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Temperature Effects on Surface Potential of Electron Irradiated Polyimide Film

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Background

- Dielectric films on spacecraft surface become charged in plasma and radiation environment
  - Electrons and protons

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- Charging analysis is necessary
- Selection of dielectric material is crucial for spacecraft design

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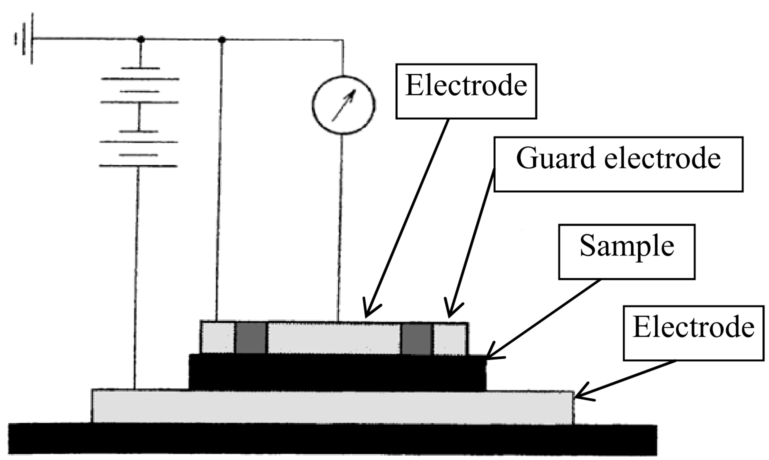
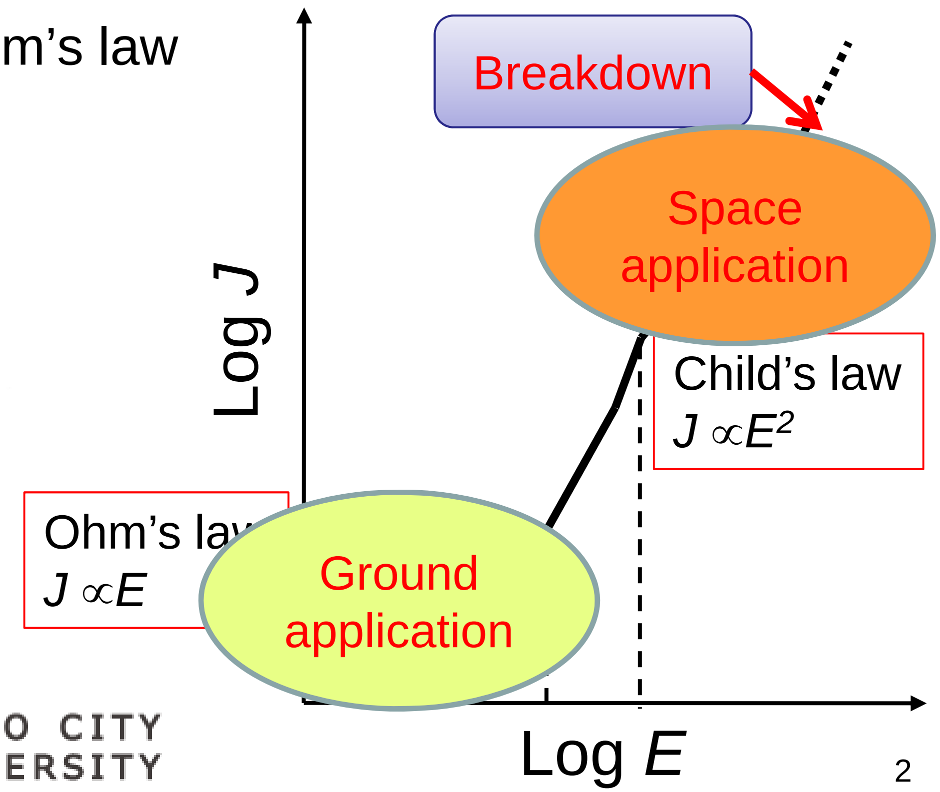
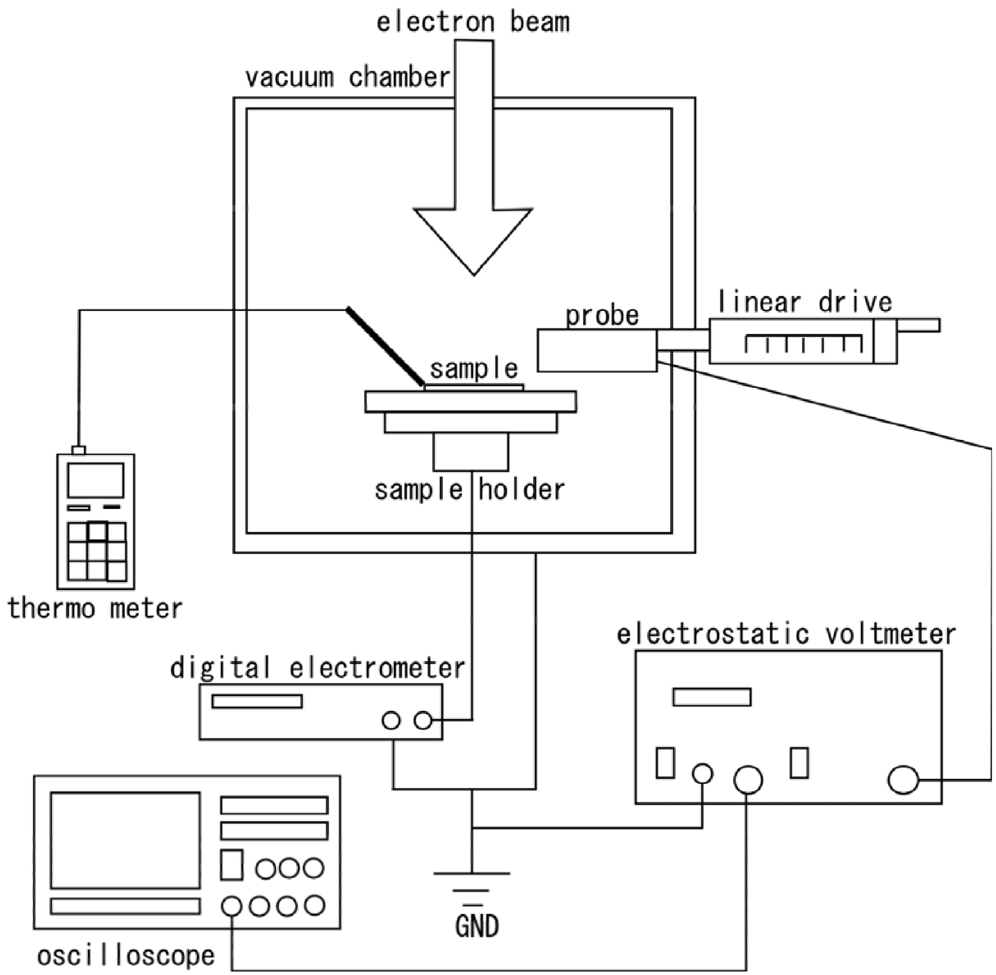
Volume Resistivity

