Temperature and Frequency Dependence of Electrical Parameters of Irradiated Silicon Diodes

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Introduction

Charge signal (for mips) $\propto$ depletion depth $\propto$ 1/Capacitance

C(V)/I(V) – much easier, than CC(V)

BUT:

Hard irradiation → High leakage current → Cooling is necessary;
↓
High deep traps concentration → Strong dependence on temperature and frequency;

Well-known: $I(T) \propto T^2 \exp\left(-\frac{E}{kT}\right)$, where $E \sim 0.6$ eV

Petterson et al. (NIM A583): also for *CV* measurements

$$f(T) \propto e_n(T) \propto T^2 \exp\left(-\frac{E_a}{kT}\right)$$, where E_a is like E for current scaling

Devices under test

Silicon pad diodes:

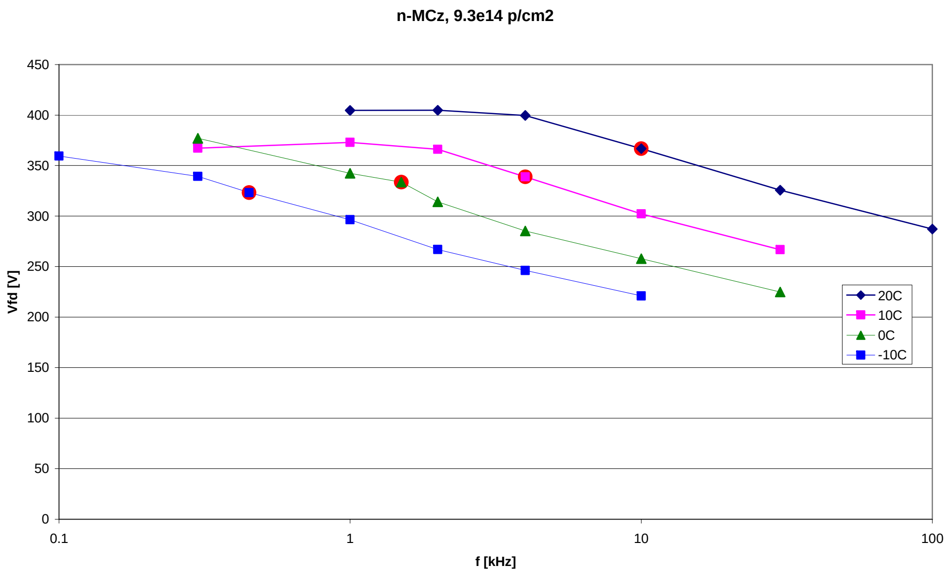
- n- MCz (280 μm, 1 kΩ·cm): 24 GeV/c protons, $(2\text{-}9)\cdot 10^{14}$ p/cm^2; reactor neutrons, $(2\text{-}10)\cdot 10^{14}$ n/cm^2;
- p- MCz (280 μm, 3 kΩ·cm) 24 GeV/c protons $(2\text{-}9)\cdot 10^{14}$ p/cm^2;
- n- Epi-DO (100 μm, 300 Ω·cm) reactor neutrons $(10^{14} – 4\cdot 10^{15})$ n/cm^2;

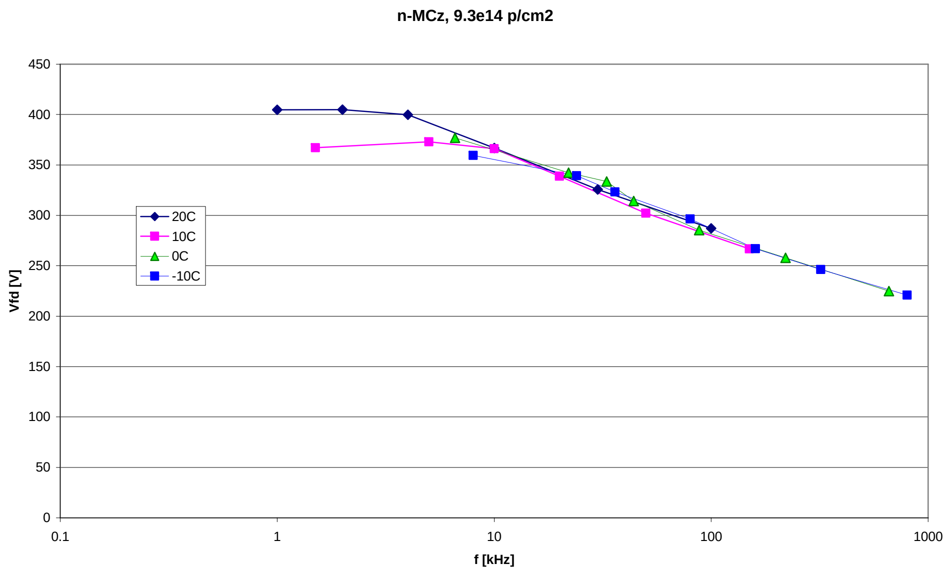
For all samples – CV/IV: temperature (–10 to 20)ºC,
frequency (0.1–100) kHz;

