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Investigating Secondary Electron Yield of Materials of Interest for High Power Vacuum Electron Devices and High Voltage Vacuum Insulators

I. Kern[1], Talal Ahmed Malik[1], Bilal Ahmed Malik[1], M. Gilmore[1], J. M. Lehr[1], A. S. Steiner[2]

1) The University of New Mexico, Albuquerque, NM 2) Sandia National Laboratories, Albuquerque, NM

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ELECTRICAL & COMPUTER ENGINEERING

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Abstract

- Secondary electron emission (SEE) from conductors is thought to play an important role in the initiation of multipactor breakdown in vacuum electron devices. SEE from insulators is believed to play a key role in flashover on insulating surfaces in vacuum. Additionally, the SEE of an insulator may depend on its electrical stress history. In both cases, SEE strongly depends on any conditioning of the material surface. We present measurements on both conducting and insulating materials of interest in these applications. Measurements are being made in an existing test stand, recently modified to enable measurements on insulators as well as conductors. The system utilizes a hemispherical current collector placed above the sample to collect secondary electrons. Primary electrons are supplied by a < 3 uA, 0 – 1000 eV electron gun. A second gun with energies up to 50 keV is also available. The experimental setup will be described, and recent measurements of SEE of materials under investigation for reduced SEE and improved flashover resistance will be presented.

Motivation

- Measure the Secondary Electron Yield of dielectric and conductive materials.
  - Measure the SEY of dielectric materials of interest as pulse power insulators.
  - Characterize the SEE of dielectric materials before and after subjection to electrical stress

Secondary Electron Emission

- Secondary Electron Emission (SEE) is the release of secondary electrons in a material.
  - Incident electrons collide with a material's electron lattice, thereby imparting energy into surrounding electrons. If the energy is sufficient, releases a secondary electron.

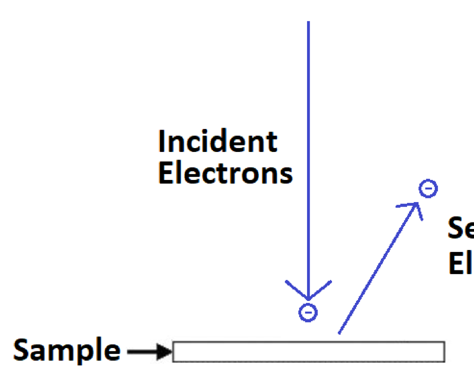

FIG 1.2a: Secondary electron being released

  - Secondary electrons can cause the release of other secondary electrons via secondary electron cascade.

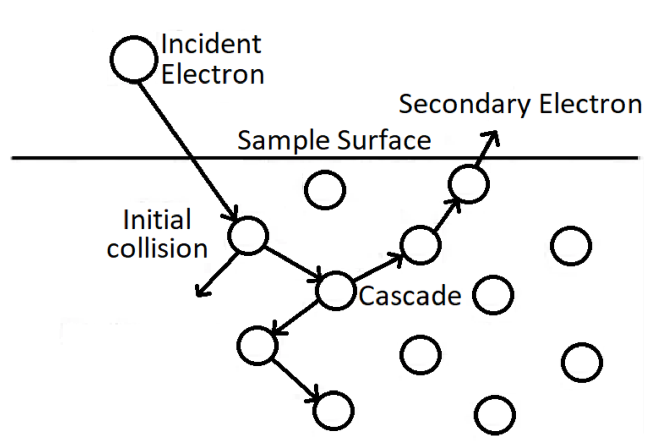

FIG 1.2c: Secondary electron cascade

- Secondary Electron Yield (SEY) is the ratio of total secondary electrons and incident electrons.

