Investigation of Secondary Electron Emission from Nb Surfaces with Different Surface Treatments

Proposal for LCRD/UCLC 2005

Classification (subsystem)

RF cavity for the main linac

Personnel and Institutions requesting funding

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Collaborators

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Introduction

Electron field emission and multipacting inhibit goals in achieving a high gradient in Nb superconducting rf (SRF) cavities. Understanding and characterization of the secondary electron emission (SEE) from Nb surfaces in the superconducting state and with various surface treatments are important for the design of SRF cavities.

Adsorbants, whether physisorbed or chemisorbed, change the surface characteristics of the niobium relative to the bulk. This affects the electronic properties of the material. These electronic properties, namely the true secondary electron, inelastically backscattered primary electron, and the elastically reflected primary electron properties, are surface material dependent and, consequently, are dependent of the cleaning protocols employed. [1-5]

The niobium cavities support significantly large electromagnetic fields that not only accelerate the beam but may undesirably promote field emission leading to electron acceleration and electron impacting with the niobium wall. This impact can lead to the generation of one or more secondary electrons (based on the electronic properties of the niobium walls) that, in turn, act as primary electrons, which may result in the generation of more electrons in a localized region. Once resonance is achieved with the fields supported by the cavity, the number of impacting electrons grows, yielding an avalanche growth of impacting electrons denoted as multipacting. [1] Consequently, RF power is absorbed and/or dissipated in this multipacting beam, preventing the power in the supported cavity fields to increase as the power supplied to the cavity is increased. The electron collisions with the walls of the structure lead to a localized increase in temperature. When the localized temperature increases beyond a critical value, the superconductivity property of the localized region is compromised. Therefore, the Q_0 (quality factor) of the cavity is significantly reduced at the multipacting thresholds.

It becomes important to simulate the electronic properties or its effects in design codes to optimize the full potential of the material with surface structure and surface contaminants when designing cavity configurations.

Motivation

The Electromagnetics and Pulse Power groups at UNLV continue to develop and refine a novel technique to measure secondary electron emission from niobium under cryogenic temperatures in an ultra high vacuum (UHV). Ultra high vacuum pressures ($\sim 1.2\text{x}10^{-9}$ Torr without baking) attained by the vacuum system fits well within the parameter regime of interest. Conventional secondary electron emission techniques provide lumped secondary electron yields relative to incident primary electron energies.

The novel technique under development in the Electromagnetics Laboratory at UNLV should provide intimate knowledge of the initial conditions of the emitted secondary electrons. The current secondary electron emission system, Fig. 1, contains a particle position detector, a 50 eV to 5 keV pulsed electron gun, and a target on a rotatable cryostat. The resolution of the system is well characterized with particle tracking codes and controlled with a detector grid. [6] With the aid of a look-up table developed for the specific experimental setup, one can determine a family of initial conditions (momentum and energy) for secondary electrons emitted at the point of primary electron impact and terminating at the point of detector interception.

Varying the detector grid voltage offers one means to narrow the selection of all possible secondary electrons that may impact the detector at the same location. Because the SEE system contains no moveable parts, field perturbations from the measuring instrument are eliminated. Consequently, low energy secondary electrons may be characterized.

Preliminary experimental studies should commence in February of 2005. Experimental results are to be compared against an existing Monte Carlo code developed by Dr. Joy (ORNL and Univ. of Tenn.) [7] for scanning electron microscopy applications with ongoing enhancements incorporated by UNLV to handle surface impurity layers more rigorously. Single primary electron studies in the code complement the low current primary electron beam requirement in the experiment. The code’s greatest asset, speed, stems from approximate calculations based on probabilistic techniques in lieu of time consuming exact calculations and hard to acquire parameter specifications.