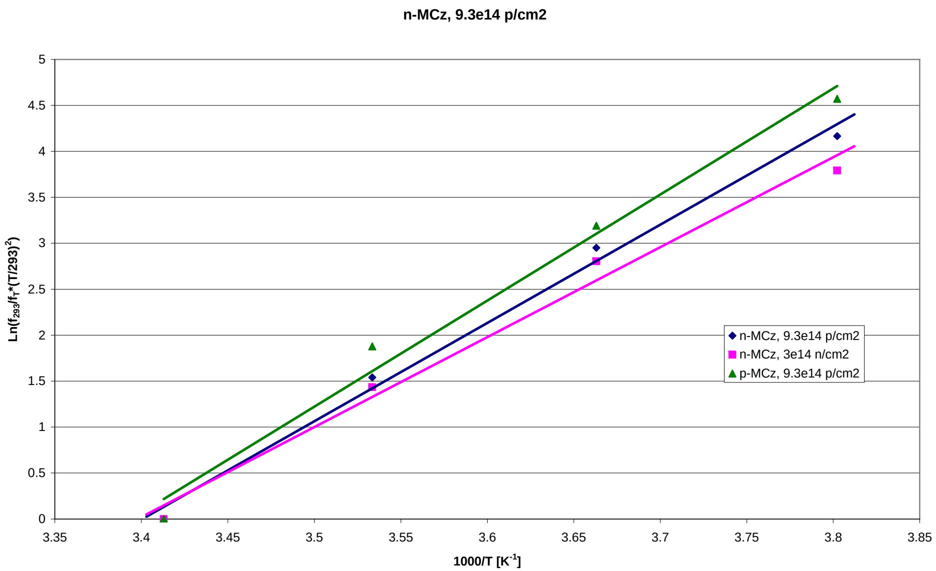
Epi-DO: isothermal annealing at 80ºC up to 30 min;

MCz: CCE with Sr-90 β-particles;

