6th International Workshop on Mechanisms of Vacuum Arcs (MeVArc 2017)

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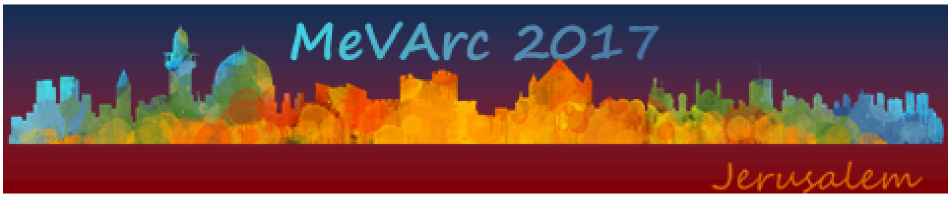
Other Institutes



Book of Abstracts

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welcome and opening remarks

Applications and Background / 7

CLIC High-Gradient Accelerator Studies

Author: Walter Wuensch[1]

[1] *CERN*

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Significant progress has been made by the CLIC collaboration to understand the phenomena which limit gradient in normal-conducting accelerating structures and to increase achievable gradient in excess of 100 MV/m. Scientific and technological highlights from the CLIC high-gradient program are presented along with on-going developments and future plans. I will also give an overview of the range of applications that potentially benefit from high-frequency and high-gradient accelerating technology.

Type of contribution:

Oral

session:

Applications - materials and devices

Applications and Background / 12

Manipulating Relativistic Electrons with Intense Laser Pulses

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Laser Plasma Accelerators (LPA) rely on the control of the electrons motion with intense laser pulses [1]. Improvements of electron beam parameters such as divergence, energy or energy spread are possible thanks to this fine optical control. This manipulation of electrons with intense laser pulses allows a fine mapping of the longitudinal and radial components of giant electric fields that can be therefore optimized for accelerating charged particle or for producing X rays. To illustrate the beauty of laser plasma accelerators I will show different experimental results that we recently performed that allow to improve the quality of the electron beam, its stability [2] and its energy gain in longitudinal field [3], or the reduction of its divergence using radial field [4]. I'll then show how by controlling the quiver motion of relativistic electrons intense and bright X-rays beam are produced in a compact and elegant way [5-7]. Finally I'll show some examples of applications [8].

[1] V. Malka, Phys. of Plasmas 19, 055501 (2012).
[2] E. Guillaume et al., Phys. Rev. Lett. 115, 155002 (2015).
[3] C. Thaury Scientific Report, 10.1038, srep16310, Nov. 9 (2015)
[4] C. Thaury et al., Nature Comm. 6, 6860 (2015)
[5] K. Ta Phuoc et al., Nature Photonics 6, 308-311 (2012).
[6] S. Corde et al., Review of Modern Phys. 85 (2013)
[7] I. Andriyash et al., Nature Comm. 5, 4736 (2014)
[8] V. Malka et al., Nature Physics. 4, 447 (2008)

Type of contribution:

Oral

session:

Experiments and Diagnostics

Applications and Background / 2

Vacuum arc plasma in devices. Modeling and experiments

Author: Michael Keidar[1]

Co-author: Isak Beilis [2]

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We will present overview of plasma modeling and experiments related to vacuum arc devices. The character of the plasma flow depending on the anode geometries relatively to the expanding plasma jet will be analyzed. Specifics of the high-current vacuum arc will be examined including several effects associated with high-current arc behavior in a magnetic field and transition from diffusion to constricted arc. Specifically we will address phenomena relevant for vacuum arc circuit breakers such as behavior of the vacuum arc in a magnetic field, V-shape of the arc voltage in an axial magnetic field, near anode phenomena etc. In addition we will discuss breakdown process in the case of a micro-vacuum arc device. This includes effects of insulator material, cathode material deposition and cyclic nature of insulation of the inter electrode layer.

Type of contribution:

Oral

session:

Applications - materials and devices

Applications and Background / 3

Plasma Window for Various Applications

Author: Ady Hershcovitch[1]

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The Plasma Window is a novel apparatus that utilizes a stabilized plasma arc as interface between vacuum and atmosphere or pressurized targets without solid material. Additionally, the plasma has a lensing effect on charged particles. Furthermore, plasma from a plasma window was extended over 2 cm into atmosphere to form a plasma shield (Plasma Shield is basically a Plasma Window extended to engulf a target object).

The best results to date have been the following:
1. Vacuum (pressure of ˜ 10^{-6} Torr) was successfully separated from atmosphere or argon gas target pressurized up to 9 bar.
2. A 2 MeV proton beam was propagated from vacuum through the plasma window into atmospheric pressure.
3. Electron beams with energies of 90 - 175 KeV were transmitted from vacuum through the plasma window to atmosphere. And, Self-pinched beam propagation was achieved with 6 - 25 mA, 90 – 150 KeV electron beams. By comparison previously demonstrated self-pinched propagation used kA multi-MeV electron beams.
4. Successful transmission of X-rays from a light source to atmosphere.
5. Gas cell pressurized to 3 bar was successfully separated from atmosphere and HeNe laser light was transmitted through the gas cell and plasma window to atmosphere.

6. High quality electron beam welding in atmosphere performed.
7. Helium gas target (over 1 bar) sandwiched between two plasma windows was separated from vacuum on two opposite ends.

Scientific and industrial applications involving beam transmission from vacuum to atmosphere or to high pressure targets (like high quality electron beam welding that was performed in atmosphere) be enhanced by this technology. Specifically, the plasma window/shield can be beneficial to a number of scientific devices and machines like synchrotron light sources, high power lasers, internal targets, high current accelerators, and spallation neutron sources. A number of possible applications including windowless beamlines to atmosphere (or to high pressure targets) for neutron and/or x-ray generation will be discussed.

- Work supported by Contract No. DE-AC02-98CH1-886 with the US DOE

Type of contribution:

Oral

session:

Applications - materials and devices

Field Emission Theory and Experiments / **37**

Vacuum Field Emission Models, Measurements, and Simulations

Authors: Matthew Hopkins[1]; Ezra Bussman[1]; Sean Smith[1]; David Scrymgeour[1]; Michael Brumbach[1]; Paul Clem[1]; Harold Hjalmarson[1]; Peter Schultz[1]; Christopher Moore[1]

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In this talk we will introduce a new effort at Sandia to better understand the mechanisms involved in vacuum field emission from real, contaminated surfaces. We concentrate on the vacuum field emission of electrons from a surface based strongly on the role of initial emission as a necessary precursor to vacuum discharge. Although other ongoing work at Sandia is concerned with the evolution of the discharge process, including surface-gas interactions, plasma creation and growth, plasma chemistry, etc., we are solely concerned with vacuum field emission in this work.

To better understand field emission physics we are developing experimental and modeling capabilities to investigate the processes governing subsurface electron transport resulting in surface emission. The goal of the work is to develop models (captured in computational simulation capabilities) that predict correct electron transport and emission through conductors and heterogeneous surfaces (e.g., applied dielectric films). Progress is measured through improved comparisons between our experimental measurements and simulation results.