$$SEY = \frac{I_{primary} - I_{secondary}}{I_{primary}}$$

FIG 1.2c: SEY measured through the sample without HCC

$$SEY = \frac{I_{secondary}}{I_{primary}}$$

FIG 1.2d: SEY of sample measured through HCC

Electrostatic Modeling

- In order to aid in the understanding of the electron beam behavior, SIMION was utilized to simulate the effects for different collector/electrode geometries and biases in the vacuum chamber.
- The initial model that was operated with the following parameters:
  - Electron kinetic energy: 1-1000eV
  - Electrode biases: +/- 1-100V

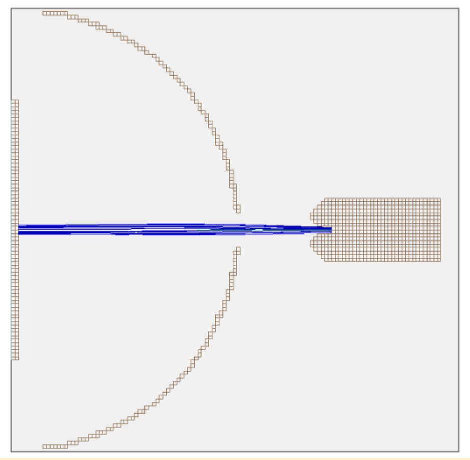

FIG 2.1a: SIMION electron beam simulation, sample Bias = +93VDC, Beam Energy = 30eV

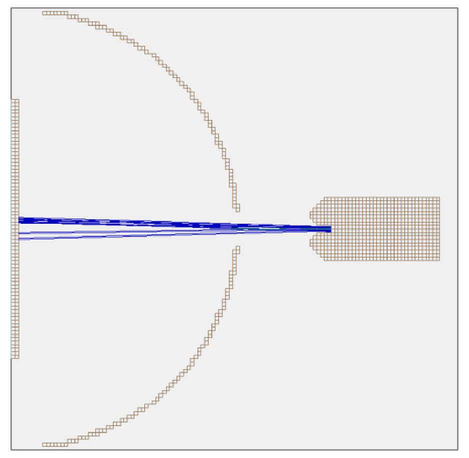

FIG 2.1b: SIMION electron beam simulation, sample bias = +93VDC, Beam Energy = 1000eV

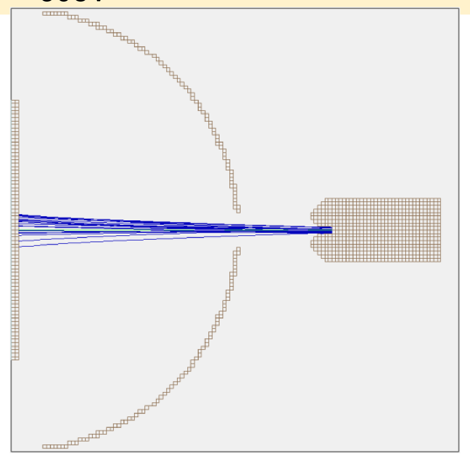

FIG 2.1c: SIMION electron beam simulation: sample bias = -20VDC , beam energy = 30eV.

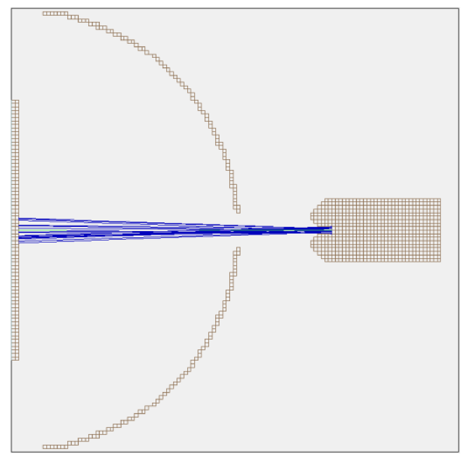

FIG 2.1d: SIMION electron beam simulation, sample bias = -20VDC, beam energy = 1020eV.

