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Power and Charge Deposition in Multilayer Dielectrics undergoing Monoenergetic Electron Bombardment

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In Conclusion

- When electrons interact with matter they can deposit both power and charge
- Both power and charge deposition are energy dependent
- Using our approximation of the range we can predict both power and charge deposition
- These models enable the effect of the space environment on spacecraft to be predicted to ensure proper spacecraft design and material selection.

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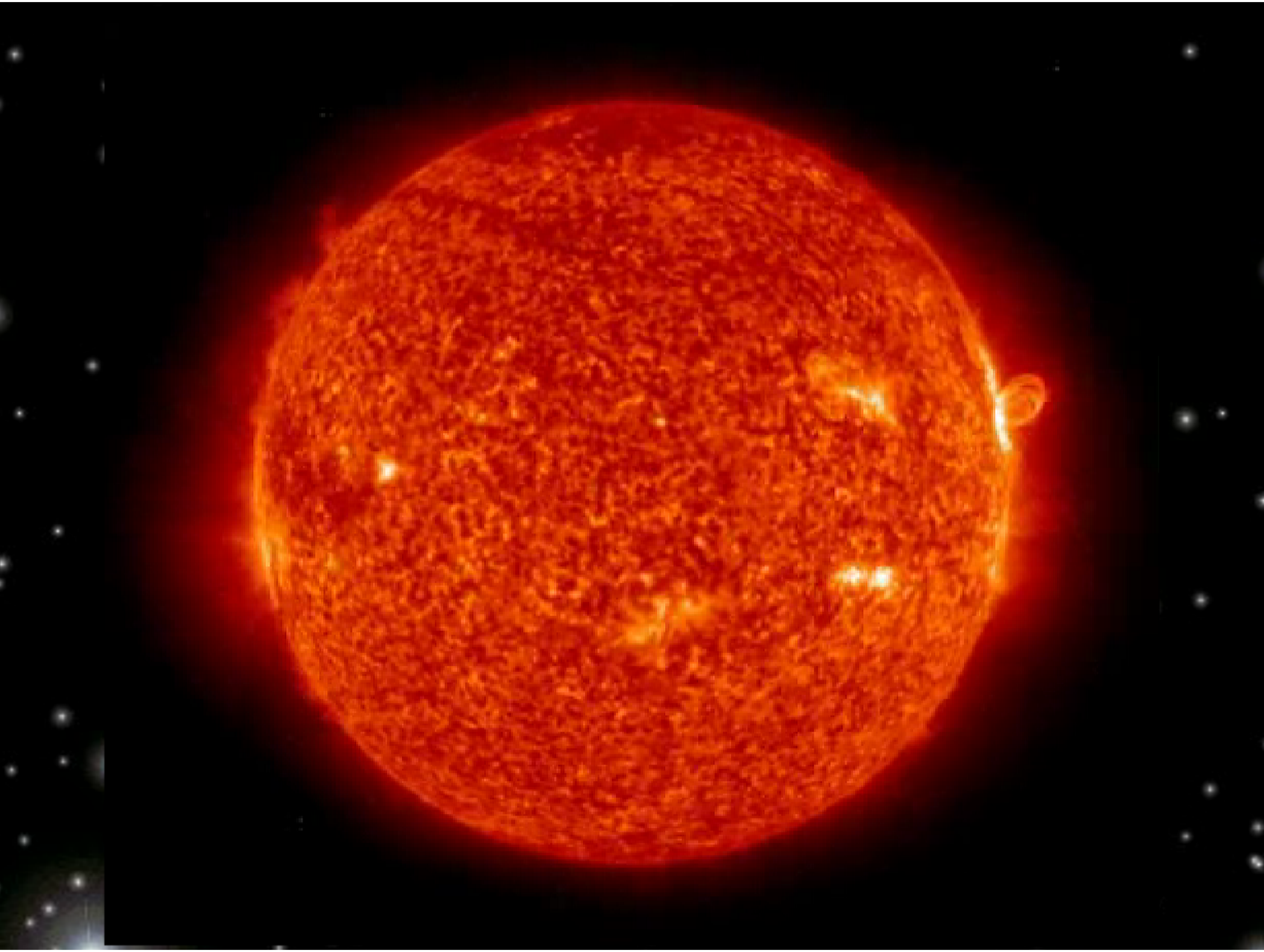
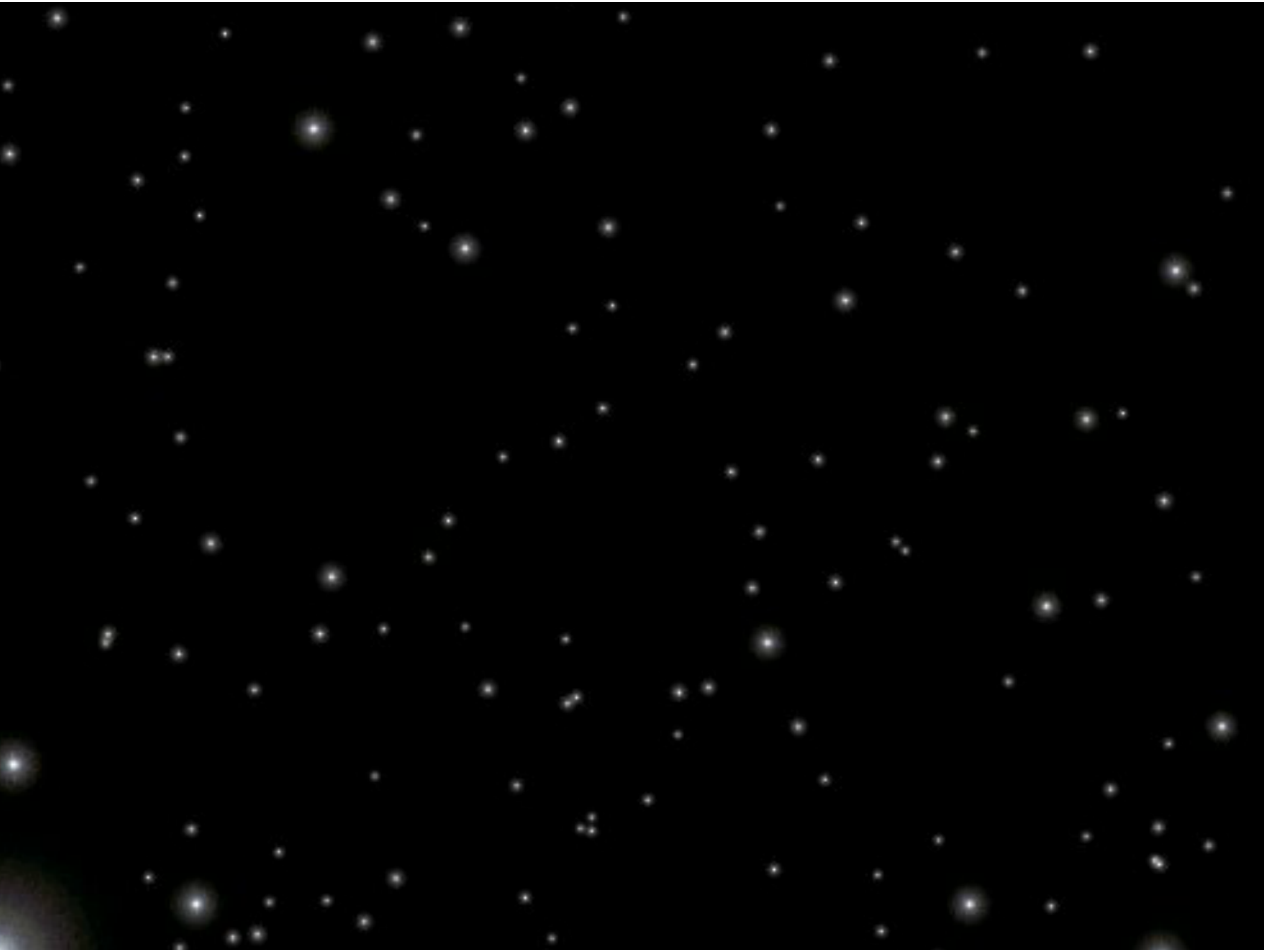
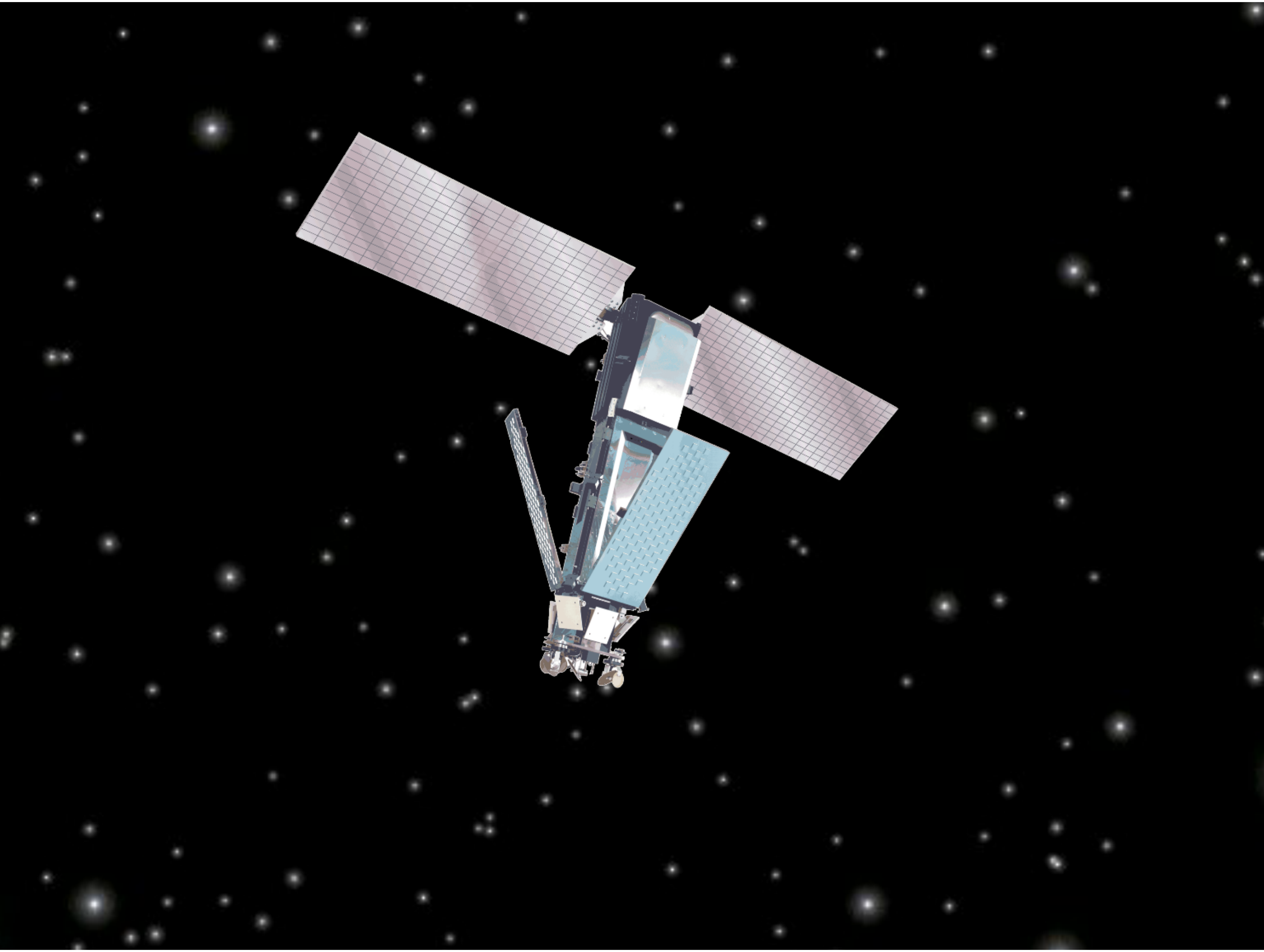
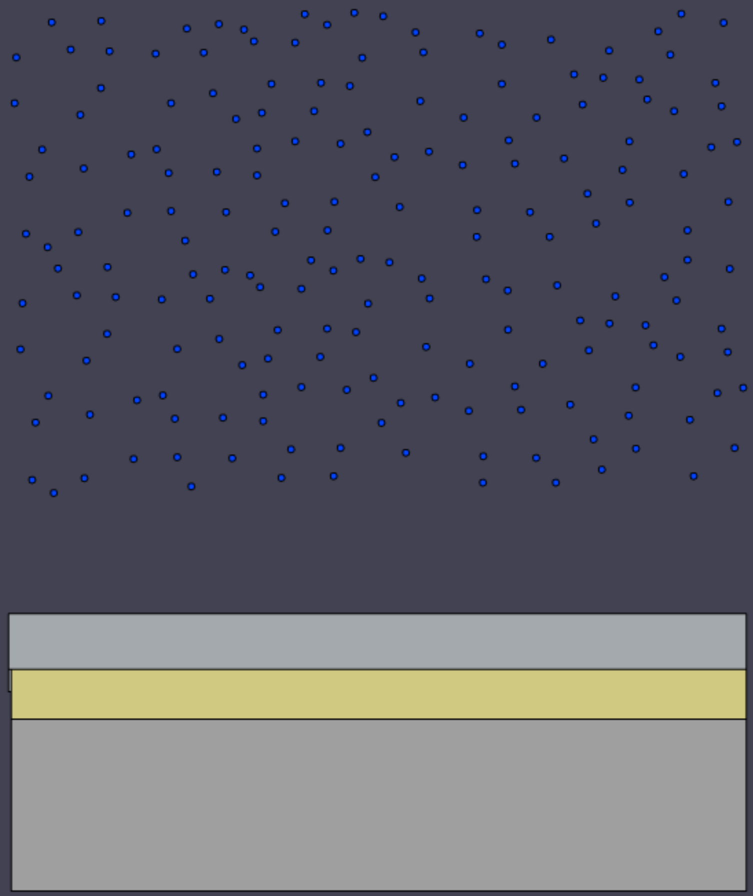