Over 100’s of thousands of trajectories may be followed in about one-minute duration. Based on Dr. Joy’s experiences, [7] the code should be reasonably valid for electrons with energies from as low as 50 eV to those well over many ten’s of keV. The code’s accuracy, based on the programmed physical model, yields reasonable results for primary electron energies above 1 keV. The time and space resolution of the particle

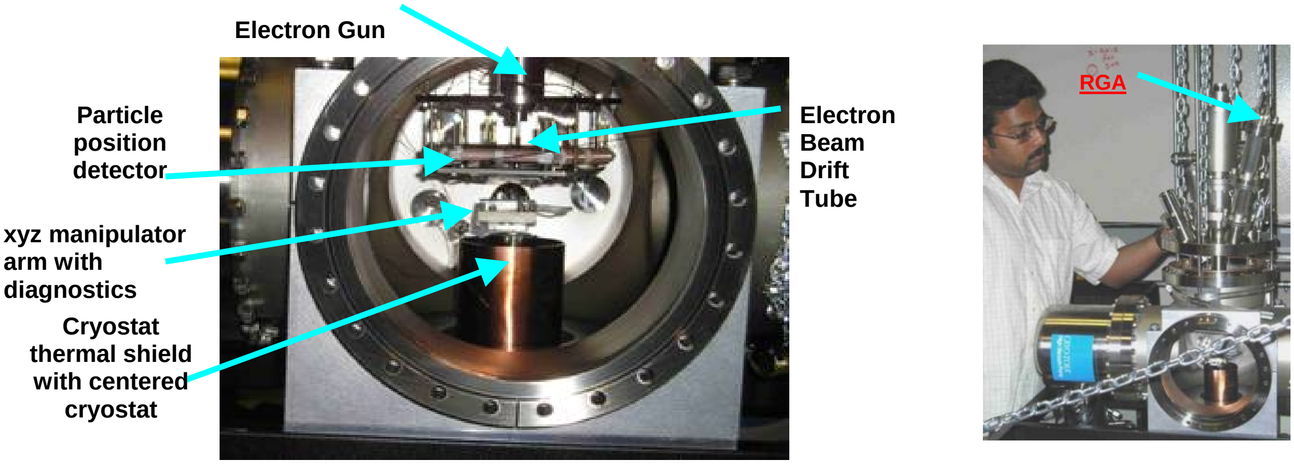


Figure 1. The SEE detection system showing the cryostat, xyz manipulator, electron gun, particle position detector, beam tube, residual gas analyzer, and vacuum chamber.

position detector place limits on the primary beam current. Only low beam currents may be employed.

The benefit of knowing the initial dynamics of the secondary electrons, whether of the true or of the backscattered type, leads to understanding how primary electrons deposit energy into the material. In studying the surface physics for the generation of SEE, minimal interactions among incident primary electrons internal to the target is desired. Low current electron beams accomplish this task. It is anticipated that the incident primary energy, angle of incidence, target material, and target temperature will map into a statistical distribution of secondary launch positions, momentums, and energies (dynamic surface statistics).

Knowledge on where and how energy deposition results may relax or guide design requirements. For example, high-energy primary electron beams will behave differently than low energy beams when interacting with a material containing a crystalline lattice structure. Electron diffraction can be significant at the higher energies. Heating the surface of the materials perturbs the crystalline structure resulting in a broadening of the diffracted electron beam. With flat energy profiles and low primary beam currents, changes in the scattering dynamics may be observed for each SEE mechanism. It is anticipated that energy deposition of low- and high-energy primary electron beams will differ.

Current UNLV Electromagnetics Laboratory Collaboration with LANL

The SEE system under development in the Electromagnetics Laboratory at UNLV is motivated by typical parameters for SRF cavities. Table 1 stipulates approximate parameter regimes that represent present and future needs for SRF cavities and the design capabilities of the SEE system in the UNLV Electromagnetics Lab. Interests and capabilities compare well.

One of the major thrusts of this proposal is to aid in the design of a thermal barrier to minimize large thermal gradients experienced by the cryostat support mount. As observed in Fig. 1, the secondary cooling stage surrounding the cryostat cylinder allows for line of sight access between the sample and the view ports and between the sample and the detector. At present, large thermal gradients exist that prevent the sample from reaching the desired temperatures. These gradients can not be avoided due to various operations that need to be performed by the system.