Experimental Results

- Previous SEY experimental meaurements via current thru the sample were used for comparisons with pulsed and HCC measurements.
- In the HCC case, the equation in Fig. 1.2d was used to determine SEY.
- A preliminary comparison of SEY measured 1. via sample and 2. via the HCC is shown in Fig 4.1a.
  - Thru sample and HCC SEY curves clearly differ in magnitude, shape, crossover energy, and peak energy.
  - In the HCC case, there appears to be no crossover voltage and SEY begins above 1.
- Possible reasons for this discrepancy include:
  - Electrons on the outer diameter of the electron beam are being attracted to the HCC.
  - The HCC aperture is too small and perturbing the beam.
  - The electron beam is inducing a current within the copper HCC.
- The SEY of copper measured using a pulsed incident beam versus a steady-state beam are shown in Fig 4.1b.
- It was found that the Keithley Electrometer 6514 is not capable of measuring 200µs pulses.
- The electrometer was replaced with an oscilloscope and transimpedance amplifier to allow for voltage measurements.
- SEY pulsed and steady state beam measutrements show good agreement in shape, crossover energy, and peak energy.
- Changes in SEY magnitude are strongly influenced by surface conditions. The discrepancy in SEY magnitudes is not unexpected.

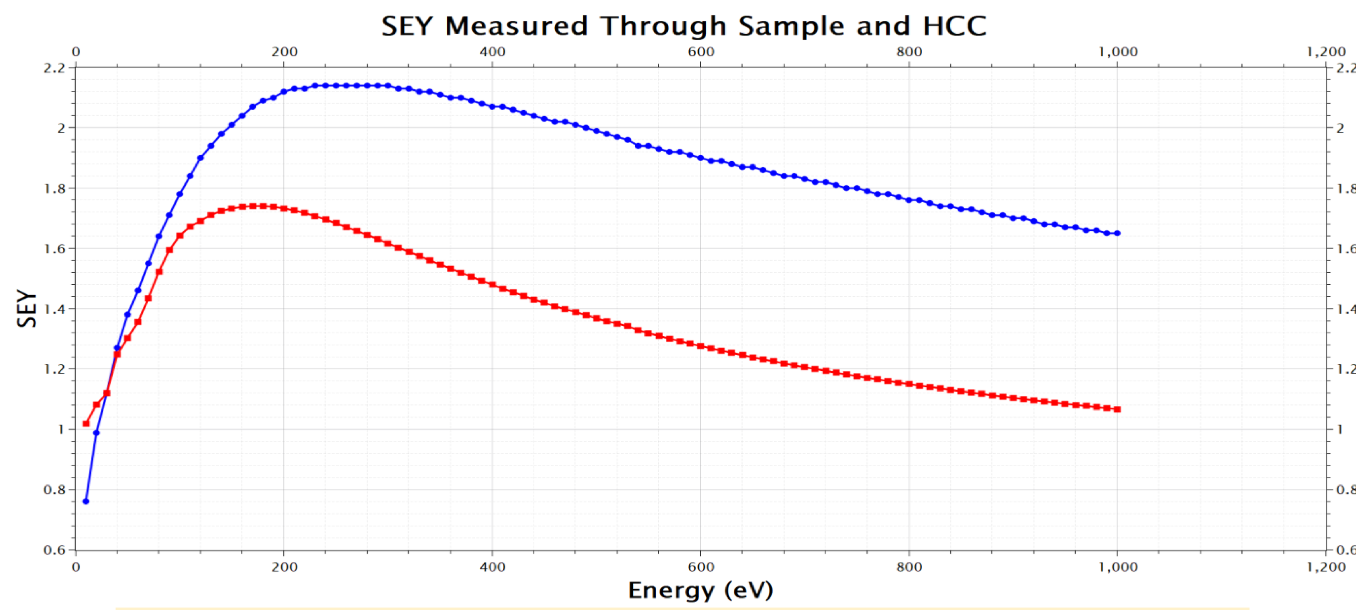

FIG 4.1a: SEY of Copper Sample without the HCC (Blue) and with the HCC (Red).