CV measurements: MCz + protons





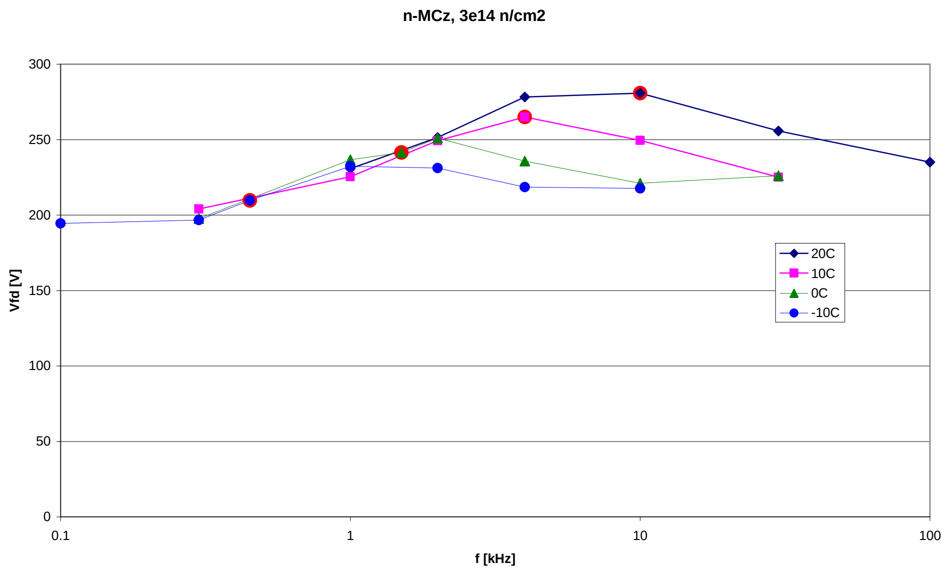


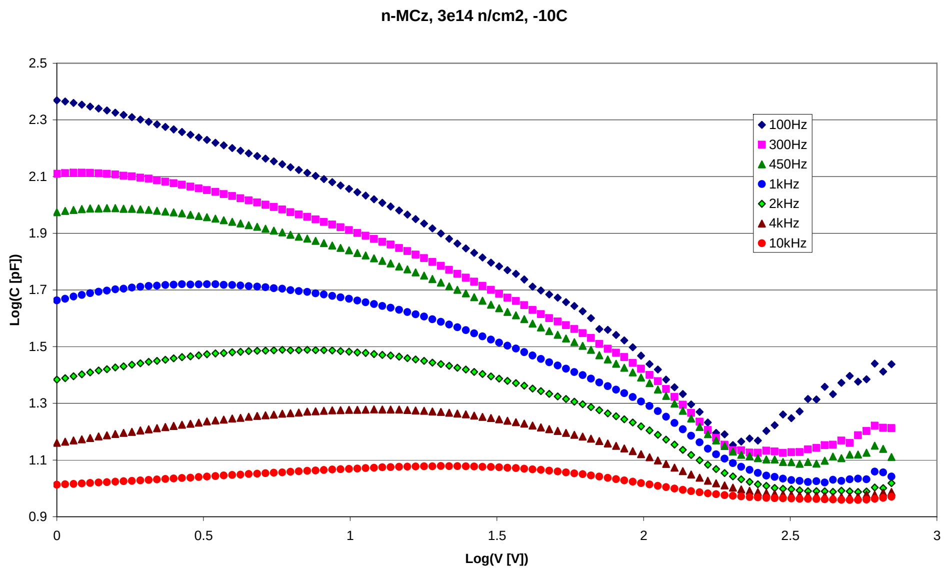
Shift by f to RT curve to get $f_{293\mathrm{K}}/f_T$

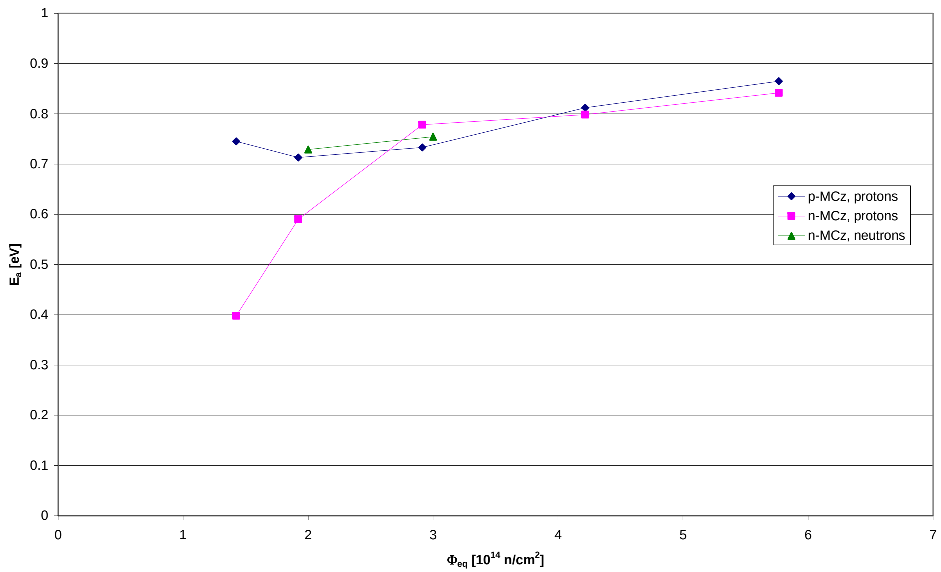
$$\ln\left(\frac{f_{293K}}{f_T}\cdot\left(\frac{T}{293}\right)^2\right)=\frac{E_a}{k}\left(\frac{1}{T}-\frac{1}{293}\right)$$