Table 1. Typical SRF cavity and UNLV parameter regimes interests and capabilities.

Parameter	**Parameter Regime of Interest**	**Existing UNLV Setup**
Incident e beam currents	on the order of nanoamps and higher	30 nA (50 eV) to 2.5 μA (5 keV)
Incident e beam energies	2 eV – 1.5 keV	50 eV – 5 keV
Beam repetition rate	100 Hz	100 kHz max.
Material temperatures	Liquid helium temperature ~2° K or <9.2K	Cryostat cold head ~8.5° K Cryostat support mount ~17° K
Material types	BCP or EP Niobium	Any material can be mounted
Vacuum pressures	$<10^{-9}$ Torr	2.5×10^{-9} Torr
Pulse duration	1 ms - CW	0.5 μs to 10 μs

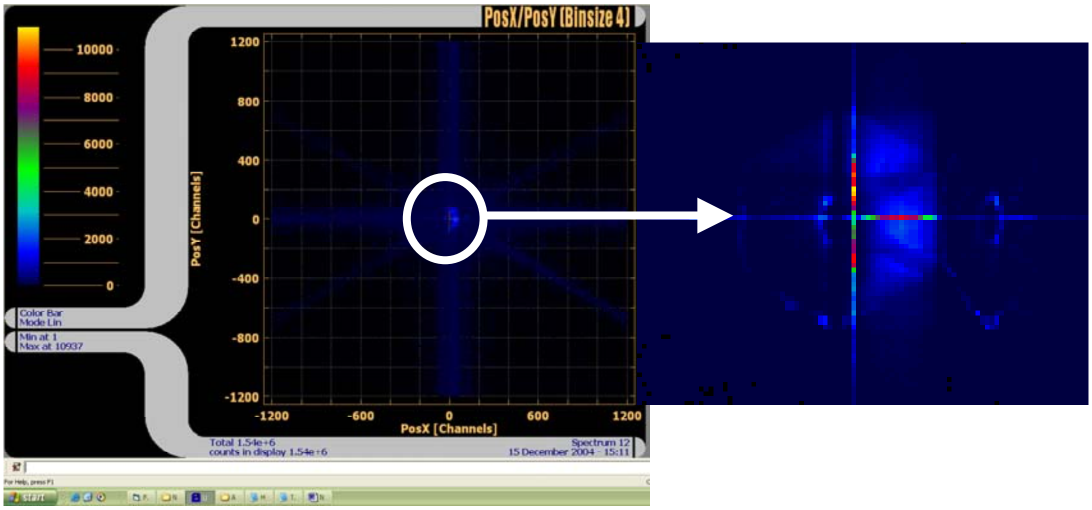
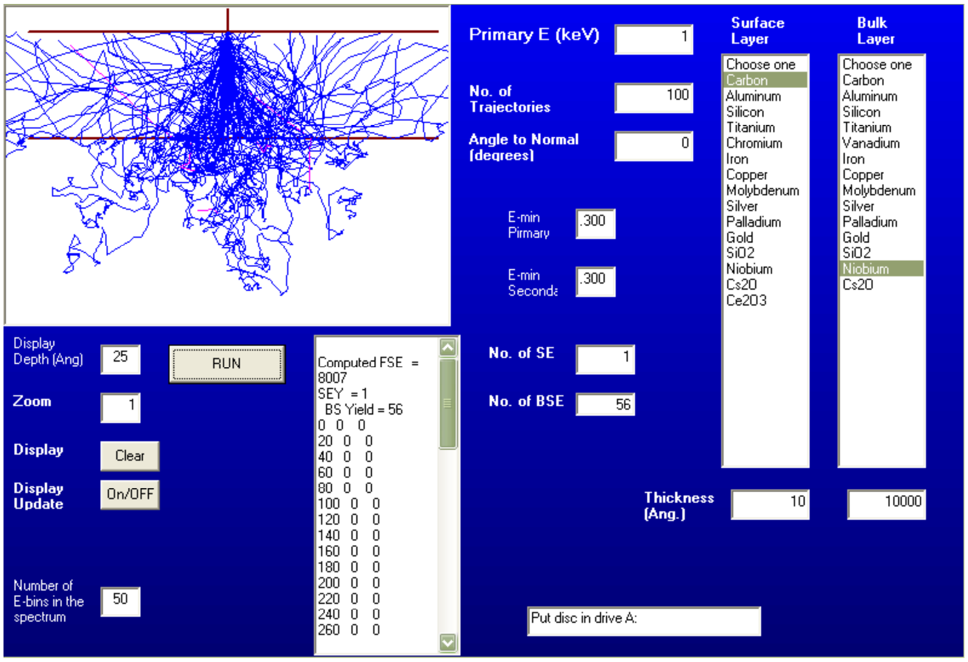


