Discharging of Dielectric Materials as Related to Secondary Electron Emission

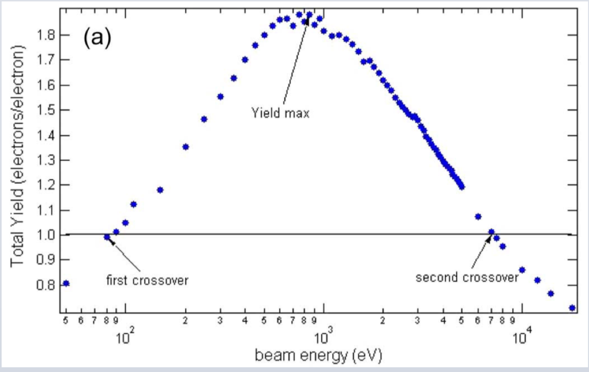
Nikola Protic (Cornell University), advised by Professor Yevgeny Raitses (Princeton Plasma Physics Laboratory)

Motivation

- **Refinement of Plasma-Wall Sheath model to account for wall charging by plasma and secondary electron emission fluxes.**
- **Gain insight into space charge distribution of the plasma-facing wall**
- **Development of a SEE model which accounts for charging effects**

Background: SEE and Charging

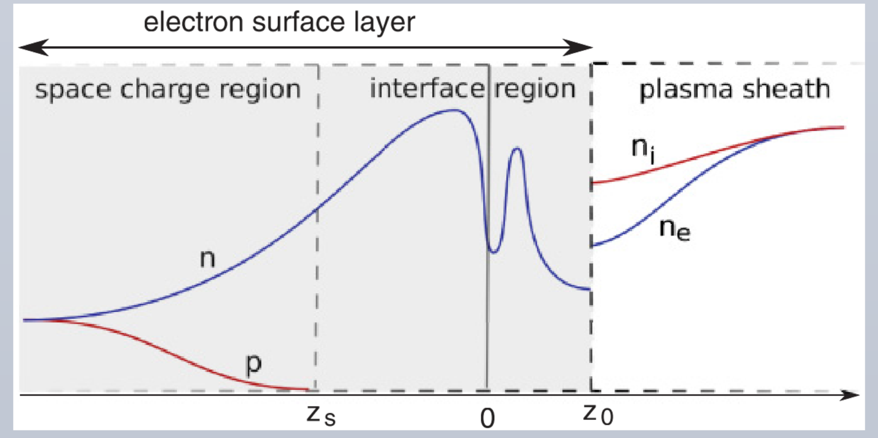
- Electron bombardment of dielectrics can result in both positive or negative charging depending on incident electron energy, due to secondary electron emission:



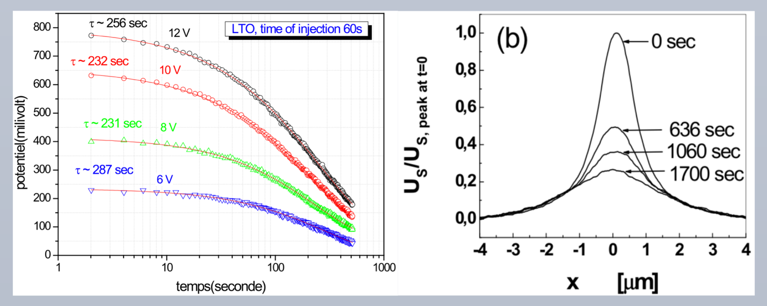
- A quantitative three step model has been proposed for SEE; however, the model fails to account for space charge on the wall surface:

$$\delta(E_0,Q) = \int_0^{R(E_0,Q)} n(x,Q;E_0)\cdot f(x,Q;E)\cdot B(E,Q)dx$$

- To study surface charging insight can be taken from refinement of the plasma-wall potential:



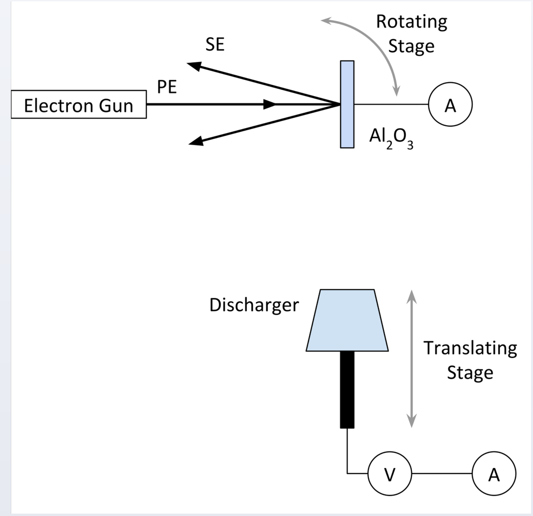
- Ab initio studies of discharging have been conducted, but conclusions have yet to be reached:



Experimental Setup

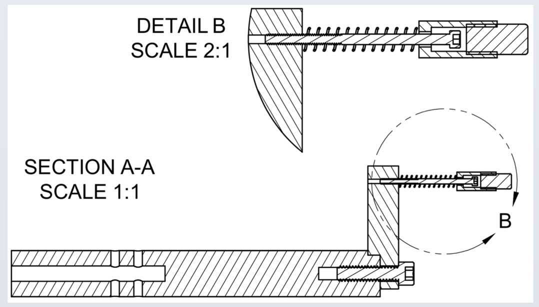
Idea: Discharging of the charged surface by a biased contact.

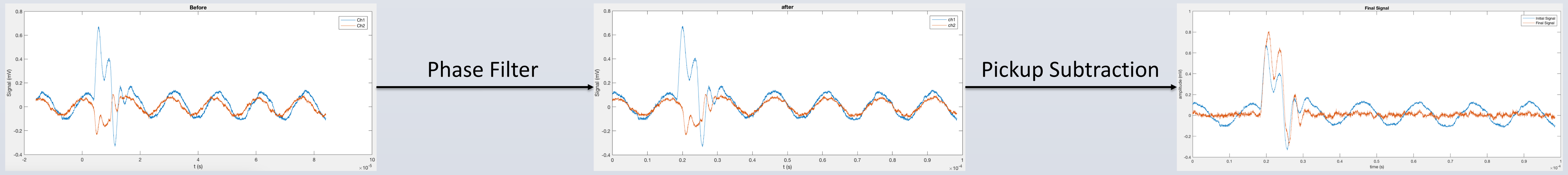
- Al_2O_3 Sample is bombarded by a Kimball Physics Inc. ELG-2 Electron Gun in 5 μs pulses.
- Sample is rotated and placed in contact with a discharger
- Discharging is monitored independently by measuring the discharger current and relative pulse response after discharging.



Noise Filtering

- Noise source causing ~50 kHz & ~7kHz beating noise over all channels
- All channels experiencing pickup from an external source (ground loop through bias source).
- A solution: Collect desired signal & pickup signal simultaneously, post process in MATLAB using Fourier techniques.
- Both Phase Filtering and Notch Filtering attempted with limited success.





Discharging Characteristics

Partial Discharge is Bias-Dependent

- Modeled charging as disk above grounded plane in order to estimate number of pulses until yield reaches unity (space charge saturation):