Power Deposition vs Charge Deposition



- As electrons penetrate a material they impart energy to the material through several inelastic collisions
- When the electron's Kinetic energy is depleted it deposits it's charge at the range $R(E_b)$ where E_b is the incident energy of the electron.

Continuous Slow Down Approximation

- In the CSDA, the rate of energy loss, dE/dz (or total stopping power, S), at every position along the penetration path is assumed constant
- For a given incident energy, E_b, the CSDA range is obtained by integrating the total stopping power over the full penetration depth

$$\underbrace{\frac{dE}{dz} \equiv S_{CSDA}(E_b)}_{\text{Stopping Power}} = \underbrace{{E_b}/{R}}_{\substack{\text{Total Energy}\\ \text{over Total Range}}} = \underbrace{{\bar{E}}/{\bar{\lambda}}}_{\substack{\text{Mean Energy loss}\\ \text{over IMFP}}} = \underbrace{{E_{min}}/{\lambda_{min}}}_{\substack{\text{Minimum Energy Loss}\\ \text{over Minimum IMFP}}}$$

Electron Range

- High Energy

$$\underbrace{b\,E_b{}^{n}}_{\text{Power law}}\ \underbrace{\left[1-\left[1+\left(\frac{E_b/N_V}{m_e c^2}\right)\right]^{-2}\right]}_{\text{Relativistic factor}}$$

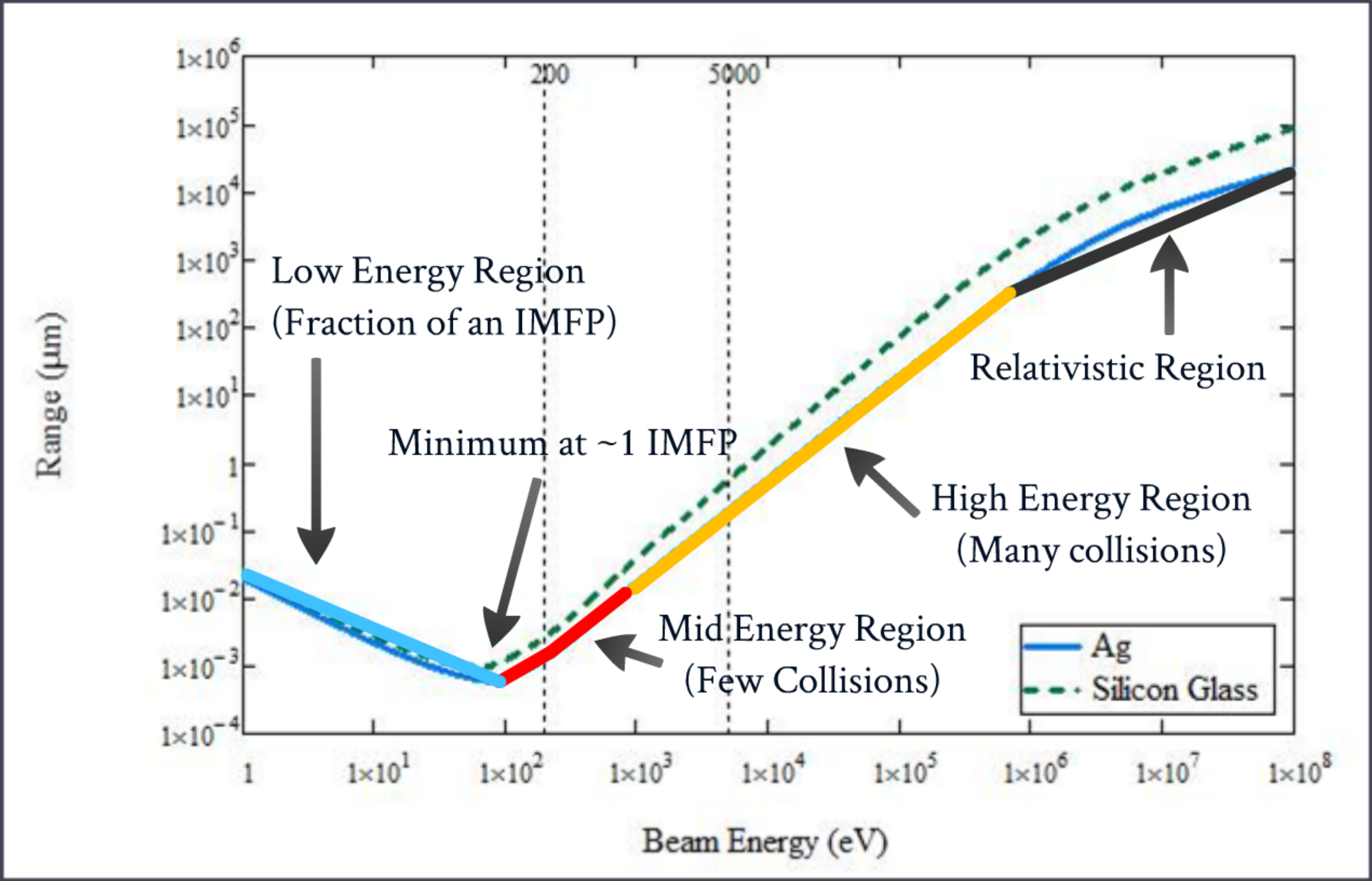
- Mid Energy

$$\underbrace{\left[\frac{E_b}{\bar{E}}\right]}_{\text{\# of collisions}}\ \underbrace{\lambda_{IMFP}(E_b)}_{\text{\# of IMFPs that occur}}\ \underbrace{\left(1-e^{-E_b/\bar{E}}\right)^{-1}}_{\text{The likelihood of a collision (~1)}}$$

- Low Energy

$$\underbrace{\left[\frac{E_b}{\bar{E}}\right]}_{\text{\# of collisions}}\ \underbrace{\left[\lambda_{IMFP}\,(\bar{E})\,\frac{\left(1-e^{-\bar{E}/\bar{E}}\right)}{\left(1-e^{-E_b/\bar{E}}\right)}\right]}_{\text{Fraction of IMFPs that occur}}\ \underbrace{\left(1-e^{-E_b/\bar{E}}\right)^{-1}}_{\text{The likelihood of a collision (<1)}}$$