In the experimental regime, we are employing scanning tunneling microscopy (STM), atomic force microscopy (AFM), tunneling electron microscopy (TEM), and x-ray photoelectron spectroscopy (XPS) capabilities in novel experiments to bridge the tunneling-to-field-emission regime on specially prepared surfaces. Initially using single crystal Pt as a well characterized and well behaved emission surface, we add controlled specific layers of selected dielectrics (e.g., TiO_2, Al_2O_3) through atomic layer deposition (ALD) techniques, and make similar local I vs. V measurements under differing field strengths and tip-to-sample distances to understand the role of surface dielectric barriers (of varying thickness), grain boundaries, dislocations, and other micro- and nanoscale features on emission.

In the modeling regime we will couple density functional theory (DFT) models to describe a potential field, and apply electron Ensemble Monte Carlo transport methods developed at Sandia to account for the transport of electrons in the material leading to eventual surface emission. These detailed models will eventually be incorporated into coarser level modeling capabilities (e.g., PIC-DSMC) for use in simulating behavior of real devices.

Type of contribution:

Oral

session:

Field Emission

Field Emission Theory and Experiments / **28**

News from DC-pulsed system at CERN

Author: Iaroslava Profatilova[1]

Co-authors: Walter Wuensch [2]; Xavier Stragier [3]

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[2] *CERN*

[3] *Eindhoven Technical University (NL)*

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High-field and breakdown experiments are being carried out at CERN using a pulsed dc set-up. The objective of the pulsed dc experiments are to complement the ongoing high-gradient radio frequency experimental program and for optimizing material treatments, parameters of conditioning process and methods of minimization of breakdown events in accelerating structures. The latest hardware developments and results from DC-pulsed systems will be presented including: influence of pulse length on breakdown rate, breakdown localization, dark current measurements and the high-field behaviour of different materials.

Type of contribution:

Oral

session:

Experiments and Diagnostics

Field Emission Theory and Experiments / **10**

Dark and Breakdown Currents Studies with RF and In-SEM Field Emission Studies.

Author: Marek Jacewicz[1]

Co-authors: Roger Ruber [1]; Volker Ziemann [1]

[1] *Uppsala University (SE)*

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A spectrometer for detection of the dark and breakdown currents during conditioning of new accelerating structures for CLIC, is operated at one of the 12 GHz stand-alone test-stands at CERN. The spectrometer consists of a dipole magnet, a variable collimator, and a fluorescent screen read out by a fast camera.
Built for high repetition rate operation it can measure the spatial and energy distributions of the electrons emitted from the acceleration structure during a single RF pulse.
CLIC structures operate very close to the gradient limit that is set by appearance of the vacuum breakdowns. The particles escaping the structure provide useful information about the physics of the vacuum breakdown e.g. the evolution of the surface under RF pulses or the underlying trigger mechanism. Together with the information from the measured RF powers we obtain with the new setup a more complete picture of the vacuum breakdown phenomenon that can help in achieving higher reliability and long life-time for the structures.
Here we present the first results and progress of the project.

Type of contribution:

Oral

session:

Experiments and Diagnostics

Field Emission Theory and Experiments / **26**

Update on the status of field electron emission theory

Author: Richard Forbes[1]

[1] *University of Surrey, UK*

Corresponding Author: r.forbes@trinity.cantab.net

This presentation aims to provide brief updates on our current understanding of the theory of field electron emission (FE), on progress in putting FE theory onto a more scientific basis, and on progress in interpreting measured FE current-voltage [Im(Vm)] characteristics. Possibly the main use of FE theory in vacuum breakdown is to provide good formulae for use in simulators, with some assessment of their likely reliability. Other topics to be covered that may be of interest are issues relating to: (1) the concept of the emitter's electrical surface and its location; (2) the definition of field enhancement factors (FEFs), and the prediction of FEF values; (3) alternative definitions of emission area; and (4) the extraction of area and FEF estimates from Im(Vm) data. Warnings will be given that large parts of current FE literature are somewhat unreliable, with defective equations often stated, and spuriously large FEF values often reported (the latter can often be detected by an "orthodoxy test"). If time permits, some of the immediate and longer-term tasks necessary to improve both our understanding of FE theory and its clear presentation, and some of the obstacles, will be described.

Type of contribution:

Oral

session:

Field Emission

Field Emission Theory and Experiments / **22**

A generalized method for calculating electron emission and thermal evolution of metal nanotips

Author: Andreas Kyritsakis[1]

Co-authors: Flyura Djurabekova [2]; Mihkel Veske [2]; Vahur Zadin [3]

[1] *University of Helsinki, Helsinki Institute of Physics*

[2] *University of Helsinki*

[3] *University of Tartu*

Corresponding Author: andreas.kyritsakis@helsinki.fi

Electron emission from nanometric emitters becomes increasingly interesting due to its involvement to vacuum breakdown phenomena and various other vacuum nanoelectronics applications. The most commonly used theoretical tool for the calculation of electron emission is still nowadays the Fowler-Nordheim (F-N) equation, although it has been shown that it is inadequate for nanometrically sharp emitters or in the intermediate thermal-field regime. We have recently developed a general computational method [1] (and corresponding code named GETELEC) for the calculation of emission currents and Nottingham heat from sharp metallic protrusions. GETELEC is combined with a modified version of the existing Molecular Dynamics - Finite Differences Method (MD-FDM) code HELMOD and the recently developed Finite Elements Method (FEM) code FEMOCS into a complete simulation tool that combines MD, electrostatics, heat diffusion and electron emission calculations. We use this tool to simulate the thermal and shape evolution of Cu nanotips of various shapes under strong electric fields and determine the conditions under which the tips can evaporate. We find that their behaviour predicted by the new model is significantly different from the one obtained by previous models using the F-N equation and neglecting the Nottingham effect.

[1] A. Kyritsakis and F. Djurabekova, Computational Materials Science 128, 15 (2017).

Type of contribution:

Oral

session:

Field Emission

posters session / 16

Spectroscopic Study of Vacuum Breakdown Process Under Impulse Voltage

Author: Zhipeng Zhou[1]

Co-authors: Jianhua Wang [1]; Yingsan Geng [1]; Zhenxing Wang [1]; Zhiyuan Liu [1]

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In order to investigate the evolution of species type during a vacuum breakdown, a spectroscope with a ICCD was adopted to detect the spectrum during the breakdown, and the state of species can be deduced from the spectra. A tip-to-tip gap was installed in a vacuum chamber; the gap distance varied from 0.5 mm to 3 mm; and copper and tungsten were chosen as the cathode and anode material, respectively. Under such conditions, spectra at different stages of the breakdown were obtained and also the state of plasma.