Figure 2 A first result obtained from the particle position detector. Undesired ghost images and loss of signal on the left half side of the detector is currently being corrected. The color intensity of the regions over the hexane shaped detector indicates the number of electrons detected at that position over time.

Figure 2 displays a first result from the particle position detector. The enlarged signal to the right indicates that some fine-tuning in the software and hardware is required. Even so, the detector responds to the secondary electrons emitted from a niobium sample at room temperature as initiated by a primary electron beam.

For a typical cavity design, particle trajectory studies over a large parameter space of initial conditions for secondary electrons launched from the niobium surface has been performed and stored in a large data base look-up table. Conventional particle tracking codes have been employed. To aid in verifying and limiting the family of particles with the same final conditions, a secondary electron emission Monte Carlo code has been secured and is being continuously enhanced.

The second major thrust of this proposal is to enhance the current code to allow for multiple layers of material to exist on a bulk medium in a more rigorous manner. Currently the code follows both the primary and all of the generated secondary electrons making use of cross-sections and mean free paths characterizing stopping powers and most probable types of collision (elastic or inelastic) for bulk mediums.



Primary E (keV) 1
No. of Trajectories 100
Angle to Normal (degrees) 0
E-min Pirmary .300
E-min Seconda .300
No. of SE 1
No. of BSE 56
Surface Layer: Carbon
Bulk Layer: Niobium
Thickness (Ang.) 10 10000
Display Depth (Ang) 25
Zoom 1
Number of E-bins in the spectrum 50

```
Computed FSE  =
8007
SEY  = 1
  BS Yield = 56
0   0    0
20   0    0
40   0    0
60   0    0
80   0    0
100   0    0
120   0    0
140   0    0
160   0    0
180   0    0
200   0    0
220   0    0
240   0    0
260   0    0
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Put disc in drive A:

Figure 3. Typical graphical user interface output of Joy's code providing secondary electron emission and back scattering emission yields.

Project Overview

The proposed work would allow the current research effort to further complement superconducting cavity design environment. At first blush, a few degrees Kelvin may not seem to be significant. In effect, the significance lies in the change in state of the material from its normal state to its superconducting state. It is believed that secondary electron emission from a superconducting material may be different than from a cold material in a normal state. Further, what is adsorbed on the superconducting surface through natural pumping of a cold surface may influence the superconducting properties of the material. Therefore, the addition of a thermal shield may allow for new physics. To delineate this physics, enhancing the secondary electron emission Monte Carlo code is required.

Broader Impact

Particle accelerators have been used for various science including those using X-rays, free electron lasers, neutrons. The accelerators that use superconducting RF cavities made of niobium have increased significantly in the past few decades due to its higher efficiency and for other reasons.

Successful characterization of the secondary electron emission from the actual Nb surfaces after various conditions will allow cavity designers for better prediction of field emission and multipacting phenomena in the cavity. This in turn will lead to a more reliable cavity and accelerator design.

The students to be involved will learn the RF fields distribution in the cavity and various surface science that can be useful for other areas such as nuclear fusion.