Electron Range



Low Energy Region
(Fraction of an IMFP)

Minimum at ~1 IMFP

Mid Energy Region
(Few Collisions)

High Energy Region
(Many collisions)

Relativistic Region

Dose Rate

- The dose rate in a homogeneous material is approximately inversely proportional to the volume in which radiation energy is deposited.

$$D(\dot{E}_b) \equiv {}^{\partial D}/_{\partial t} = \frac{E_b\, J_b}{\rho_m\, R(E_b)\, q_e} \propto \frac{E_b}{R(E_b)}$$

- To calculate the deposited power for each layer we can multiply the dose rate by the amount of material radiated

Power Deposition

- First Layer: R(Eb) < d

$$\boldsymbol{P(E_b) = \frac{E_b J_b A}{q_e}}$$

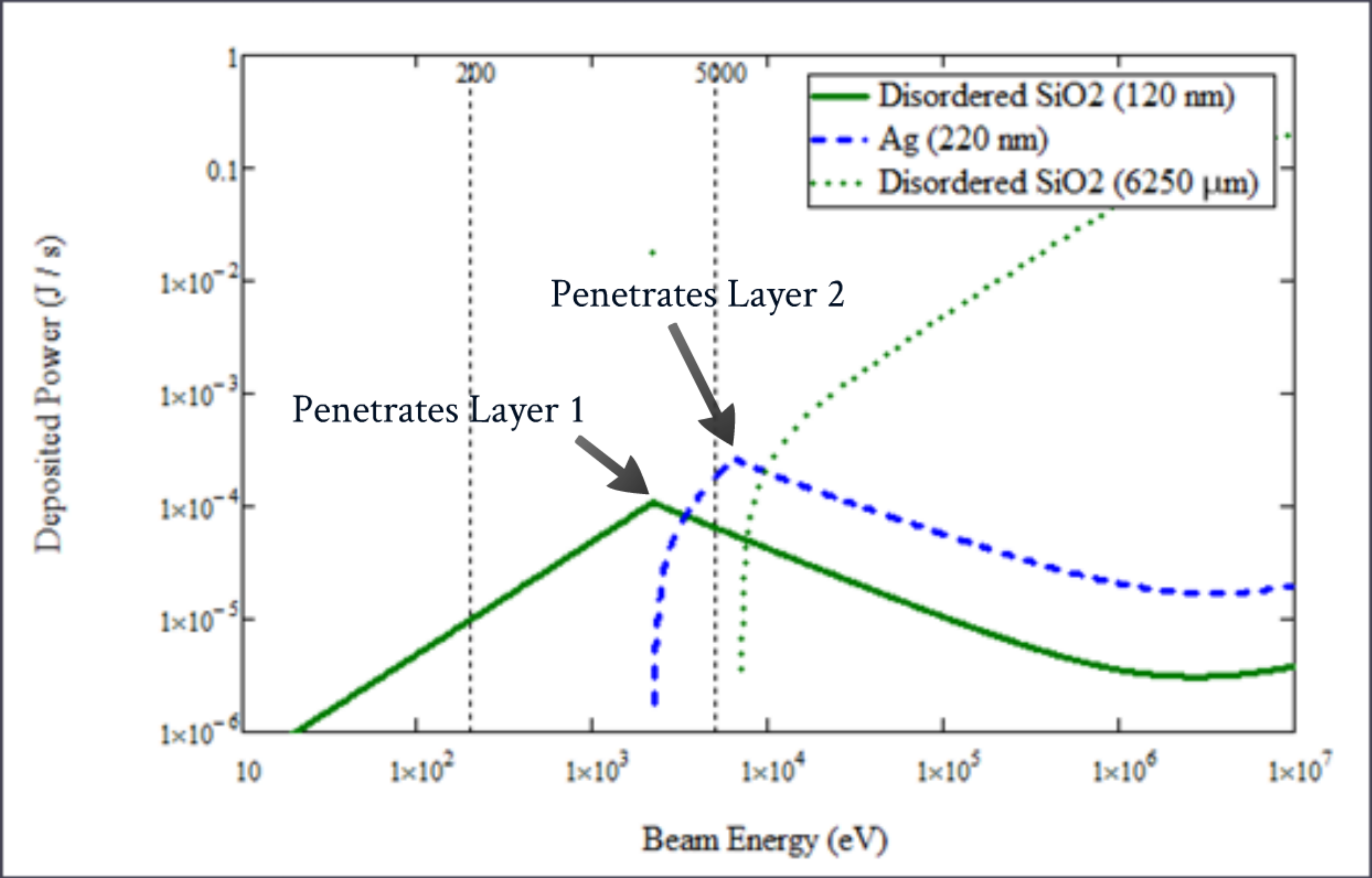
- First Layer: R(Eb) > d

$$\boldsymbol{P(E_b) = \frac{E_b J_b A}{q_e}\frac{d}{R(E_b)}}$$

- Subsequent Layers

  The equations are the same for all subsequent layers but you must scale E_b as the energy at which the electrons enter that particular layer