- Volume resistivity => electrical insulation
  => E-field relaxation time
- Measurement
  - Conventional “Capacitor Method” -> ASTM D-257
    - DC voltage applied -> Ohm’s law





Charge Storage Method*



Measurement setup for Charge Storage Method

- Vacuum chamber
- E-beam gun
- Surface potential
  - Trek
- Leakage current
  - Keithley

*A.R. Frederickson and J.R. Dennison, IEEE Trans. on Nuc. Sci., Vol. 50, No. 6(2003)

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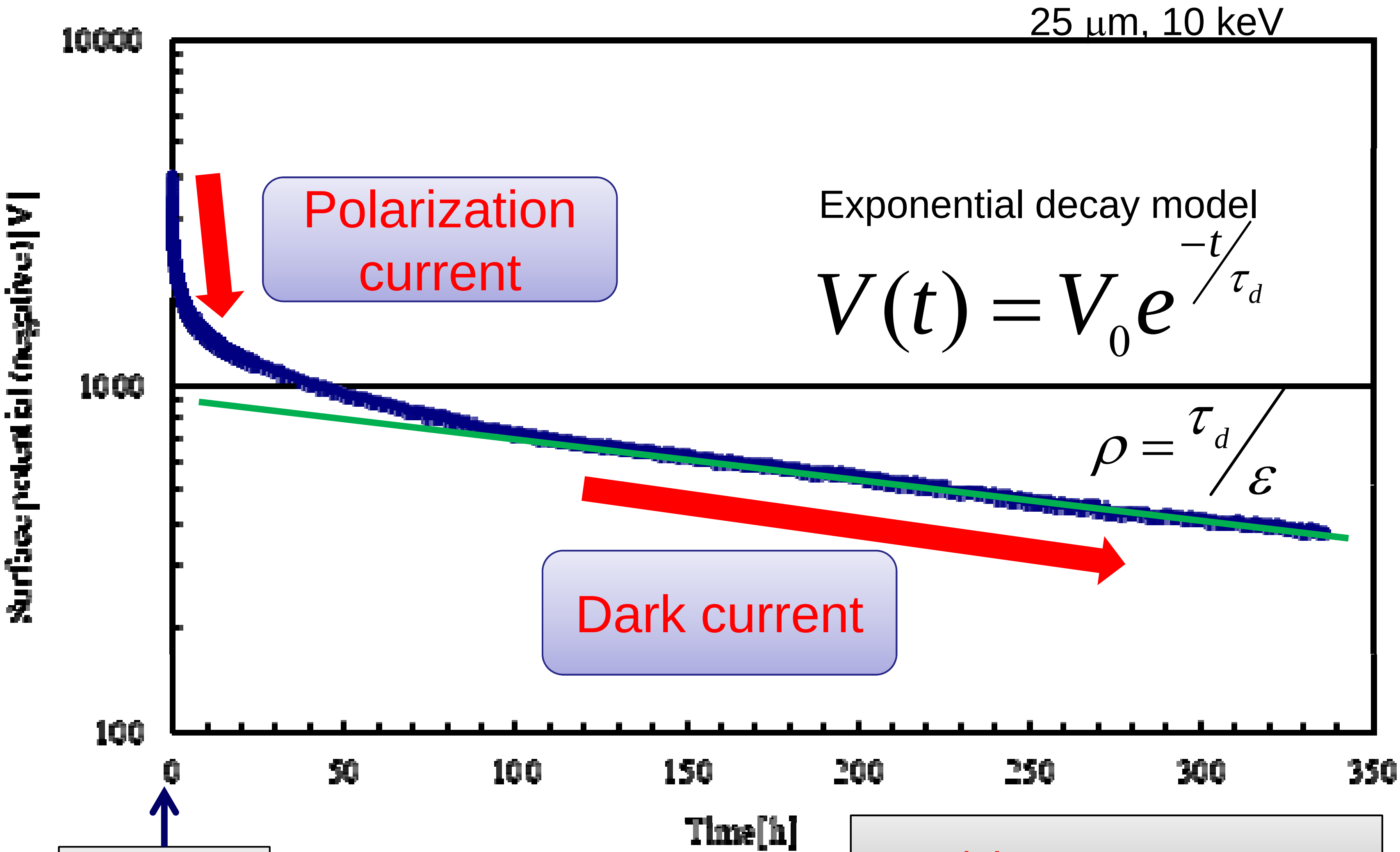
Surface Potential on Irradiated Kapton© Film



E-beam ceased

Week long measurement !!

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Volume Resistivity (surface potential) Dependency

Temperature

- Boltzmann type $\rho(T) \propto \exp\left(\frac{U}{kT}\right)$
- Mott type → Cryogenic temperature $\rho(T) \propto \exp\left(\frac{T_0}{T}\right)^n$

Electron energy and flux

- Penetration depth (Range)
- Dose effect (Radiation Induced Conductivity)

Sample thickness

- E-field enhancement for thin film

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Temperature Variation in Space

- 120 K to 400 K → LEO environment
- Keeping at tens of Kelvin (cryogenic temperature) is required for space telescope (X-ray, Infrared-ray)