Type of contribution:

Oral

session:

Experiments and Diagnostics

posters session / 15

Kinetic model of defects generation in oxide crystals by intense radiation

Author: SUSUMU KATO[1]

Co-author: ATSUSHI SUNAHARA [2]

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[2] *Institute for Laser Technology(ILT)*

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Many optical elements such as mirror, window, amplifier, and wavelength conversion elements are made from oxide materials. The elucidation of damage threshold and mechanism is indispensable to the development of high-power system. Especially, in high-repetition-rate system, the accumulation of defects such as color center causes the damage.
In this work, we propose a kinetic model including generation from excited state to defect in oxide crystals and evaluate the influence of defects accumulation on crystal damage.

Type of contribution:

Poster

session:

Modelling and Simulations

posters session / 29

Simulations of gold surfaces under high electric fields

Author: Simon Vigonski[1]

Co-authors: Alvo Aabloo [1]; Ekaterina Baibuz ; Flyura Djurabekova [2]; Vahur Zadin [1]; Ville Jansson [2]

[1] *University of Tartu*

[2] *University of Helsinki*

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Surface defects are thought to play an important role in vacuum breakdowns. Possible nanoprotrusions can significantly enhance the electric field, leading to increased field emission, atom evaporation, and eventually arcing. Atomic scale simulations are very useful in studying dislocation behaviour and surface defects. However, the main material of interest, copper, is in practice covered by an oxide layer, which complicates the simulations. Gold, which also exhibits similar surface behaviour as copper in experiments, is free of this concern and studying it could provide insights into the general processes leading to a breakdown event.

We use a Kinetic Monte Carlo (KMC) method combined with Molecular Dynamics (MD) to simulate diffusion and relaxation processes on the gold surface. To characterize the diffusion of surface adatoms, we have developed an improved migration barrier calculation method. This tethered Nudged Elastic Band (NEB) method is better at describing unstable atomic configurations, which occur frequently around surface defects. We use the MD simulations, as well as KMC with tethered NEB, to study defect formation and stability on gold surfaces under high external electric fields.

Type of contribution:

Poster

session:

Modelling and Simulations

posters session / 4

Metal Vacuum Arc Variants for High Charge State Ion Generation

Author: Ady Hershcovitch[1]

[1] *BNL*

Corresponding Author: hershcovitch@bnl.gov

Certain adaptations of metal vapor vacuum arcs can be a promising approach as high charge state ion sources for various applications including relativistic heavy ion colliders, heavy ion inertial confinement fusion and with modifications to boron phosphorous as well as for As, and Sb ions for ion implantation for semiconductor manufacturing as well. Two approaches have shown good promise: E-MEVVA and LIZ-MEVVA, which are the acronyms for electron beam metal vapor vacuum arc and low-inductance Z-discharge metal vapor vacuum arc respectively. In the first a metal vapor vacuum arc is generated through which an intense electron beam is injected to successively ionize the vacuum arc generated ions to high charge states. Charge state enhancement in the latter is achieved by ignition of a high current magnetized axial in low charge state metal vapor vacuum arc generated ions. Large currents 10's mA of Pb^{7+}, Bi^{8+}, Sn^{+6} , Cd^{+5}; In^{+5}, P^{4+}, and Sb^{6+} were generated by E-MEVVA with electron beam current of 80 A; very large currents 100's mA of Au^{+19} were generated by LIZ-MEVVA with currents of 88 kA. Devices, physical processes for generating the high charge state ions, well as novel embodiments for generating larger ions beam with even higher charge state will be described.

- Work supported by Contract No. DE-AC02-98CH1-886 with the US DOE

Type of contribution:

Oral

session:

Experiments and Diagnostics

posters session / 20

Dislocation interactions in subsurface copper inducing electric breakdowns

Author: Anton Saressalo[1]

Co-authors: Flyura Djurabekova [2]; Iaroslava Profatilova [3]

[1] *Helsinki Institute of Physics (FI)*

[2] *University of Helsinki*

[3] *Nat. Acad. Sci., Inst. Appl. Phys. (UA)*

Mechanisms behind breakdowns on copper surfaces have been studied with various methods using both experiments and simulations. The high-voltage direct current measurements with the Large Electrode System in CERN have been proven good in acquiring statistics on a large number of breakdown events. Recently, similar experiments have started at the University of Helsinki in order to provide information about copper electrodes treated in various ways.

Based on the fact that the breakdown hardness is correlated with the crystal structure of the material, dislocations have been suggested to have impact on stresses in the near-surface region and eventually on the breakdowns. Grain boundaries and other crystal defects are expected to act as dislocation concentrators.

Discrete Dislocation Dynamics (DDD) method has been used to simulate the movement of dislocation segments in near-surface copper and to see how they interact with different obstacles and each other. As the simulation conditions have been adjusted to match the experiments and the DDD allows the scales of simulations to be in the same order of magnitude, they are both able to complement each other.

The poster presents the preliminary results from these simulations and the first observations from the experiments in Helsinki.

Type of contribution:

Poster

session:

Modelling and Simulations

posters session / 32

Anode Temperature Measurement in a Vacuum Arc with a Black Body Electrode Assembly

Author: Itzhak Beilis[1]

Co-authors: Raymond L. Boxman [1]; y Koulik [1]

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In a Vacuum Arc with a Black Body Assembly (VABBA), cathode material is

emitted into a closed chamber formed by the end surface of a water-cooled cylindrical

cathode and a cup shaped refractory anode that is heated by the arc. Material is eroded from

the cathode spots as plasma and MPs. They impinge on the hot anode and are re-evaporated

from it, forming a dense high-pressure plasma within the chamber. The closed chamber operates as a black body for the macroparticles (MPs) while the plasma can be emitted through either a single small anode apertures or a "shower head"array of holes.
In the present study, the Cu cathode was a 30 mm diameter and the anode was 50 mm outer diameter and 40 mm inner diameter, and constructed from Ta. The arc plasma was ejected through an array of 250 holes of 0.6 mm diameter in the anode. The arc currents were I=175, 200 and 225 A and the arc duration was 160 s. The anode temperature was measured using high-temperature thermocouples in the top and side of the anode body. The observed anode temperature increased sharply during a transient time of ˜70-90 s and then it slightly increased with time up to 160 s, reaching 1650 K (I=175 A) and 1850K (I=225 A) on the top, and 150-200 K lower on the side.

Type of contribution:

Poster

session:

Experiments and Diagnostics

posters session / **40**

A theoretical link between voltage loss, field-enhancement-factor reduction, and Fowler-Nordheim-plot saturation

Author: Richard Forbes[1]

[1] *University of Surrey, UK*

Corresponding Author: r.forbes@trinity.cantab.net

When an individual post-like field emitter (modelled as standing on one of a pair of parallel planes) is sufficiently resistive, and current through it sufficiently large, then voltage loss occurs along it. This Poster shows this voltage loss is directly and inextricably linked to a reduction in the field enhancement factor (FEF) at the post apex. A formula relating apex-FEF reduction to this voltage loss was obtained by Minoux et al. [1] by fitting to numerical results from a Laplace solver. This Poster derives the same formula analytically, using a "floating sphere" model. The analytical proof brings out the underlying physics more clearly, and shows the effect is a general phenomenon, related to reduction in the magnitude of the surface charge in the most protruding parts of an emitter. Voltage-dependent FEF-reduction is one cause of "saturation" in Fowler-Nordheim plots. Another is a voltage-divider effect, due to measurement-circuit resistance. An integrated theory of both is presented. Both together, or either by itself, can cause saturation. Other putative causes exist, so the present theory is a partial story. Its extension seems possible, and could lead to a more general physical understanding of saturation.
E. Minoux et al., Nano Lett. 5, 2135 (2005).