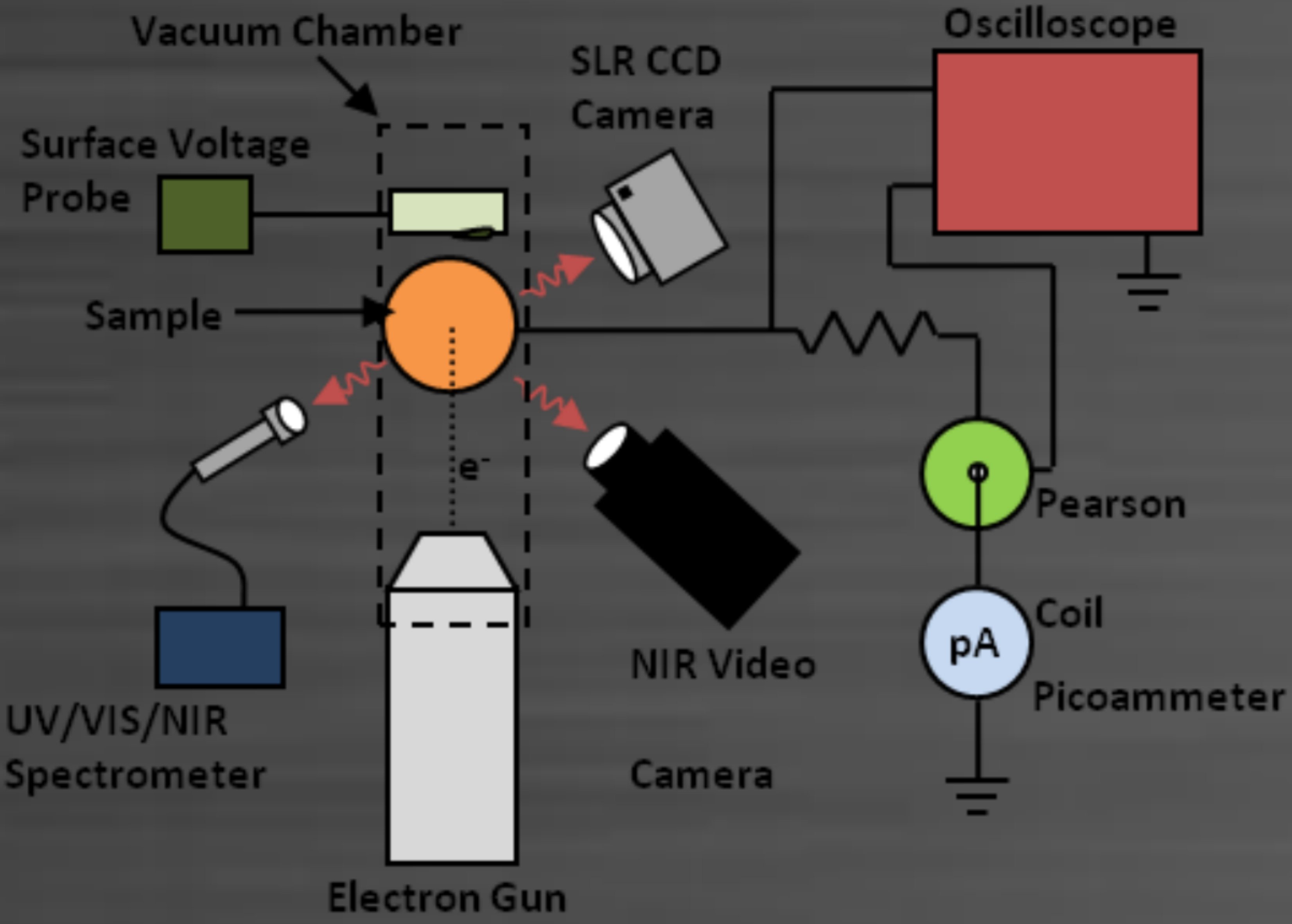
Multilayer Power Deposition



Penetrates Layer 1

Penetrates Layer 2

Experimental Setup



Experiment Parameters

- Charge Deposition

  Multilayer SiO_2 (120 nm SiO_2, 220 nm Ag, 0.625 cm SiO_2)