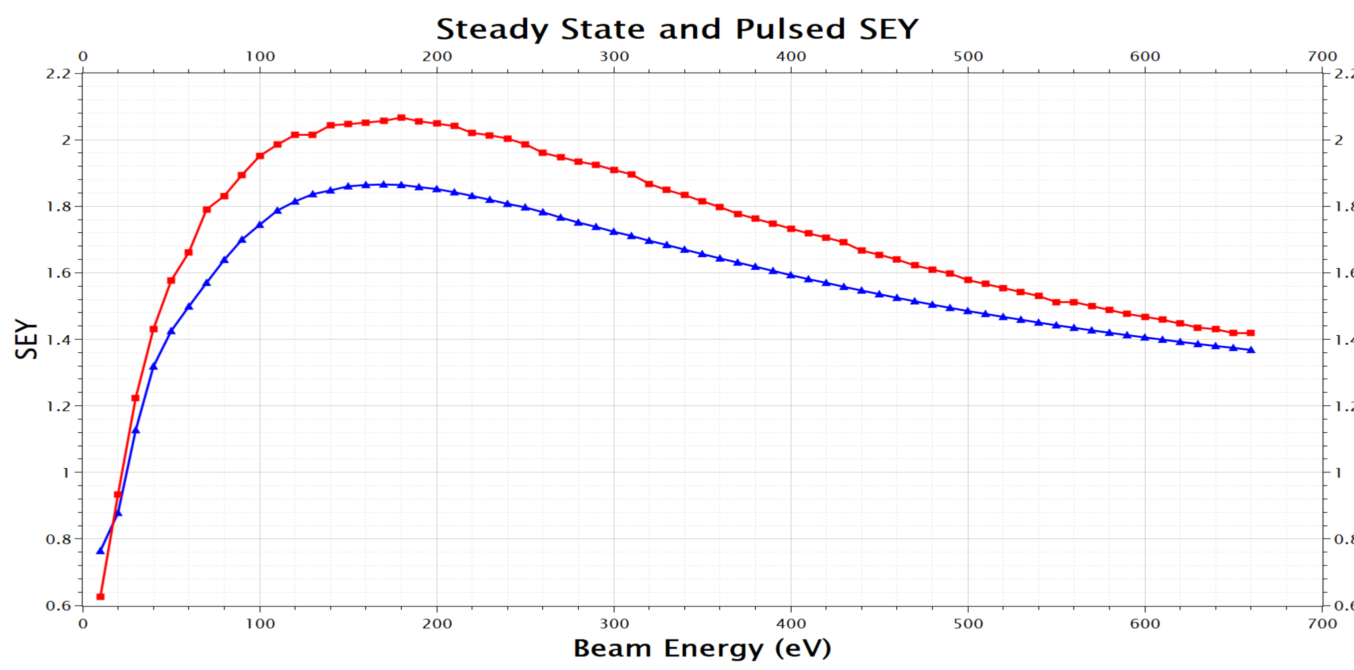

FIG 4.1b: Pulsed Measurement of SEY via HCC (Red) versus Steady-State Measurement of SEY via HCC (Blue)

Experimental Setup

- A Kimball ELG-2 electron gun with the capacitive junction box is used as the primary electron source.
  - Provides a beam dot size of < 2.5 mm.
- The system utilizes a Hemispherical Current Collector (HCC) mounted above the sample to measure current induced by secondary electrons.
  - The HCC has a 1cm diameter aperture to allow through the electron beam.
  - Samples are controlled via a linear/angular manipulator.
- Vacuum maintained below 10^{-7} torr.
- Pulsed measurements are made using an altered capacitive junction box with parameters:
  - 20ns to 200µs pulse width and 10ns rise/fall time.
- A Keithley 6514 Electrometer is used to measure the current across the sample for SteadyState modes.
  - -20VDC applied across sample to measure secondary current.
  - +93VDC applied across sample to measure primary.
- Pulsing method is conducted by DC biasing the HCC and measuring voltage across conductive sample.
  - -20VDC applied across HCC to measure primary current.
  - +45VDC applied across HCC to measure secondary current
  - Transimpedance amplifier connected to sample converts input current to proportional output voltage with a gain of 100k (V/A).
  - Voltage is measured across sample using an oscilloscope.