Type of contribution:

Poster

session:

Field Emission

posters session / 41

Note on using the principal Schottky-Nordheim barrier function v(x)

Author: Richard Forbes[1]

[1] *University of Surrey, UK*

Corresponding Author: r.forbes@trinity.cantab.net

This note suggests improvements in presenting field electron emission (FE) theory. It relates to the so-called principal Schottky-Nordheim (SN) barrier function "v" used in Murphy-Good-type FE theory. I argue that: (1) we should separate the mathematics of v from its applications in tunnelling theory; (2) we need to change the independent variable used; and (3) we can improve the notation.
It is now known that v is a special mathematical function that is a very special solution of the Gauss Hypergeometric Differential Equation. Denote the independent variable in this equation by x, and call x the Gauss variable. The best mathematical convention is to write v(x), with "v" typeset upright (like "sin" or "Ai"). [Previously I wrote v(l'), which is a clumsy notation derived from the theory of complete elliptic integrals. This change is just a re-labelling.]
When this mathematics is applied to tunnelling through an SN barrier, one can either put x=f, where f is the scaled barrier field (which is the modern approach), or put x=y2, where y [=f1/2] is the Nordheim parameter (which is the historical approach). This poster re-states the scientific reasons why the modern approach is considered superior.

Type of contribution:

Poster

session:

Field Emission

posters session / 42

Testing Fowler-Nordheim-type equations

Author: Richard Forbes[1]

[1] *University of Surrey, UK*

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Fowler-Nordheim (FN) theory uses "smooth-surface" conceptual emitter models. It is not accurate theory because it disregards the existence of atoms, and takes the emitter surface charge as confined to an infinitesimally thin classical layer. Developing fully self-consistent field emission theory will be intensively difficult, and has received limited attention. It could take 50-100 years. However, it seems long overdue that we seriously consider how to test FN-type equations, to get a better idea of where physical weaknesses lie.
Deciding how to do this testing is itself a very complex problem, because many assumptions go into derivations, and up to seven parameters may appear in a FN-type equation. It seems best to start with the exponential. The inverse dependence on field has been well tested, and probably the dependence on w[illegible] adequately tested. The largest poorly tested assumption is that the tunnelling barrier is better modelled as a Schottky-Nordheim ("planar image rounded") barrier rather than an exactly triangular barrier. Eight putative methods are identified in the Poster, but very few

are actually decisive. A summary will be given of current conclusions. Briefly, the SN barrier looks the more plausible model, but the evidence to date is not completely decisive.

Type of contribution:

Poster

session:

Field Emission

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Dark current fluctuations in pre-breakdown conditions

Author: Sagy Lachmann[1]

Co-authors: Yinon Ashkenazy [2]; Tomoko Muranaka [3]

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[2] *The Hebrew University of Jerusalem (IL)*

[3] *CERN*

Cathodic Breakdown (BD) is a main failure mode of systems relying on maintaining high fields under vacuum.
It has been suggested that field emission (FE) currents, known to exist in the system prior to breakdown, are linked to the BD process.
We report on observations of non-Gaussian fluctuations in FE currents measured in CERN DC setups and analyzed using a moving average filter. These events have time scales of a few tens of nano-seconds and are characterized by an increase in the FE current. Such behavior is consistent with suggested surface fluctuations leading to pre-BD dynamic surface evolution, which may in turn lead to a temporary increase in observed FE current.
Initial results are reported and future experiments validating these results are proposed.

Type of contribution:

Poster

session:

Field Emission

posters session / 56

Crater evolution and droplet generation in vacuum arcs during the cathode spot development

Authors: Itay Nachshon[1]; Isak. I. Beilis[2]; Yinon Ashkenazy[3]

[1] *Racah Institute of Physics, Hebrew University of Jerusalem*

[2] *School of Electrical Engineering, Tel Aviv University*

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Abstract: Electrical breakdowns and cathode spot initiation are important phenomena in applications used for components with high voltage assemblies. During the cathode spot formation, dense and hot plasma is produced that generates an intense heat flux towards to the cathode surface. As result the cathode melts. Under the plasma-surface interaction, droplets and craters are formed. The arbitrary geometry of the crater rim and remnants of the surface droplets in the form of tips, stimulate new breakdown processes, changing the character of electrical field distribution and generates hardening processes of the material. This causes a technological challenge. Therefore the dynamics of the cathode heating and cathode phase transition under high pressure spot plasma is an issue for understanding of the processes leading to breakdown under high electric fields for various applications that require the maintaining of such fields.
The present work presents a physical and mathematical model including the heat flux that takes in account the ion kinetic and potential energy, cathode heat conduction, the plasma pressure due to hot ionized and neutral particles, metal melting, convection and liquid flow. The plasma spot characteristics obtained from a previously developed spot theory [1] were used in order to formulation the requested boundary conditions. Specifics of the time-scale that relate to controlling the shape of the craters as well as of it re-solidification were considered.
Using Finite Element modeling we investigate effects controlling the complicate geometry and flow of the liquids as well as elasto-plastic response. Plasma effects are simulated using non-trivial boundary conditions. Initial results regarding crater characteristics and their dependence on plasma spot parameters are presented. Results can help link crater population statistics to that obtained in experiments and help explain plasma parameters in these experiments.

[1] I.I. Beilis, "Cathode Spot Development on a Bulk Cathode in a Vacuum Arc", IEEE Trans. Plasma Sci., Vol.41, N8, Part II, 2013, (pp. 1979-1986)

Type of contribution:

Poster

session:

Modelling and Simulations

posters session / 57

Pulsed DC System Facilities

Authors: Walter Wuensch[1]; Sergio Calatroni[1]; Enrique Rodriguez Castro[2]; Iaroslava Profatilova[3]; Xavier Stragier[4]; Thomas Lucas[5]; Noora-Mari Pienimaki[1]

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For the development of high gradient accelerating structures of CLIC and other similar machines it is vital to understand the mechanism of vacuum breakdown. Previous investigations into the phenomena were performed through lengthy and costly RF conditioning of accelerating structures and cells. In an attempt to more efficiently investigate the effects of different materials and conditioning algorithms a novel pulsed DC system has been developed at CERN. This system allows for the creation of high fields between two electrodes at a repetition rate far beyond current RF systems, conditioning the surface in weeks rather than months. Complementary to this, a newly installed camera system located breakdowns through triangulation, which along with post processing microscopy, allows great insight into breakdown trends during conditioning.