E_a from linear fit

CV measurements: MCz + neutrons

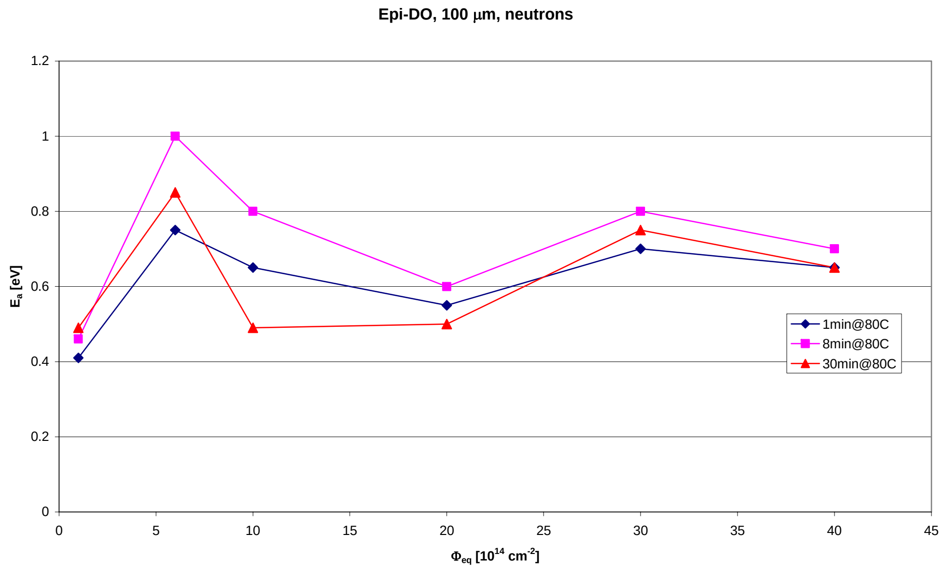






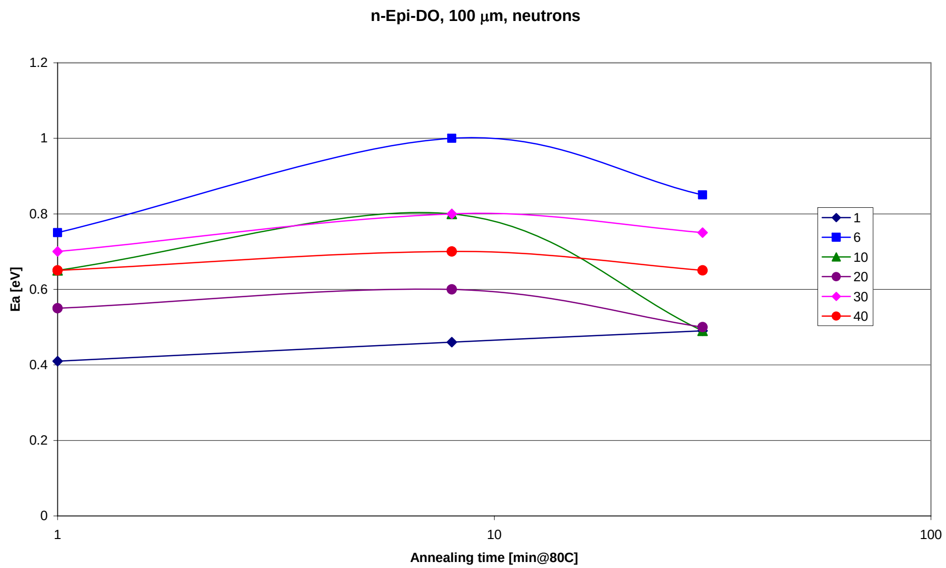
- Neutrons: more damage to MCz: C_{end} increase for low f; V_{fd} underestimated – scaling not possible for high Φ
- E_{a} depends on Φ
- Generally higher (~0.8 eV) than for current scaling (~0.6 eV)