Project Activities and Deliverables

A single year of funding is being requested. The following activities will result during the funding cycle:

1) Design and have built a suitable thermal shield or cooling mechanism to bring the niobium test sample to cryogenic temperatures.
2) Have a load lock chamber incorporated to the existing vacuum system to prevent changes in the vacuum environment when performing tests on a number of samples.
3) Modify the existing SEE Monte Carlo code to allow for a more rigorous study of multi-layer, multi-component surface contaminant. In this case, a weighted probability based on “a throw of the dice” will be the deciding factor if a electron collides with a particular type of molecule. Boundary interfaces require careful considerations in the collision process. [NOTE: Superconducting effects of materials will NOT be incorporated in the code during this funding cycle.]

Measurements from at least two samples prepared by Buffered Chemical Polishing (BCP) or Electro Polishing (EP) will be provided by way of a report. Based on findings uncovered, it is anticipated that measurements of the sample in both its superconducting state and its normal state (cold temperatures) will be compared and submitted for publication.

References:

1. Hasan Padamsee, Jens Knobloch, and Tom Hays, **RF Superconductivity for Accelerators**, Wiley Interscience Publication, John Wiley, N.Y. 1998.
2. I. Bojko and N. Hilleret, *Influence of Air Exposures and Thermal Treatments on the Secondary Electron Yield of Copper,”* **J. Vac. Sci. Technol. A 18** (3), 2000*.*
3. M. Grundner and J. Hilbritter, *“On Surface Coatings and Secondary Yield of NbSn and Nb,”* **J. Appl. Phys. 51** (10), 1980.
4. R. Noer *et. al*, *“Secondary Electron Yield of Nb RF Cavity Surfaces,”* Int. Conf. on High Energy Accelerators, KEK, Japan, 2001.

5. H. Padamsee and A. Joshi, *“Secondary Electron Emission Measurements on Materials used for Superconducting Microwave Cavities,”* **J. Applied Phys. 50** (2), 1979.
6. Anoop George and Robert A. Schill, Jr., *Preparation Studies for Secondary Electron Emission Experiments on Superconducting Niobium*, 2004 American Nuclear Society Student Conference, at University of Wisconsin Madison, Madison, Wisconsin, April 1-4, 2004.
7. D.C. Joy, **Monte Carlo Modeling for Electron Microscopy and Microanalysis,** Oxford University Press, New York, 1995. (ISNB 0-19-508874-3)

Budget

The activities outlined above will involve UNLV and a LANL staff member for the fiscal year of 2005.

Table 2: Budgetary estimate for the UNLV - LANL collaboration

Item	FY 2005	FY 2006	FY 2007
Faculty	$ -		
Other professionals	$ -		
Graduate Student	$ 9,000		
Total Salaries (incl. fringe benefits)	$ 10,600		
Equipment	$ 28,000		
Travel	$ 1,500		
Materials and Supplies	$ 6,000		
UNLV Consultants (Vacuum Specialist and a Material Scientist)	$ 8,000		
LANL Consultants (Dr. Tsuyoshi Tajima)	$ 10,000		
Total direct costs	$ 64,100		
Total indirect costs (47.5% of direct cost minus equip. [> $2000])	$ 17,148		
Total direct and indirect costs	**$ 81,248**		

Budget Justification

Faculty	Schill (Faculty)– ($9471/mo) – 0 mo. Electromagnetics, plasma, pulse power, and charged particle background. SEE and SED mechanics have close analogies to plasmas science mechanics.
Other Professionals	1 Engineering Research Associate (Professional) 1) Craig Nielsen - $4585/mo. for 0 mo. – Pulsed power, machine shop, and electronics expert – tasked to train students to operate machine, provide continuity in experiment, and perform necessary machining and assembling of SEE machine
Graduate Students	1 Graduate Students One $1,500/mo. for 6 mo.