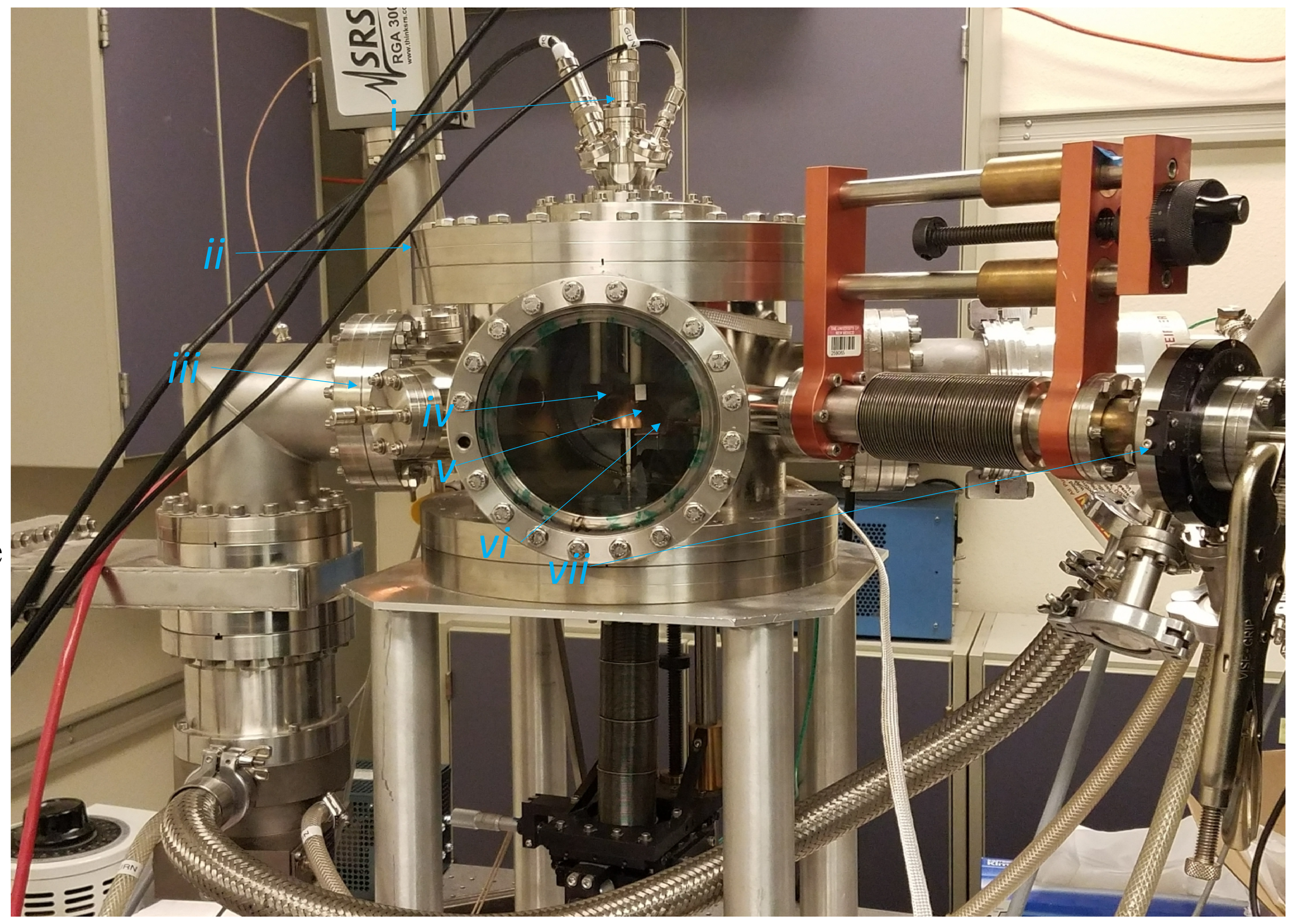

FIG 3.1a: *i*: Electron Gun, *ii*: Vacuum Chamber, *iii*: HCC Measurement Feedthrough, *iv*: HCC, *v*: Sample, *vi*: Sample Holder, *vii*: Angular Manipulator