Accumulated charges are not dissipated → No E-field relaxation

Sample Temperature Control

- Heater and cryogenic shroud (liquid nitrogen) are widely used
- Higher operational cost

Week long measurement is required for the charge storage method

- Alternative ways
  - Thermodynamic devices-----Joule-Thompson effect, Gifford-McMahon cycle, Pulsed tube
  - Electrical device----Peltier device

Peltier Device

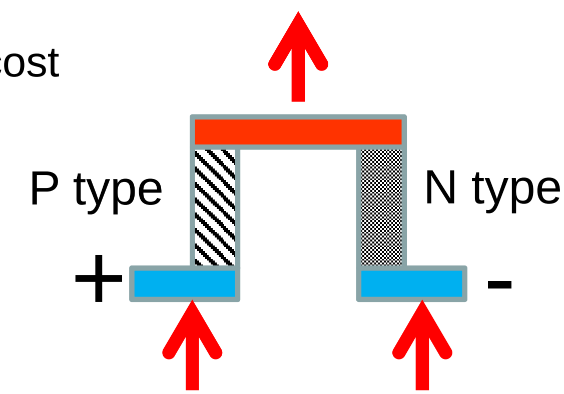
Advantage

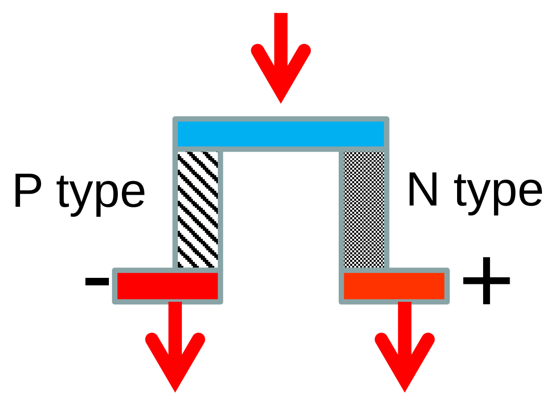
- High and low temperature
- Controlled by applying voltage
- High accuracy temperature control
- Lower operational cost

Disadvantage

200 K to 360 K

- Narrow temperature range
- Lower efficiency < 10 %
- Device itself generates heat (heat removal required)