Fringe Benefits & Salary	**UNLV Fringe Benefits Breakdown** Research Professionals - 14% of salary plus $6800/yr. prorated medical ins. Graduate Students – 10% of salary plus $1231/yr. prorated medical ins.
Materials, Supplies, Software and Training	***Total ($6,000)*** Vacuum equipment **($3,500)** -- conflat flanges, consumables), gloves, cleaning supplies, repairs Machining **($1,000)** – sample mounts, tools, gun mounts. Gas **($500) –**gasses for venting Materials **($1,000)** – target materials,
Permanent Equipment	***Total ($28,000)*** Load lock chamber with essentials **($23,000)** Manipulator arm with thermal cover **($5,000)**
Travel	One trip to LANL.
Consultant Services	***Total ($18,000)*** Stan Goldfarb -- $4,000 [Vacuum Science Expert. He works with students will coordinating research efforts associated with vacuum studies and sensors. He also alters and designs new vacuum geometries for modifications in the experiment.] Dr. Richard Kant -- $4,000 [Physicist. Extensive background in material science. He is enhancing an existing SEE Monte Carlo code which is a key software component needed to interpret experimental results.] Dr. Tsuyoshi Tajima – $10,000 [Consulting Engineer at LANL involved in collaborative efforts and overseeing progress of the materials research relevant to the rf superconducting cavities]
Indirect Costs	The UNLV indirect cost rate is 47.5% of all direct costs excluding equipment over $2000

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EDUCATION

Ph.D. (E.E.) *University of Wisconsin - Madison (Aug. 1986)*
Thesis: Free Electron Sources of High Frequency Radiation
Major Area: Plasma and Controlled Fusion
Secondary Area: Electrodynamics
(Thesis Advisor: Dr. S.R. Seshadri)
M.S.E.E. *University of Wisconsin - Madison (May 1981)*
B.S.E.E. *Milwaukee School of Engineering (May 1979)*

POSITIONS HELD

Sept. 1986 - Aug. 1993	*Assistant Prof., University of Illinois at Chicago (UIC)*
Aug. 1993 – June 1997	*Assistant Prof., University of Nevada-Las Vegas (UNLV)*
July 1997 – Present	*Associate Prof., University of Nevada-Las Vegas (UNLV)*

SOME RECENT AND RELEVANT PUBLICATIONS (*REFEREED JOURNALS*)

1. V.A. Subramanian and R.A. Schill, Jr., "Measuring the Characterisctics of a Lossy Transmission Line System Using Only the Vector Network Analyzer Measured S_{11} Parameter," **IEE Proc. on Science, Measurement & Technology,** December 3, 2004.
2. R.A. Schill, Jr., *A Closer Look at the General Relation for the Vector Magnetic Field Generated by a Circular Current Loop,* **IEEE Trans. on Magnetics, 39** 2 (2003), pp. 961-967.
3. R.A. Schill, Jr., *A Simplistic Plasma Dust Removal Model Employing Radiation Pressure*, **Laser and Particle Beams 20**, 2 (2002) pp. 341-357.
4. R.A. Schill, Jr. and K. Hoff, *Characterizing and Calibrating a Large Helmholtz Coil at Low AC Magnetic Field Levels With Peak Magnitudes Below the Earth's Magnetic Field*, **Review of Scientific Instruments 72**, 6 (2001) pp. 2769-2776.

Some Relevant Conferences

1. Anoop George and Robert A. Schill, Jr., *Preparation Studies for Secondary Electron Emission Experiments on Superconducting Niobium*, **2004 American Nuclear Society Student Conference,** at University of Wisconsin Madison, Madison, Wisconsin, April 1-4, 2004. **[!!Awarded Outstanding Student Paper Award!!]**
2. M. Holl, M. Trabia, and R. A. Schill, Jr., *Optimization of a Five-Cell Niobium Cavity,* **Sixth International Topical Meeting on the Nuclear Applications of Accelerator Technology, (Accelerator Applications 2003: Accelerator Applications in a Nuclear Renaissance),** San Diego, California, June 1-5, 2003, pp. 202-206.
3. Q. Xue, S. Subramanian, M. Trabia, Y. T. Chen, and R. A. Schill, Jr., *Modeling and Optimization of the Chemical Etching Process in Niobium Cavities,* **International Congress on Advanced Nuclear Power Plants,** Hollywood, Florida, June 9-13, 2002.