  15 s pulses at 2 nA/cm^2 to 20 nA/cm^2 flux densities

  Beam energies of 200 eV and 5 keV

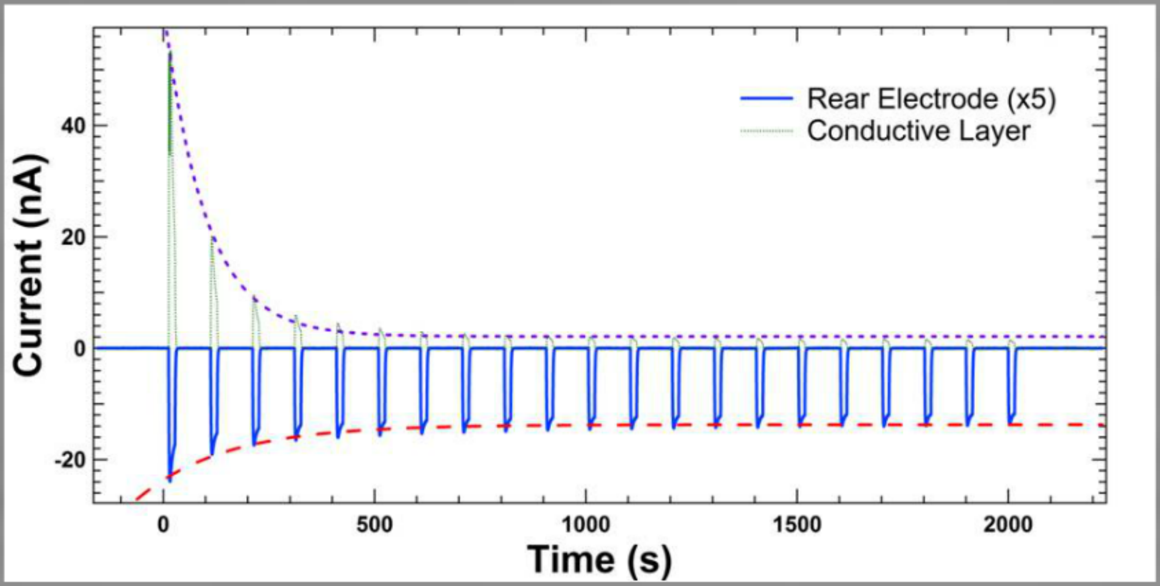
- Power Deposition

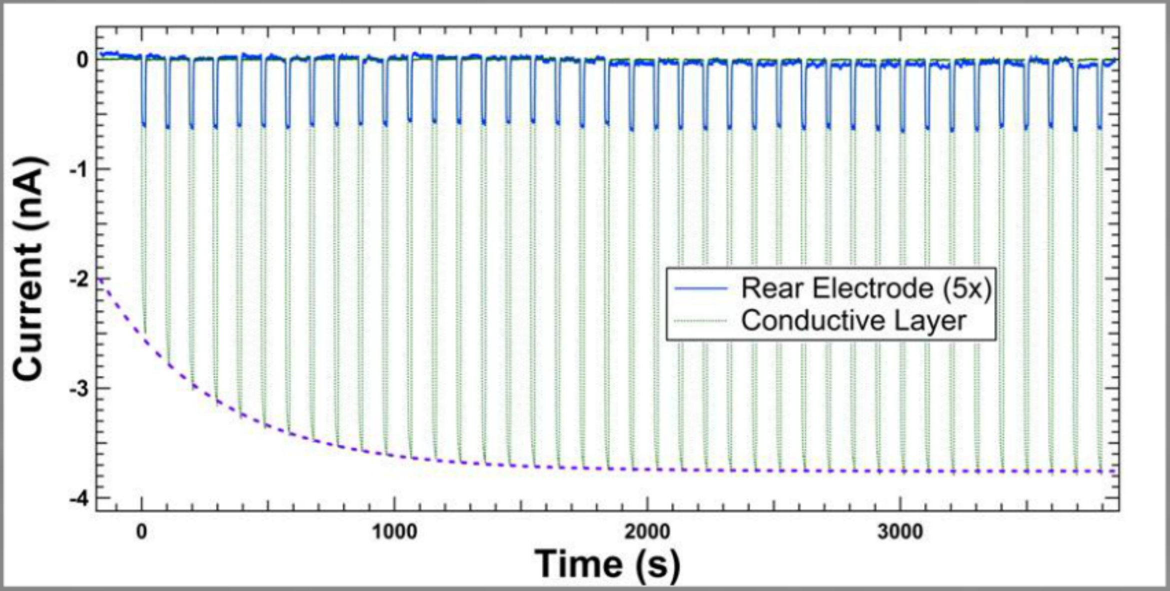
  Multilayer SiO_2 (~65 nm SiO_2, 220 nm Au, 0.625 cm SiO_2)