CV measurements: Epi-DO + neutrons + annealing



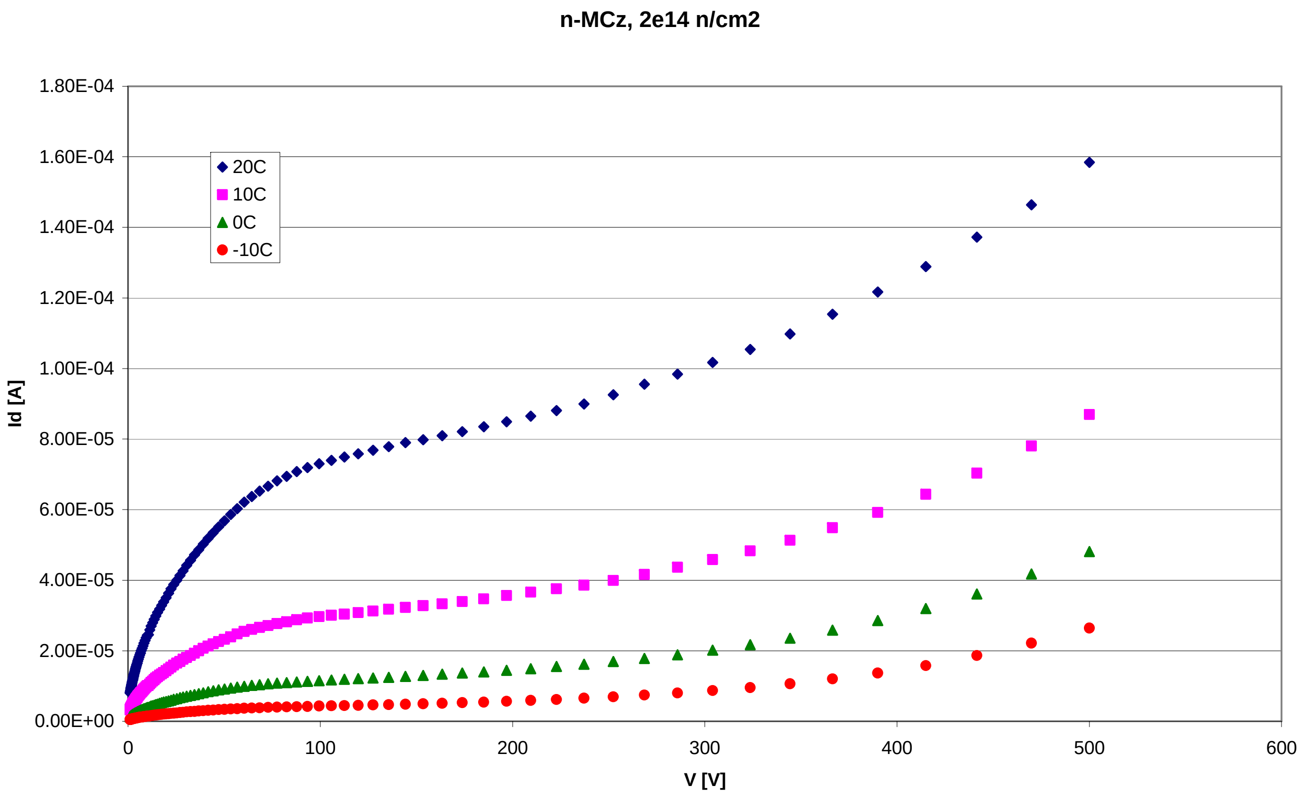
- 100 μm Epi-DO are more radiation hard, than thick MCz ones;
- E_a (Φ_{eq}) not smooth:

  $6 \cdot 10^{14}$ n/cm^2 – close to SCSI, low V_{fd};



- Maximum of $E_a(t_{ann})$ at 8 min at 80ºC
- Correlation with beneficial annealing?