Type of contribution:

Poster

session:

Experiments and Diagnostics / 33

STUDIES OF HIGH-POWER MICROWAVE STRUCTURES THAT EMPLOY BIMODAL CAVITIES

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ABSTRACT

Theory and simulations predict that metallic microwave accelerating structures, including RF guns, should operate at high acceleration gradients with reduced breakdown rates and/or with improved beam quality if their cavities operate simultaneously in two harmonically-related modes, rather than only in the fundamental mode. Examples include structures that are driven by external RF sources, as well as structures that are beam driven. The status will be described of these studies, including on-going experiments to test the predictions.

Type of contribution:

Oral

session:

Experiments and Diagnostics

Experiments and Diagnostics / 35

RF breakdown study on choke-mode damped accelerating structures

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X-band high gradient accelerating structures has been studied in Tsinghua University, especially the choke-mode damped structure. Several single-cell standing-wave structures have been built for high power test. One choke-mode structure achieved a max gradient of 75 MV/m and the choke breakdown limited further increasing of the gradient. Postmortem inner surface inspection of the choke-mode cavities indicates that the axial part of the choke limits the performance of the structure. This phenomenon is comparable to what is observed in DC system with two parallel plates.

Based on this observation, two new choke-mode cavities are designed and manufactured for testing. Details of the structure and high-power test result as well as the RF breakdown analysis will be presented.

Type of contribution:

Oral

session:

Experiments and Diagnostics

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Arcing on fuzzy nanostructures

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Helium ion bombardment, which can occur on plasma facing walls in nuclear fusion devices, forms metallic fuzzy nanostructures on the surface [1]. Interestingly the nanostructure growth accompanied by helium bubble formation occurs on various metals, such as tungsten, molybdenum, tantalum, iron, nickel, and rhenium. In this study, we conducted (unipolar) arc experiments using the nanostructured materials in plasma environment, which simulates the environment in nuclear fusion devices. By using laser pulses and/or biasing the sample, arcing were ignited on the material. Fractal features and retrograde motion of arc spot were observed using the fast framing camera and on trails recorded on the surface. The retrograde motion significantly altered by changing the magnetic field strength and the thickness of the nanostructured layer. Especially when the nanostructured layer is thick, say thicker than 1 micron meter, arc spots were entangled together and formed grouping. Formation of grouping and spot splits were frequently identified from the arc trail recorded on the nanostructures. Also, from the field emission measurement from the material, it is shown that field emission significantly enhanced by the nanostructures.

[1] S Kajita et al, Nucl. Fusion 49 (2009) 095005.

Type of contribution:

Oral

session:

Applications - materials and devices

Experiments and Diagnostics / 31

Influence of Cathode Melted Layer on Vacuum Insulation

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Co-authors: Jianhua Wang ; Yingsan Geng [1]

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The objective of this paper is to determine influence of depth of cathode melted layer on vacuum insulation. A 12kV vacuum interrupter with a pair of rod-plane electrode was designed. A DC current source is applied on the test vacuum interrupter, in which the rod electrode is chosen as anode. A drawn vacuum arc is used to generate different depth of melted layer on the rod electrode in an anode spot arc mode. The arcing time can be controlled as 0ms, 10ms, 46ms and 73ms, respectively. Then the vacuum gap was adjusted at 1mm to measure the basic lightning impulse breakdown voltage. Positive polarity standard 1.2/50μs lightning impulse voltage was applied by a basic up-down method, in which the rod electrode was the cathode. Experimental results revealed that the breakdown probability distribution followed a Weibull distribution when the breakdown voltage reached saturation. The 50% breakdown voltage of different arcing time 0, 10, 46 and 73ms corresponded to 55.6, 73.3, 75.5 and 77.9kV, respectively. After that, rod electrode surface and cross section of the rod electrode were analyzed by electron microscope and the average depths of melted layer were 0, 5, 35 and 65um, corresponding to current arcing time 0, 10, 46 and 73ms, respectively. The depth of melted layer was approximately linear to the arcing time. The of vacuum gap with the melted layers increased significantly than that without melted layer. The of vacuum gap with different depth of melted layer were very close each other. Thus, the melted layer did improve the breakdown voltage but the depth of melted layer has no significant influence on the breakdown voltage.

Type of contribution:

Oral

session:

Experiments and Diagnostics

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The spatial evolution of species during vacuum breakdown

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Co-authors: Jianhua Wang ; Yingsan Geng [1]; Zhipeng Zhou [1]; Zhiyuan Liu [1]

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The initial stage of vacuum breakdown is still lack of direct experimental evidence because it is difficult to observe and measure. The objective of this study is to observe the light emission in the initial stage by optical diagnosis.We adopted a ICCD camera to catch a series of images in a breakdown and two optical filters to distinguish the light from copper atom (Cu I) or singly charged copper ion (Cu II). A tip-to-tip gap was installed in a vacuum chamber; the gap was 2mm; the voltage was provided with a impulse source with a peak value of 30kV; the current was measured by a Pearson sensor with a bandwidth of 200MHz; From the results, a vacuum breakdown was initiated by the electron emission from the cathode surface, leading to a strong copper atom evaporation. Consequently, single charged ions were triggered and expanded from the cathode to the anode. After a short delay, the anode region became much more luminous than the cathode, and the plasma formed in front of anode was spread from the anode to cathode.

Type of contribution:

Oral

session:

Experiments and Diagnostics

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Gas breakdown investigation and mitigation in complex geometries

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Co-authors: Alan Howling [2]; Ben Gaffinet [2]; Daniel Bommottet [3]; Ivo Furno [2]; Paul Martens [2]

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Increasing satellite bus voltages from 28-100 V to 300-600 V is presently under investigation [1]. High voltages will be required to power new generations of ion and Hall effect thrusters [2], with higher power efficiencies, lower power system costs and substantial mass savings. At the same time, increasing bus voltage could lead to a higher risk of electrical breakdown for several satellite components, in particular for solar panels and slip ring assemblies (SRAs). Gas breakdown inhibition in satellites is a technological challenge. Satellites experience a wide range of pressure, from atmospheric pressure before the launch to high vacuum ($\leq 10^{-8}$ mbar) in orbit. Many poorly-defined physical parameters and pressure fluctuations characterize the environment surrounding a satellite during its operating life.
This work focuses on gas breakdown on the standard cylindrical configuration of a SRA, which ensures the electrical power transmission between the rotating solar panels and the rest of the satellite. The SRA features a complex geometry, including gold-plated brushes slipping on a stack of gold-plated rings, surrounded by a conducting housing at the ground reference voltage of the satellite. Optimization studies of the SRA design to inhibit gas breakdown will be presented [3].

[1] T. Yoke, *et al.* IEEE Trans. on Plasma Science **41**, 3477 (2013).

[2] A. Leporini, *et al.* "DEVELOPMENT OF A 20 kW-CLASS HALL EFFECT THRUSTER", Proceedings of Space Propulsion, (2016).

[3] R. Schnyder, *et al.* J. Phys. D: Appl. Phys. **46**, 285205 (2013).