  15 s pulses at 2 nA/cm^2 to 100 nA/cm^2 flux densities

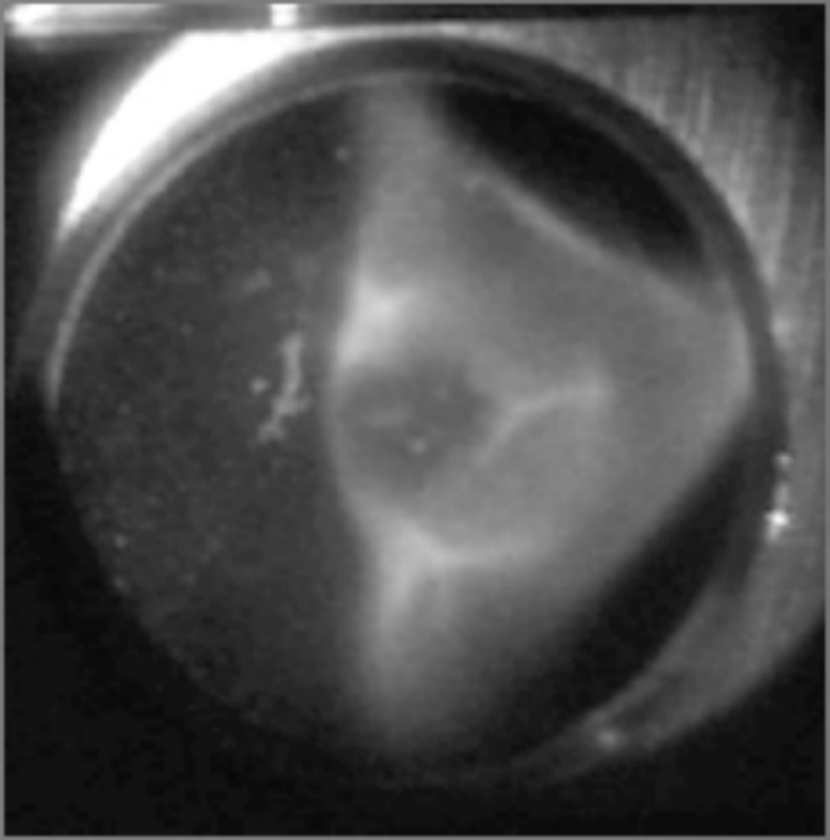
  Beam energies of 5 keV to 25 keV

Charge Deposition



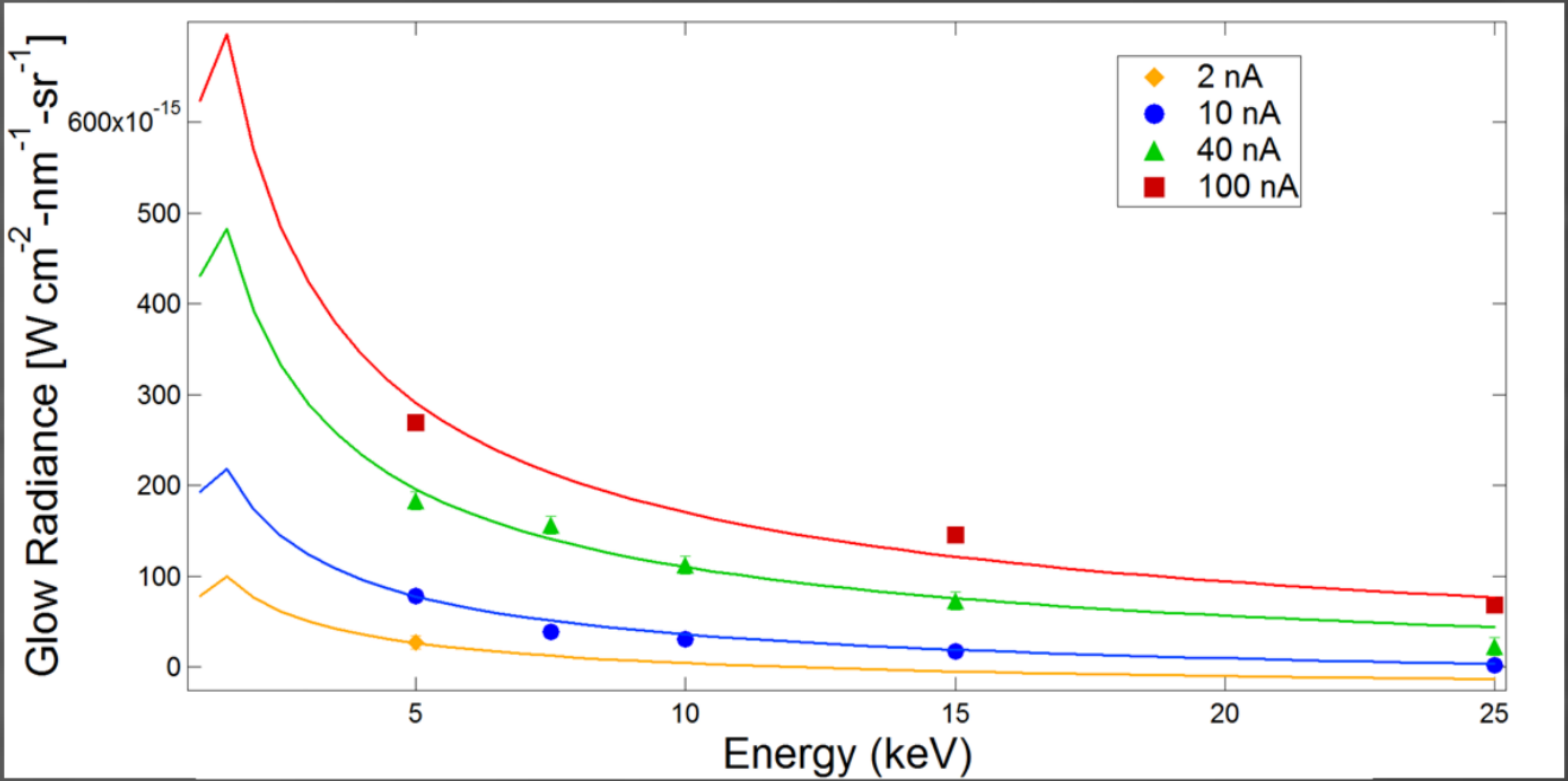


Power Deposition



Disordered, thin-films of fused silica undergoing electron beam irradiation have been shown to produce a low-efficiency cathodoluminescence

Power Deposition



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