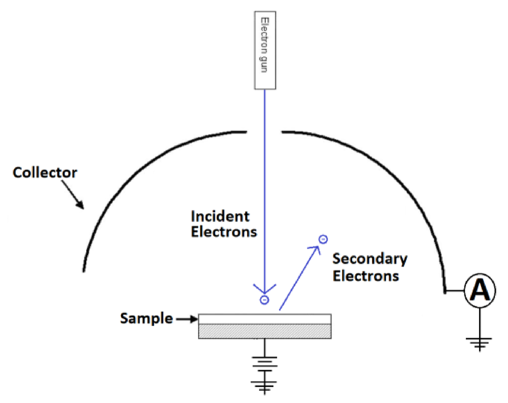

FIG 3.2a: HCC 2-D diagram

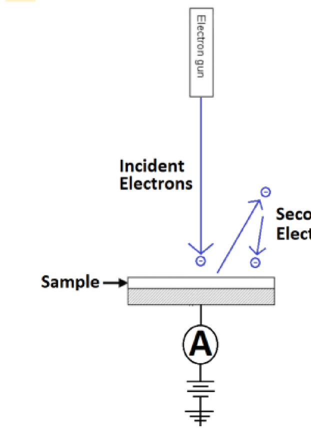

FIG 3.2b: Measuring primary current without HCC

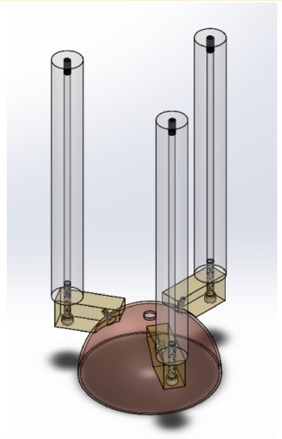

FIG 3.2c: Image of hemispherical collector

Future Work

- Pulsed measurements will be utilized to limit dielectric sample charging.
- To allow for improved pulsed measurements the following will be completed:
  - Have specific DC biases across the HCC for different beam energies.
  - Change LabVIEW code to allow for Oscilloscope to measure and record data via GPIB to the computer.
- Attempt to quantify and minimize beam perturbation by the HCC by:
  - Increasing HCC aperture size.
  - Extend electron gun through the HCC aperture.
  - Increase size of HCC.
- Bias HCC with a DC voltage instead of the sample.
- Add a conductive plate (grounded to chamber wall, with a hole smaller than the aperture of the HCC) above the HCC.
  - This will prevent the electron beam from interacting with the HCC.
  - With the plate having a smaller than the aperture of the HCC, the focus voltage will not be as consequential.
  - With a plate limiting the electron beam allowed through the aperture of the HCC, there might be an effect on the SEY curve.
- Characterize the SEY of pre and post flashover dielectric samples procured from The University of New Mexico flashover test stand.

Acknowledgments and References

1. Malik, Talal Ahmed. "SECONDARY ELECTRON YIELD MEASUREMENTS ON MATERIALS OF INTEREST TO VACUUM ELECTRON COMMUNICATION DEVICES." (2020). https://digitalrepository.unm.edu/ece_etds/489
2. "The software used in this work was developed by David Manura, Adaptas Solutions, LLC (SIMION 8.x, 2006-2020)"

3. This work is supported by AFOSR MURI Grant FA9550-18-1-0309