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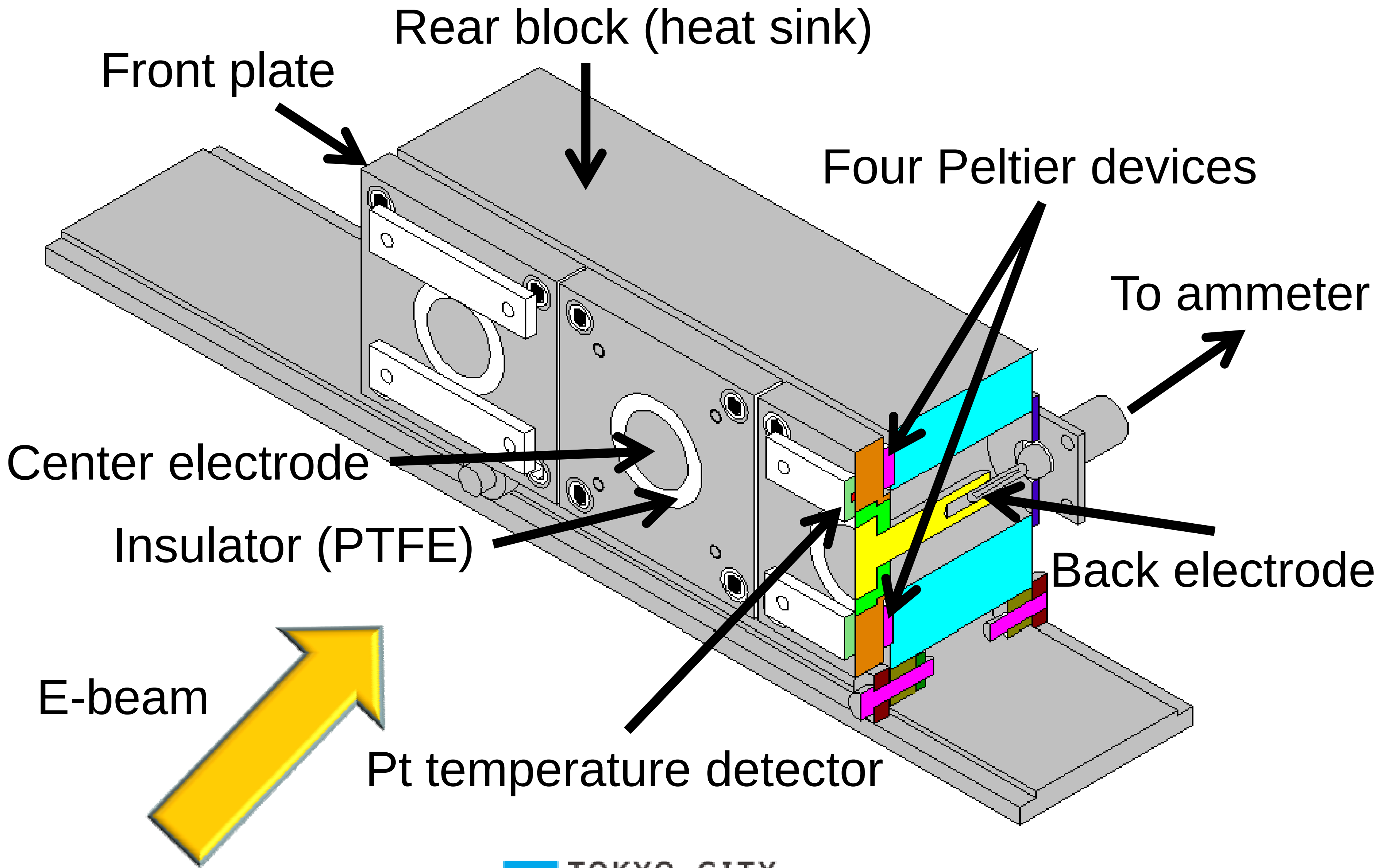
Purpose of Study

- Examining availability of the sample temperature control system using Peltier device
- Analyzing the effect of temperature on surface potential history of electron-irradiated dielectric film
- Temperature dependency on volume resistivity