Type of contribution:

Poster

session:

Applications - materials and devices

Experiments and Diagnostics / 11

Dislocation patterns in Cu-OFE by EBSD and Breakdown activity

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In the frame of the CLIC (Compact Lineal Collider) study for the development of a two-beam accelerating technology for a future TeV–scale e+e- linear collider, electrical breakdown (BD) phenomena are deeply studied. BDs are caused by the interaction of the oxygen free electronic copper (Cu-OFE) with vacuum arcs at high gradient operation. BD phenomena lead to isolated or clusters of craters on the surface of the CLIC accelerating structure (AS). The presence of dislocations into the Cu-OFE is suspected to play a role on the BD phenomena. This study focuses on the development of a quantitative and non-destructive diagnostic of the dislocations presence in the Cu-OFE. The final aim is to investigate the relationship between location of BDs features and dislocation presence.

Type of contribution:

Oral

session:

Applications - materials and devices

Experiments and Diagnostics / 25

Observations of pre- and post-breakdown structures on OFHC Cu surfaces

Authors: Ayelet Yashar[1]; Inna Popov[1]

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Numerous devices featuring diverse applications contain metal that is exposed to high electric fields and operate under a vacuum. At high electric fields, an occurrence of plasma formation inside the vacuum can lead to breakdown [BD] and failure of the device. Despite the fact that the detailed mechanisms controlling BD have been the subject of extensive study for the past several decades, currently the nature of BD formation remains elusive. However, through an examination of the features caused by the BD process we can gain a better grasp of the phenomenon in an attempt to find its root causes. Craters are the most characteristic feature of BD; other features can also be found on the surface, both in regions distant from craters as well as in close proximity to them. These other features include dendritic arms, depressions, "step-like"features, and splashes of melted copper. In order to discern which features were created in pre-BD as opposed to post-BD, we are working to distinguish between features that were created as a byproduct of crater formation, and those which came into existence independently of crater formation. Such a distinction can play a critical role in paving the way towards an understanding of the mechanisms behind BD, and thereby help in reducing the rate of BD occurrence, which in turn can lessen the damage caused to the material and consequently increase the substrate's lifetime.

Type of contribution:

Oral

session:

Experiments and Diagnostics

Applications and Background / 36

Miniature Vacuum Arc Thruster with Controlled Cathode Feeding

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A new type of micropropulsion device is presented –the inline-screw-feeding vacuum-arc thruster (ISF-VAT). This thruster couples a conventional "triggerless"vacuum arc ignition system with a feeding mechanism that maintains a steady state discharge performance. The feeding mechanism implements a screw action on a central cathode rod. At a predetermined rate, a complete and uniform erosion of the cathodes tip is obtained as well as "healing"of the insulator coating. The in-line feeding of the cathode forces the arc to emerge on the tip of the cathode eliminating the need for an additional plasma acceleration stage. The ISF-VAT feeding mechanism is computer controlled, and offers reliable operation of the thruster over a large number of pulses. Characterization of the ISF-VAT performance is presented, conducted on an experimental prototype in the Aerospace Plasma Laboratory, Technion. Measurement results of the mass flow rate, electrical parameters of the discharge, and thrust are presented. Using a Ti cathode at a discharge power of 3 W, a mass flow rate of $\approx 1.8 \times 10^{-9}$ kg/s and a thrust level ≈ 7 μN were measured. More than 10^6 pulses were demonstrated in a single
run, accumulating a total impulse of 0.1 Ns. The thruster prototype dimensions
are 15 x 15 x 65 mm^3, and is ≈ 60 g in mass.

Type of contribution:

Oral

session:

Applications - materials and devices

Applications and Background / 27

Study of vacuum RF breakdown in strong magnetic fields

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RF breakdown has a negative impact on a RF cavity's performance, especially with the presence of strong magnetic fields. This issue can arise in designs of muon ionization cooling channel, RF guns, klystrons and in many other applications. The MuCool Test Area at Fermilab is the facility that allows us to study the effects of static magnetic field on RF cavity operation. As a part of this research program, we have tested an 805MHz pillbox-like "modular"cavity in strong external magnetic fields. "Modular"structure of the cavity enables easy dismounting of the endplates to perform inspection of inner surfaces after each run as well as swapping endplates to study the effects of various materials on breakdown phenomenon. Surface inspection after high power runs of modular cavity with flat copper end walls in zero and 3T magnetic fields revealed unique damage patterns. High power runs with Be end walls allowed us to test behavior of lower radiation length material in external magnetic field and directly measure field emission properties. Analysis and results of both material configurations will be presented.

Type of contribution:

Oral

session:

Applications - materials and devices

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Dielectric Surface Breakdown in Sub-100 nm Metal-Insulator-Metal Fins with Exposed SiOx and Si3N4 Sidewalls

Author: Morgan Monroe[1]

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The study of surface flashover behavior in nanoscale dielectrics has broad application in nano- and microfabricated on-chip electronics such as energy converters, logic/memory, mass spectrometers, field emission devices, and compact accelerators. Most microscale devices incorporate planar dielectric architectures (e.g. gate oxides in transistors) without exposed surfaces. Therefore, relatively few studies have evaluated flashover in 3D nanoscale electronics with exposed surfaces. Here, we present an evaluation of dielectric breakdown across nanoscale width (<100nm) metal-insulator-metal (MIM) devices with vacuum-facing SiOx and Si3N4 sidewalls fabricated using standard microfabrication techniques. We evaluated the effects of dielectric material, contact metal, exposed dielectric surface area, and surface treatment on the breakdown strength of nanoscale dielectric surfaces. Electrical measurements indicate that optimizing dielectric and metal geometry, dielectric deposition parameters, and microfabrication-compatible surface cleaning procedure yields surface breakdown thresholds up to 0.30 V/nm in MIM devices consisting of up to thousands of exposed nanoscale dielectric sidewalls. Furthermore, we present electron microscopy studies that suggest breakdown modes unique to nanoscale devices. Our results inform techniques to sustain high surface fields on nanoscale dielectrics, which is imperative for reliability and performance of compact vacuum electronic devices, especially in light of the recent trend toward nano- and microfabricated vacuum electronics.

Type of contribution:

Oral

session:

Applications - materials and devices

Applications and Background / 9

EXPERIMENTAL STUDY OF MULTIPACTOR SUPPRESSION IN DIELECTRIC MATERIALS

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A novel coaxial resonator to investigate two-surface multipactor discharges on metal and dielectric surfaces in the gap region under vacuum conditions (˜10-8 mbar) has been developed and tested. The

resonator is ˜ 100 mm in length with an outer diameter of ˜ 60 mm (internal dimensions). A pulsed RF source delivers up to 30 W average power over a wide frequency range 650-900 MHz to the RF resonator. The incident and reflected RF signals are monitored by calibrated RF diodes. An electron probe provides temporal measurements of the multipacting electron current with respect to the RF pulses. In this paper we compare and contrast the results from the RF power tests of the alumina (97.6% Al_2O_3) and quartz samples without a coating, "the non-coated samples"and the Alumina and quartz samples with a TiN coating in order to evaluate a home made sputtered titanium nitride (TiN) thin layers as a Multipactor suppressor.