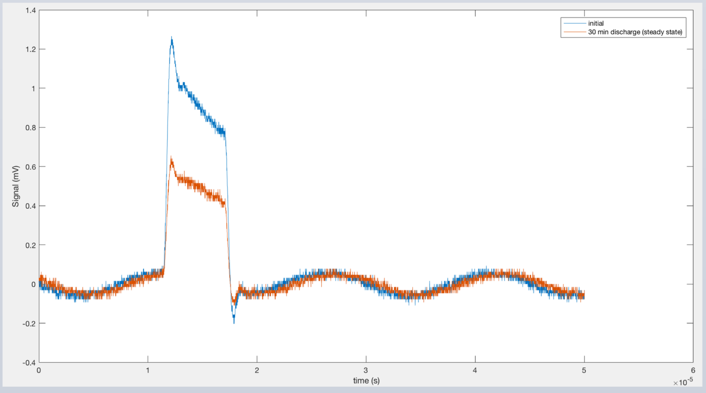
$$V \approx \frac{\sigma_{dep}(N_p)}{2\epsilon_0}\left[\sqrt{(z+d)^2+R^2} - \sqrt{(z-d)^2+R^2} - 2d\right] \approx 6V\ per\ pulse$$

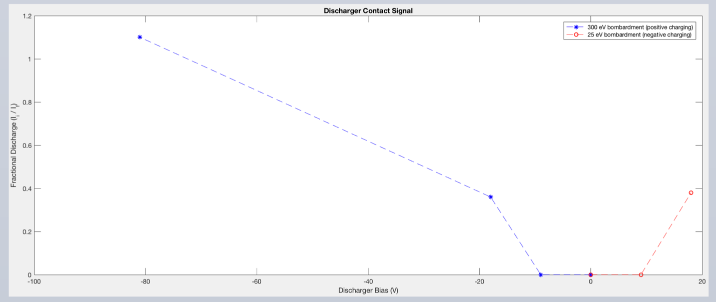
$$\rightarrow 50\ pulses\ to\ saturation$$

- Experimentally, pulse signal attenuated by 1/e in 13 pulses. Concluded that

$$I(N_p) = I_0 e^{-N_p/13}.$$

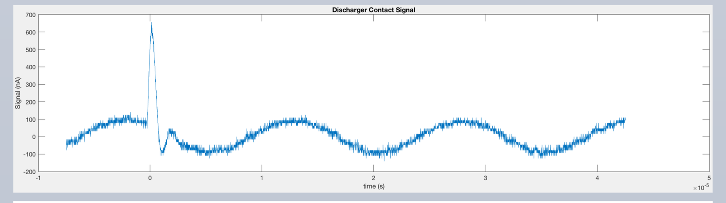
- Summing above equation, total charge deposited is about 34 pC.
- Observed incomplete discharging. Discharging reached difference non-neutral steady states depending on discharger bias.
- Indicates space charge depth distribution & work function dependence.
- From Fick's Law and Ohms Law diffusion current was roughly estimated to be on the order of femtoamperes, indicating that diffusion is not involved at room temperature.