Sample Holder



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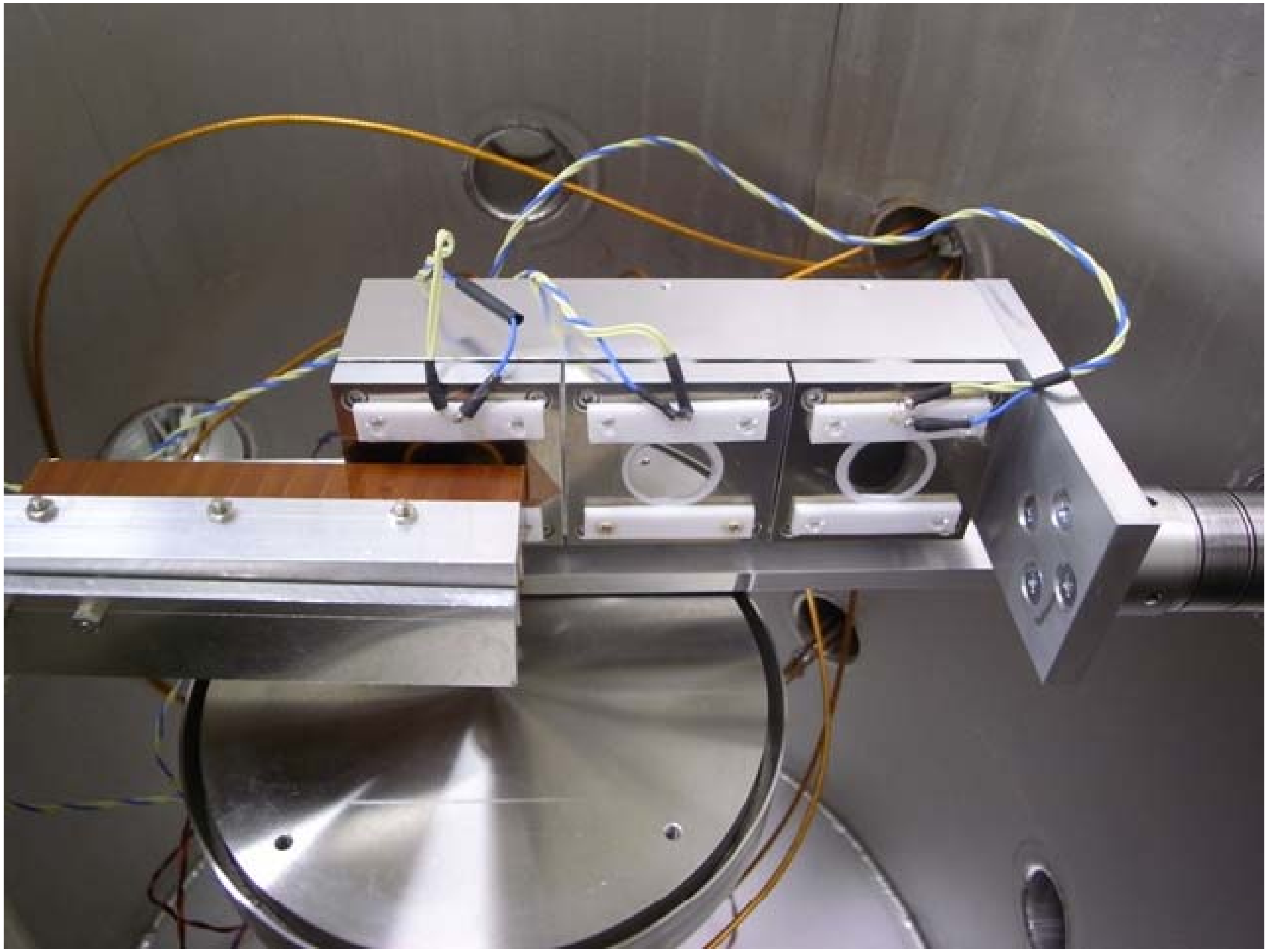
Measurement setup



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Experimental Conditions

Temperature setting [K]	233	253	273	299	323	353
Sample	Kapton® 200H					
Sample thickness [μm]	50					
Electron beam irradiation energy [keV]	20					
Irradiation time [s]	60					
Vacuum level [Pa]	10^{-6}					
Measurement time [h]	240					