Type of contribution:

Oral

session:

Experiments and Diagnostics

Modeling and simulations / 54

Review of BD related studies in HIP

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Review of BD related studies in HIP

Modeling and simulations / 30

Growth mechanism of a nano-protrusion on tungsten tip under electric field

Author: Ekaterina Baibuz[None]

Co-authors: Andreas Kyritsakis ; Flyura Djurabekova [1]; Vahur Zadin [2]; Ville Jansson [1]

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Understanding the mechanisms behind the growth of nano-protrusions on metal surfaces exposed to electric field is particularly interesting to the wide range of applications. Nano-protrusions growing on the electrode surfaces under the strong rf-field are proposed to cause vacuum arcs formations in Cu accelerating structures of CLIC. Recent experiments have shown that the femtosecond laser irradiation of a sharp tungsten tip exposed to the strong DC electric field leads to an asymmetric surface faceting mainly on the laser-exposed side along with the formation of a nano-protrusion few nanometers high. [1]

In order to research the mechanism of nano-protrusion growth, the long-term atomic diffusion should be taken into account. We have recently developed a Kinetic Monte Carlo (KMC) model of the surface diffusion for fcc and bcc metals[2]. This KMC model has to be parameterized for a material under study in terms of migration energy barriers and attempt frequencies for all possible diffusion jumps. In order to extend the KMC model with electric field, its effect on the energy barriers of the migrating atoms should be researched.

In the current work, we have used the DFT nudged elastic band (NEB) simulations to find the minimum energy paths of the diffusion processes on W surface under electric field. We have also used

the DFT calculations to find dipole moments and polarisabilities of adatoms on W and Cu surfaces. We have explored the conditions of nano-protrusion growth on W tip under the laser irradiation and the field emission conditions within the scope of Molecular Dynamics and Kinetic Monte Carlo simulations.

[1] H. Yanagisawa, V. Zadin et al., APL Photonics 1 (2016) 091305.
[2] V. Jansson, E. Baibuz, F. Djurabekova, Nanotechnology 27 (2016) 265708.

Type of contribution:

Oral

session:

Modelling and Simulations

Modeling and simulations / 19

Surface evolution in high electric fields

Author: Ville Jansson[1]

Co-authors: Andreas Kyritsakis ; Ekaterina Baibuz ; Flyura Djurabekova [1]; Vahur Zadin [2]

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A common hypothesis for explaining the occurrence of vacuum arcs is that high electric fields enable growth of nanotips on the metallic electrode surfaces. These tips are locally enhancing the field enough to cause field emission and start processes that eventually cause an arc. We have developed a Kinetic Monte Carlo (KMC) model that describes the atom diffusion on metal surfaces as thermally activated processes, while also taking into account the effect of an electric field on the diffusion processes. The model uses tabulated migration energy barriers and the values of the electric field, obtained by solving Laplace's equation at every KMC step.

We have verified the electric field model by simulating the drift velocity of a single W atom on a W{110} surface in different fields and temperatures. Our results are in a good agreement with experimental results from the literature. In strong fields, the migration of the adatom is biased towards higher fields. The field effect is different for the anode and the cathode and significantly lower for Cu than for W. For Cu surfaces, we have determined the minimal conditions, such as the minimum field, temperature and surface orientation, that allow growth of asperities into tips.

Type of contribution:

Oral

session:

Modelling and Simulations

Modeling and simulations / 18

Atomistic modeling of metal surfaces under high electric fields: direct coupling of electric fields to the atomistic simulations

Author: Mihkel Veske[1]

Co-authors: Andreas Kyritsakis ; Flyura Djurabekova [1]; Kristjan Eimre [2]; Vahur Zadin [3]

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In 2011 the hybrid electrodynamics –molecular dynamics code HELMOD was developed to study the effect of electric field to the stability of metal surface. That code has been successfully used in several projects. However, to cope with the forthcoming challenges, the efficiency of the software must be enhanced. This will be done by transferring the electric field solver from the finite difference basis into the finite element framework and by adding parallel computations capability. The code will be entirely open-source and will be shared with all the interested colleagues.

The code has the tools to generate the finite element mesh around the atomistic simulation domain, solves multi-physics problems in 3D domain and accommodates the communication layer with atomistic simulations. On the first stage of development, the code will dynamically solve the Laplace's equation in 3D domain to obtain electron emission currents, charges and electrostatic forces for surface atoms. The results of those calculations are coupled to classical molecular dynamics and kinetic Monte Carlo code in order to model the dynamic evolution of an atomistic system under high electric field.

The tests with the code have shown significant increase in computational efficiency for large systems and remarkable tolerance against system geometry.

Type of contribution:

Oral

session:

Modelling and Simulations

Modeling and simulations / **21**

Breakdown Events and Dark Current: a B.I.R.D. - eye view

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Breakdown events are a very important issue in high-voltage vacuum holding studies. These events are usually and efficiently studied using heuristic predictive models based on some experimentally-given parameters. However, the complete microscopic view is still lacking. A different, but related topic is the dark-current-emission which have been first theoretically studied by Fowler and Nordheim. Their theoretical predictions match the essential futures of experiments, but some correction, not simply justifiable, must be taken into account. Dark current emissions and breakdown events seem to be very different phenomena and have been described with a wide plethora of different models. Moreover, a third phenomenon usually occurs during the so-called conditioning phase of a pair of electrodes, i.e. the random impulsive current emissions, that can be thought as intermediate events between dark current and breakdown. In this work, we propose the B.I.R.D. model as a possible view to highlight the link between all these phenomena. The present investigation aims to arrange the different phenomena mentioned above in a single theoretical framework, also overcoming some well-known historical shortcomings.

Type of contribution:

Oral

session:

Modelling and Simulations

Modeling and simulations / 23

BD nucleation as a critical transition in dislocation population

Author: Yinon Ashkenazy[1]

Co-authors: Eli Engelberg [2]; Inna Popov [3]; Itay Nachshon [4]; ayelet yashar [5]

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It has been suggested that BD nucleation is a possible outcome of a stochastic process where the dislocation population is undergoing a critical transition leading to critical protrusion formation. In the past few years we have used a combination of post mortem microscopy work as well as acoustic emission studies and field emission studies in order to try and track the dislocation population activity and its correlation with BD nucleation

I will review the findings of this study up to now, describe hurdles and future plans

Type of contribution:

Oral

session:

Experiments and Diagnostics

Modeling and simulations / 8

Stochastic Model of Breakdown Nucleation under Intense Electric Fields

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We propose a model in which breakdowns in a metal, subject to a strong electric field, are driven by dislocations in the crystal structure.

The model is formulated using the density of mobile dislocations in the metal,
which is described using a stochastic model detailing multiplication and arrest,
leading to a fluctuating population at a metastable point with explicit probability for a critical transition.
We claim that such a transition can lead to the formation of critical nuclei for a cathodic spot,
leading to full breakdown.
The model is studied using numerical dynamic simulations and stochastic analysis.
We show good agreement between the numerical simulations and the analytical approximate solution for the mean breakdown times.
The probability for this transition increases with applied field, up to a critical field at which breakdown is immediate.
These results are compared to experimental observations, and can be used to predict additional behavior of such systems.