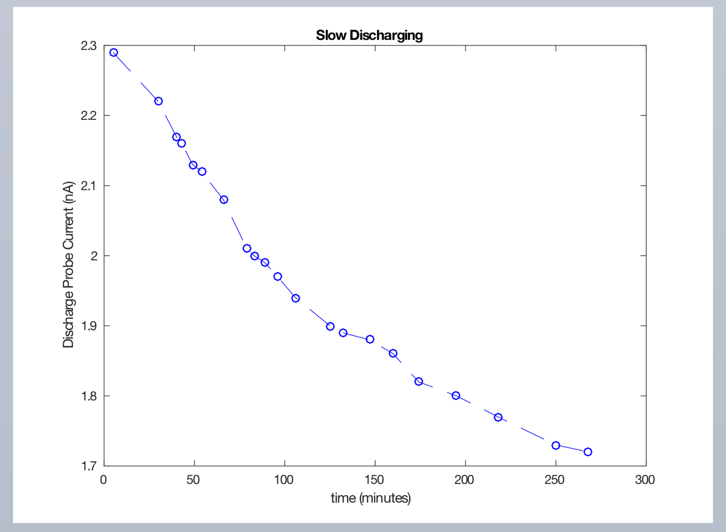




Contact Discharging is a threshold phenomenon

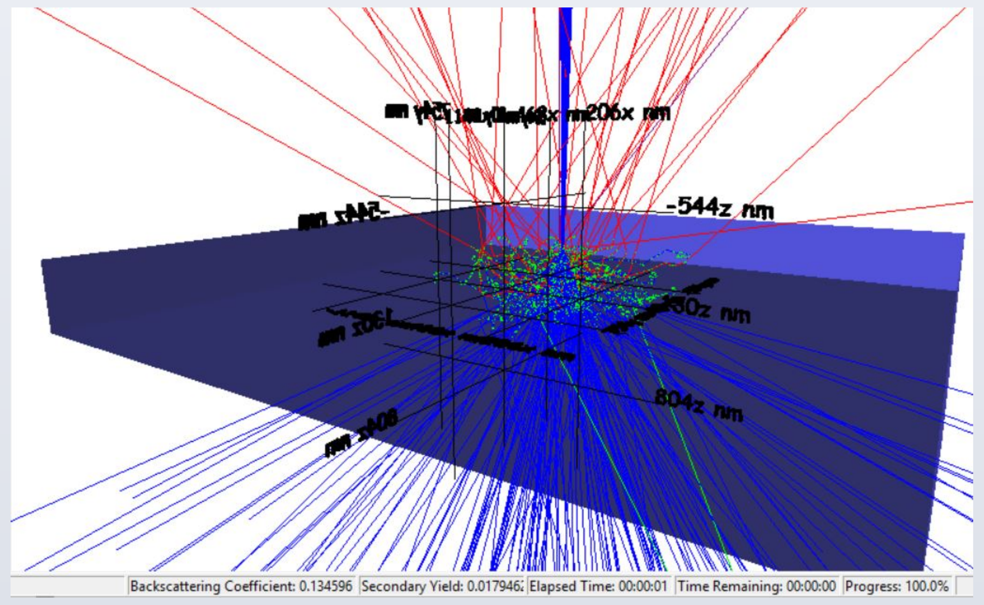
- Both fast and slow discharging of surface observed under various conditions.
- Fast Discharging observed as a threshold phenomenon: under low discharger biases no contact signal observed.
- Slow Discharging observed only for low (< |+/-18 V|) applied biases.
- Indicates a distribution of electrons by depth into the material.
- Likely that slow discharging is a thermally-mediated mechanism for bulk discharging.





Simulations of SEE in Al_2O_3

- CASINO is a software used commonly in the electron microscopy community. It employs Monte Carlo methods to model electron transport in lattice materials.
- For this work, it was used to model electron penetration depths, SEE yield, & BSE yield to verify experimental values.



Conclusions

- Achieved successful contact discharge of E-beam induced surface charging in Al_2O_3
- Observed both fast and slow time discharging behaviors, indicating multiple physical phenomenon at play.
- Different discharging phenomenon suggest SEE generates complicated space charge structure in dielectric materials

Next Steps

- Is it possible to map space charge distribution vs. depth by contact discharging?
- Can we model the effect of space charge distribution on SEE with CASINO?
- What mechanisms are responsible for slow charging?
- What effect does sample temperature have on discharging?

REFERENCES

[1] J. R. Dennison, A. Sim, and C. D. Thomson, IEEE Trans. Plasma Sci. **34**, 2204 (2006).

[2] R. L. Heinisch, F. X. Bronold, and H. Fehske, Phys. Rev. B **85**, 75323 (2012).

[3] A. Belarni, M. Lamhamdi, P. Pons, L. Boudou, J. Guastavino, Y. Segui, G. Papaioannou, and R. Plana, Microelectron. Reliab. **48**, 1232 (2008).

[4] U. Zaghloul, A. Belarni, F. Coccetti, G. J. Papaioannou, L. Bouscayrol, P. Pons, and R. Plana, TRANSDUCERS 2009 - 2009 Int. Solid-State Sensors, Actuators Microsystems Conf. 789 (2009).

CONTACT

- Nikola Protic: njp62@cornell.edu
- Yevgeny Raitses: yraitses@pppl.gov