea), J. H.

Lee (Korea Electrotechnology Research Institute, Korea), I. S. Kim (Korea Electrotechnology Research Institute, Korea), Y. W. Choi (Korea Electrotechnology Research Institute, Korea), J. I. Kim (Korea Electrotechnology Research Institute, Korea), J. H. Hwang (The Catholic University of Korea, Korea), A. R. Kim (The Catholic University of Korea, Korea), Y. J. Seol (The Catholic University of Korea, Korea), T. G. Oh (The Catholic University of Korea, Korea), N. Y. An (The Catholic University of Korea, Korea), Y. A. Oh (The Catholic University of Korea, Korea), Y. N. Kang (The Catholic University of Korea, Korea)

In the field of radiotherapy, as the treatment method which is combined with imaging devices becomes important, there is an increasing demand for miniaturization and weight reduction of linear accelerator (LINAC), which is a core part of the radiotherapy equipment. To meet these requirements, LINAC has been developed by applying X-band RF technology and side-coupled structure. The developed LINAC is operated by an RF signal with a frequency of 9.3 GHz. The length of the RF cavity is 37 cm and the shunt impedance is 116 MΩ/m. The electron beam can be accelerated up to 6.3 MeV with having about beam current of 80 mA by electric field strength of 16.8 MeV/m. Based on the design parameters, the dose rate is calculated to be more than 1000 cGy/min when the source to surface distance (SSD) is 80 cm.

14:30 ~ 14:50

24.4 / Cathodoluminescent UV-Sources Using Carbon Fiber Field Emission Cathodes

Dmitry I. Ozol (Moscow Institute of Physics and Technology, Russia), Evgenii P. Sheshin (Moscow Institute of Physics and Technology, Russia), Natalia Yu. Vereschagina (Lebedev Physics Institute of RAS, Russia), Maksim V. Garkusha (Moscow Institute of Physics and Technology, Russia) Mikhail I. Danilkin (Lebedev Physics Institute of RAS, Russia), Htet Win Aung (Moscow Institute of Physics and Technology, Russia)

The prototypes of cathodoluminescent UV radiation sources with field emission cathodes on the basis of carbon fiber are manufactured. These sources exhibit various UV spectra depending on the phosphors used.

14:50 ~ 15:10

24.5 / Carbon nanotube based cold cathode emitter employed x-ray tube fabrication for medical imaging applications

Yi Yin Yu (KyungHee University, Korea), Kyu Chang Park (KyungHee University, Korea)

A x-ray module with triode configuration was fabricated using vertically aligned carbon nanotubes (VACNTs) emitters. The I-V characteristics of the module inside a vacuum chamber with angle anode were evaluated and x-ray images were derived as well. Furthermore, taking advantages of the module compactness, we made a conventional type of glass sealed x-ray tube. We assessed the I-V characteristics and image resolution for medical imaging applications such as early diagnosis for osteoporosis.