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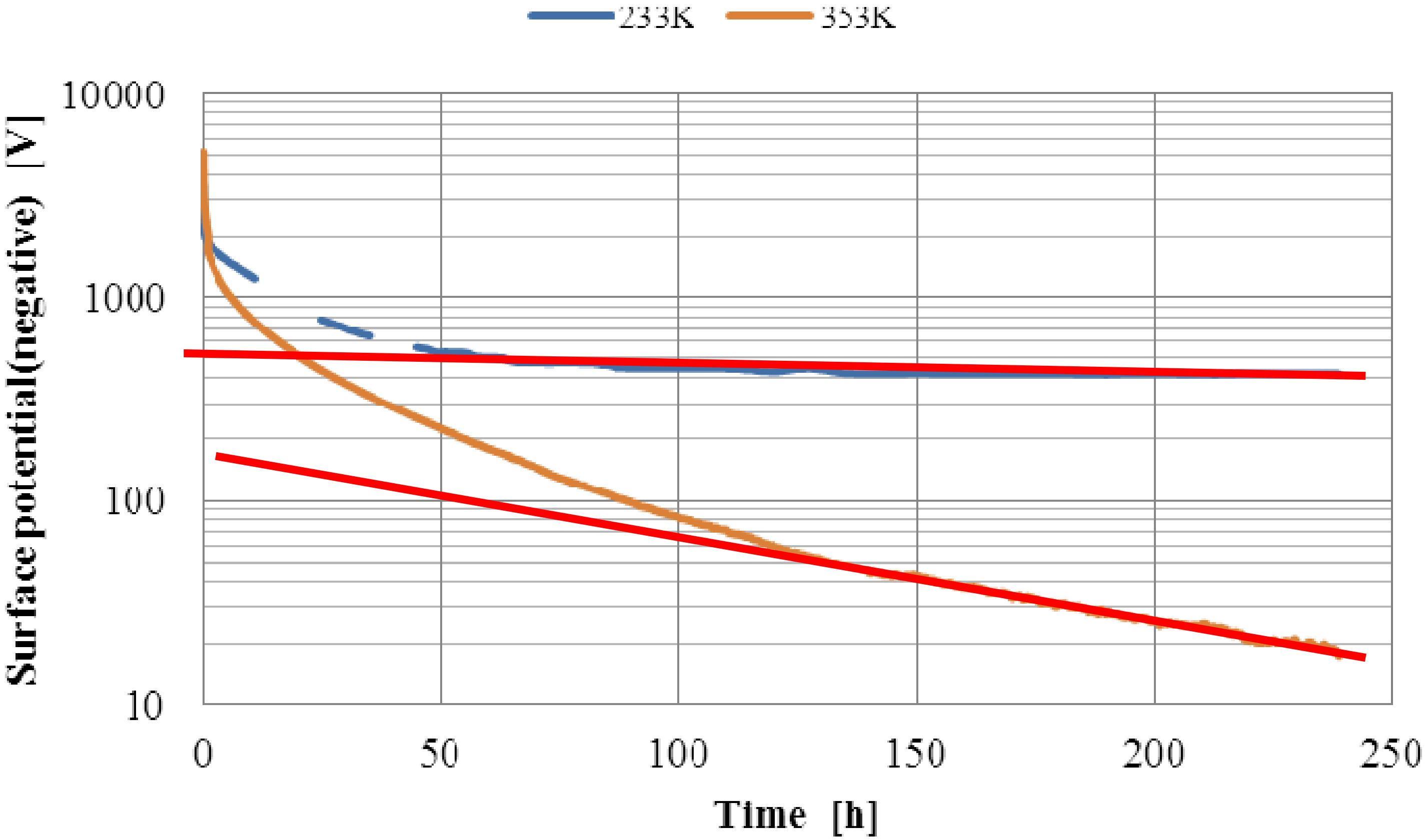
Surface Potential Histories with Temperature Change

Semi-log plot



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Lower resistivity

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Volume Resistivity Calculation

- Dark current region ---- a few days later or more

$$V(t) = V_0 e^{-t/\tau_d}$$

τ_d : Dark current decay time constant

- Short time region ---- polarization current is dominant and the model by Dennison* is applied

$$V(t) = V_0 \left[\varepsilon_r^\infty + \left(1 - \varepsilon_r^\infty\right) e^{-t/\tau_P} \right]^{-1}$$

τ_P : Polarization current decay time constant

ε_r^∞ : Relative permittivity with fully polarized dielectric

*J.R. Dennison et. al., IEEE Trans. on Plasma Sci., Vol. 34, No. 5(2006)