Type of contribution:

Oral

session:

Modelling and Simulations

Modeling and simulations / **44**

Model for Triggered Vacuum Switches

Author: Chris Moore[1]

Co-authors: Matthew Hopkins [2]; Andrew Fierro [1]; Stan Moore [1]

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Triggered vacuum spark gaps are useful as fast, high current switches in a variety of pulsed power applications. We will present a 3D PIC-DSMC model of a triggered vacuum switch in which the arc is triggered by running a current through a semi-conductive film adjacent to the cathode surface. Joule heating of the film results in both electron and material emission and the gap ultimately breaks down with significant current flow through the system. As plasma forms near the cathode, a parallel path for the trigger current forms resulting in reduced joule heating and potentially starving the developing plasma of material and delaying breakdown. The model currently includes these effects by separately solving for the film current given a total trigger current that passes through an assumed temporally varying parallel film and plasma resistances. The film current is then used to determine the electron emission and film material sublimation boundary conditions due to Joule heating. We then iterate the PIC-DSMC breakdown simulations and the solution of the film current/material supply until reasonable convergence is reached. We will show breakdown behavior such as delay time and starvation across a range of film resistances.

This work was supported by the Department of Energy Office of Fusion Energy Sciences at the U.S. Department of Energy under contract No. DE-AC04-94SL85000 and DE-SC0001939.

Type of contribution:

Oral

session:

Modelling and Simulations

Modeling and simulations / **43**

Classical array models and the location of the field emission tunnelling barrier

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Increasing interest in using DFT methods to model charged surfaces is illustrated by the MeVARC 2017 programme. However, the need to understand charged surfaces at the atomic level has long existed, most notably since Bahadur and Müller first "saw atoms" in 1956, using their new field ion microscope technique [1], and needed to explain how it worked. This didn't happen for another 20 years, until after the development of classical array models that replaced each atom by a superimposed point charge and dipole (e.g., [2]). These models were unexpectedly successful, especially for locating a field ion emitter's "electrical surface". Only relatively recently have they been made increasingly obsolescent by good DFT techniques. This talk will remind colleagues of these models, and then make connections between the physics and predictions of these models and those of quantum-mechanical techniques, including DFT. The talk will then apply old and new theory to discuss "Where is the field electron emission tunneling barrier, relative to surface atoms?" This may be relevant to a future re-examination of "What really is the nature of the tunnelling barrier experienced by a field emitted electron?", and "Can we resolve this question by experiment, rather than using "longstanding widespread theoretical belief?"
[1] E.W. Müller & K. Bahadur, Phys. Rev. 102, 624 (1956).
[2] R.G. Forbes, J. Phys .D: Appl. Phys. 18 (1985) 973-1018

Type of contribution:

Oral

session:

Field Emission

Modeling and simulations / **34**

Influence of nanoscale surface modifications to the estimated field enhancement and emission currents

Authors: Vahur Zadin[1]; Kristjan Eimre[2]; Artur Tamm[1]; Kristian Kuppart[None]; Simon Vigonski[1]; Andreas Kyritsakis[3]; Alvo Aabloo[1]; Flyura Djurabekova[4]

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High field enhancement factor, in range 50-100 is commonly measured quantity in CLIC accelerator design. Such field enhancement values are usually associated with high aspect ratio surface irregularities appearing under applied electric fields. However, if dynamic surface change is present during ramping of the electric field or due to the lower than estimated work function value, change in field enhancement can be expected. In current study, we explore the influence of pre-existing low aspect ratio protrusions to the work function using DFT calculations with and without the applied electric field. As a result, we indeed observe the change of work function due to the surface defects.

Also, the influence of the electric field is registered. Furthermore, possible mechanisms of formation of such surface inhomogeneities under the electric field are investigated by MD calculations of polycrystalline Cu. In these calculations we apply uniform electric field over the nanocrystallyne Cu (simulating the material near or at a breakdown site). As a result, grain boundaries act as the weakest part of the material and demonstrate the ability to induce the growth of small scale protrusions. Combination of such effects with the dynamic surface changes may be responsible of observed high field enhancement effects.

Type of contribution:

Oral

session:

Modelling and Simulations

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Modeling RF Breakdown

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Around 1900, it was shown that voltage breakdown could occur at a predetermined surface field, rather than through an electron avalanche. The first simple explanation of this data was given about three years later. In spite of this early progress, the field of vacuum breakdown is still not settled science. We describe our self-consistent model of rf breakdown that seems to provide useful answers to a wide variety of questions. We compare our model with mechanisms proposed by others to explain breakdown and the surface damage it produces, and describe experiments to further improve our understanding.

Type of contribution:

Oral

session:

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Application of the Voltage Holding Predictive Model

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The design of complex electrode systems insulated in vacuum to withstand voltage above 105 kV is quite a complex issue. Electric field reduction by means of the optimization of the electrode profile is not sufficient to guarantee a reliable insulation. Other effects, like the electrode area extension (Area Effect) and the Total Voltage Effect (TVE) influences the insulation strength of the system. The electrode material as well as its quality (surface finishing, presence of impurities, adsorbed gas mainly) further add uncertainty in the determination of the ultimate voltage holding.
In 2010, during the design phase of the 1 MeV –16 MW Neutral Beam Accelerator prototype for ITER, we have developed an innovative tool aimed at determining the breakdown probability distribution for any electrode multi-electrode multi-voltage system.
Starting from the clump-based breakdown mechanism proposed by Cranberg-Slivkov, we have guessed that the variable W=E_Kˆα·Uˆβ·E_Aˆγ is the real driver of any breakdown event. This variable is associated to the trajectory of a charged particle leaking the cathode (dependence on Ek) accelerates acquiring energy (dependence on U) until it clashes to the anode, where some kind of effect are produced (dependence on EA); the breakdown occurs only if W>Ws, this last parameter depending only by the material and status of the electrodes.
The experimental observations show that, once the conditioning effect has been completed, the breakdown voltages sequence follows the well known Weibull distribution. This distribution is fitted by the probability curve P=1-eˆ∫⊠ 〖-((W-W_s)/W_0)〗 ˆm , where the integral is associated to all the cathodic (emitting) surfaces. Clearly, the model asks for the knowledge of the electric field at the anode: for this reason it is necessary to calculate the trajectory from any point of the cathodic surfaces, in order to know the electric field at the anode.
The integral takes into account the Area Effect; the parameters W0 Ws and m identify the Weibull distribution curve.
So far, the model has been applied and compared with experiments, to the beam accelerator at the Megavolt Test Facility in Naka (J) and to some electrode configuration at the HVPTF, the High Voltage Padova Test Facility in Padua (I). Recently, the model has been applied also to the determination of the breakdown probability curve of Vacuum Interrupter, manufactured by Siemens; in this last case, the voltage was not dc, but it was instead a pulsed one. Investigation have been also started to analyse the effect of the exponents used in the definition of the breakdown variable W

Type of contribution:

Oral

session:

Modelling and Simulations