Discharging of Dielectric Materials as Related to Secondary Electron Emission

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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:
  
  ![Electron Bombardment](image)

- A quantitative three step model has been proposed for SEE; however, the model fails to account for space charge on the wall surface:
  
  ![Space Charge](image)

- To study surface charging insight can be taken from refinement of the plasma-wall potential:
  
  ![Plasma-Wall Potential](image)

- Ab initio studies of discharging have been conducted, but conclusions have yet to be reached:
  
  ![Ab InitioStudies](image)

Experimental Setup

- Idea: Discharging of the charged surface by a biased contact.
  
  - Al_{2}O_{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 & ~7 kHz beating noise over all channels.

- From Fick's Law and Ohms Law diffusion current was modeled as disk above grounded plane in order to estimate number of pulses:

  ![Noise Filtering](image)

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):

  \[ V = \frac{\ln(1)}{2}\text{e}^{-\frac{t}{\text{e}}} \left[ \sqrt{r^2 + d^2} + r^2 - \sqrt{(r - d)^2 + R^2} - 2d \right] \approx 6V \text{ per pulse} \]

  \[ \rightarrow 50 \text{ pulses to saturation} \]

- Experimentally, pulse signal attenuated by 1/e in 13 pulses. Concluded that \( \text{e}^{-\frac{t}{\text{e}}} \) summing above equation, total charge deposited is about 34 pC.

- Observed incomplete discharging. Discharging reached different non-neutral steady states depending on discharger bias.

- Indicates space charge density 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 (≤ |+30 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_{2}O_{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_{2}O_{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


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