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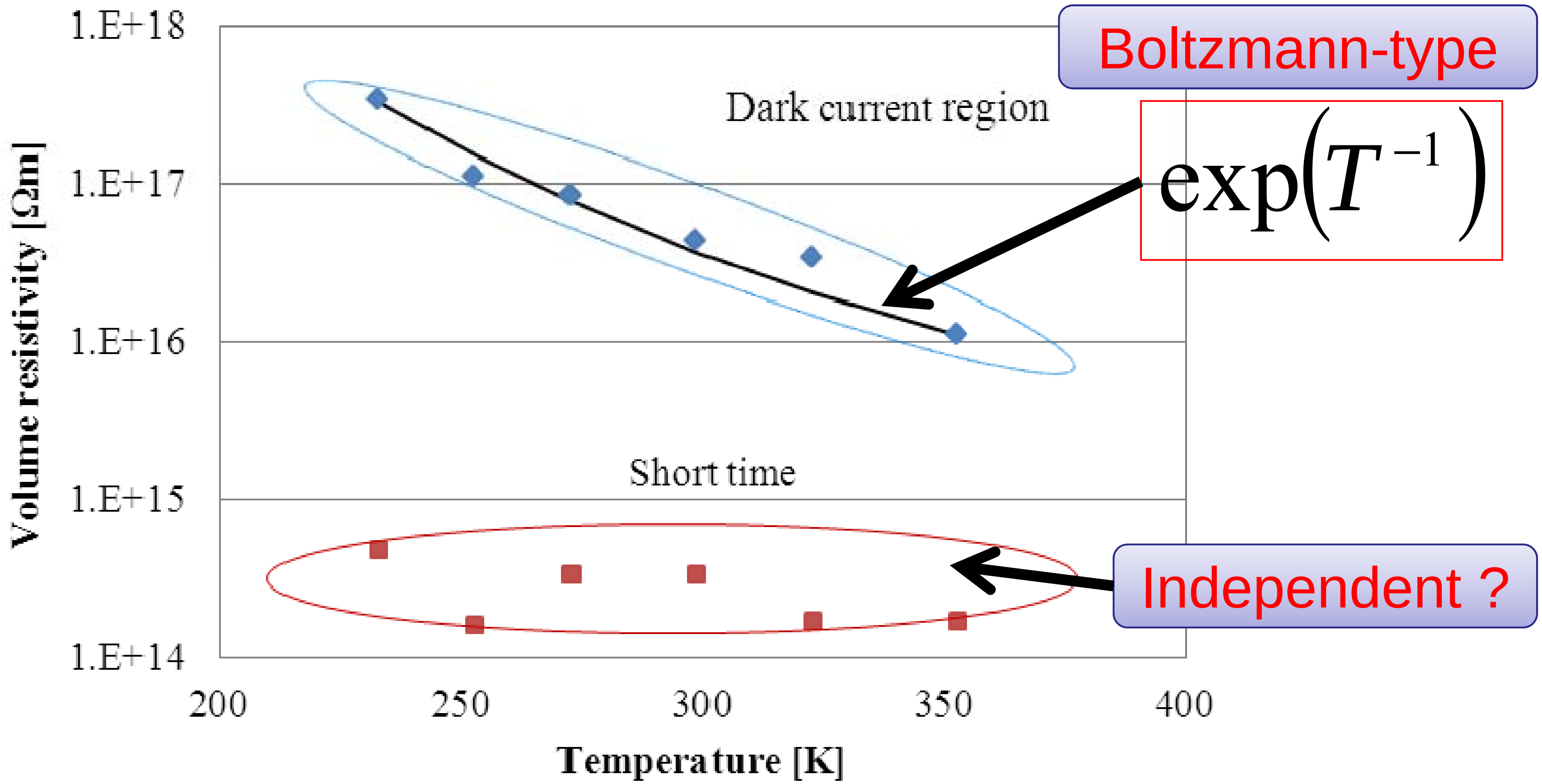
Volume Resistivities

	Volume resistivity [Ωm]	
Temperature [K]	Dark current	Short time
233	3.3×10^{17}	4.8×10^{14}
253	1.1×10^{17}	1.6×10^{14}
273	8.3×10^{16}	3.3×10^{14}
299 [RT]	4.2×10^{16}	3.3×10^{14}
323	3.3×10^{16}	1.7×10^{14}
353	1.1×10^{16}	1.7×10^{14}

c.f. Volume resistivity of Kapton film obtained by the capacitor method is 10^{15} Ωm

Temperature Dependency on Volume Resistivity



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Summary

- Temperature control system using Peltier devices is developed and the temperature range from 233 K to 353 K is attained
- Volume resistivity of electron-irradiated polyimide film with temperature change is analyzed and Boltzmann-type temperature dependency is observed
- Dark current resistivity --- from 10^{16} to 10^{17} Ωm
- Short time (polarization current) resistivity -- 10^{14} Ωm, independent of temperature

Future Works

- Cryogenic temperature
  - Thermodynamic device
  - Mott-type temperature dependency
- Establishment of volume resistivity measurement testing
  - Irradiation energy and flux, temperature, humidity, sample thickness
- Another dielectrics or glass material
  - Silver coated FEP (fluorinated ethylene propylene) Teflon
  - Cover glass and OSR (optical solar reflector)