IV measurements: Leakage current scaling



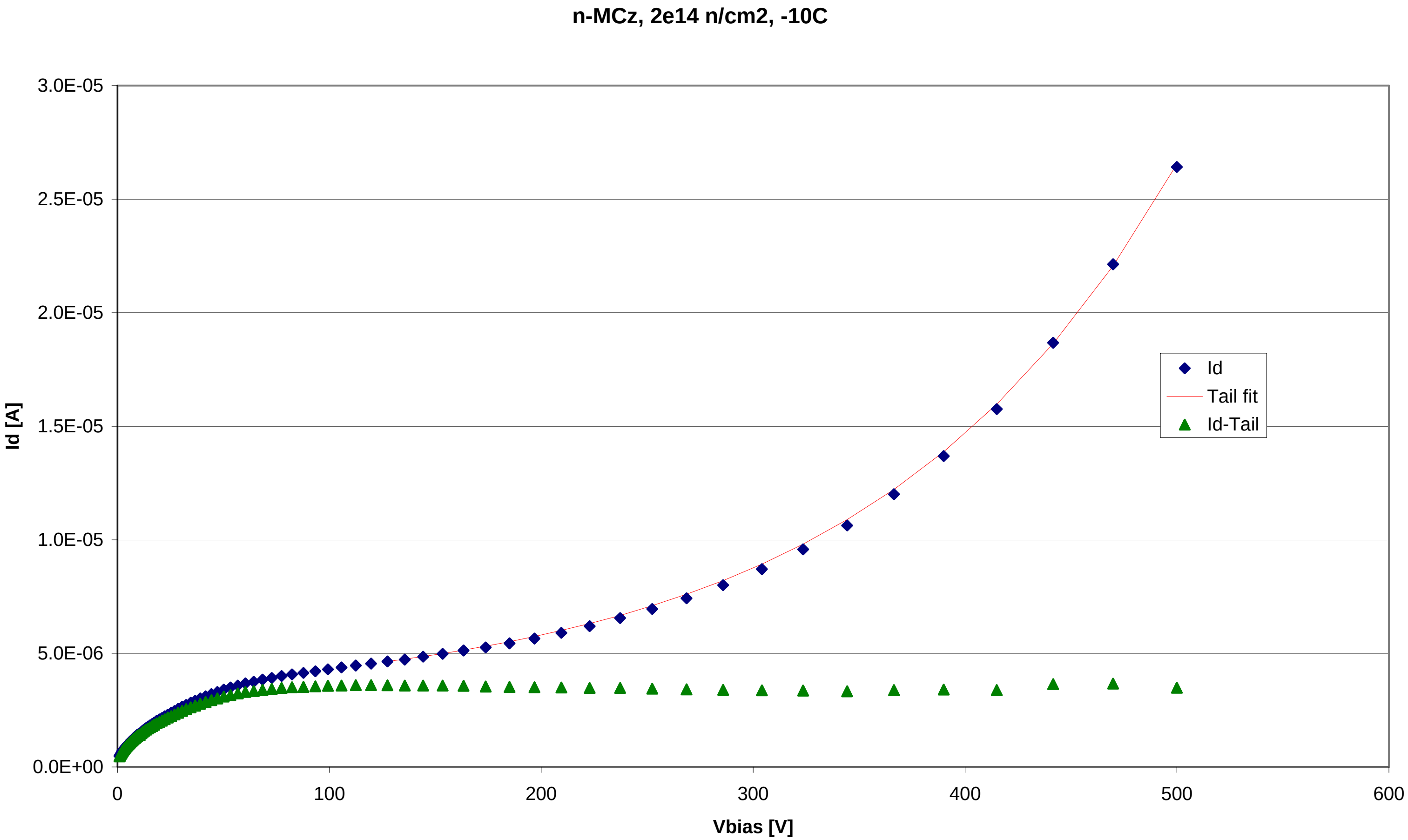
- Strong increase of leakage current;
- Micro-avalanches?
- $I_{20C}/L_{-10C} \approx 6$ at 500 V, expected value ~ 16;
- Wrong current scaling with temperature?

Tail subtraction:

$$I(V > V_{fd}) = I_{sat} + A \cdot [\exp(V/V_0) - 1],$$

where I_{sat} – saturated leakage current, A and V_0 – other fitting parameters

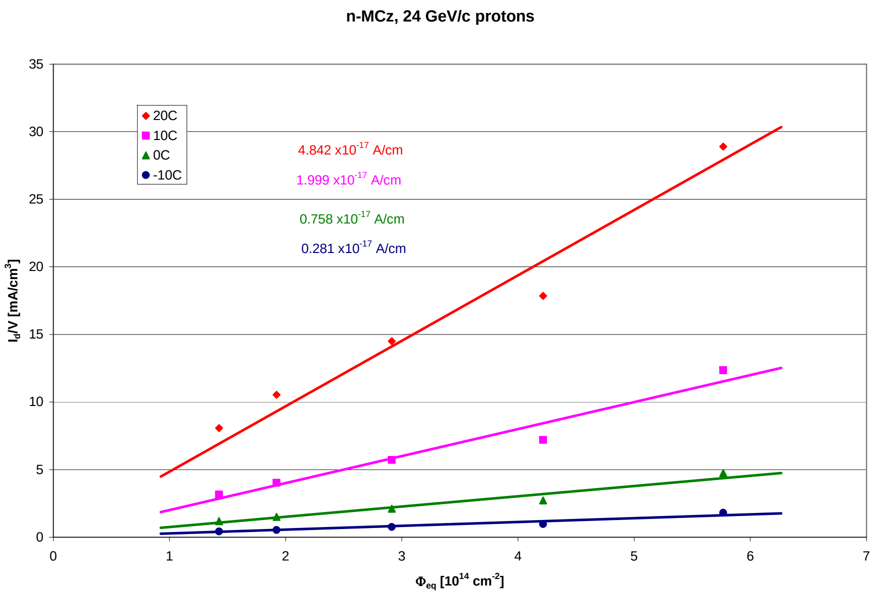
IV measurements: current fitting

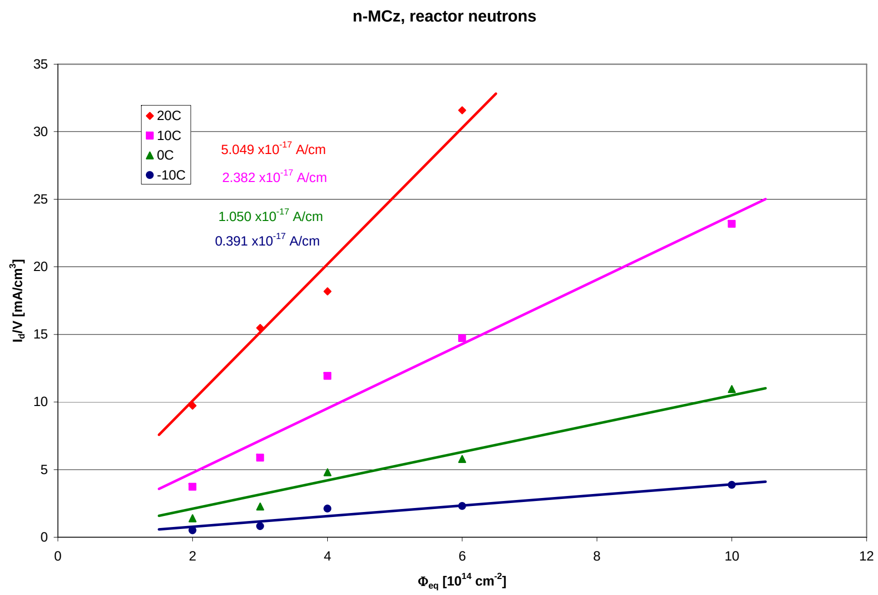


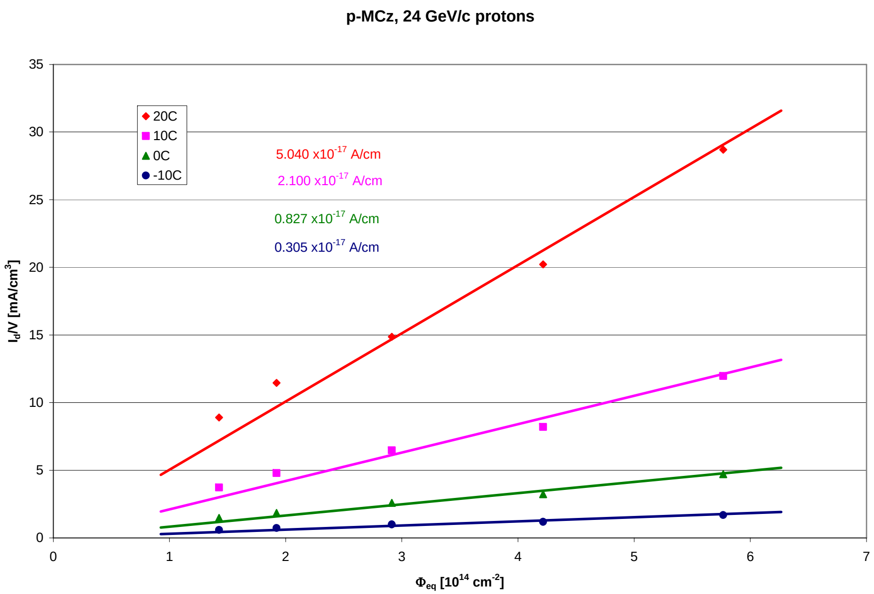
Example of tail subtraction:

- tail fits well with exponent;
- flat generation component;
- tail is much higher than generation current;
- fit worked for all IV curves

IV measurements: α values

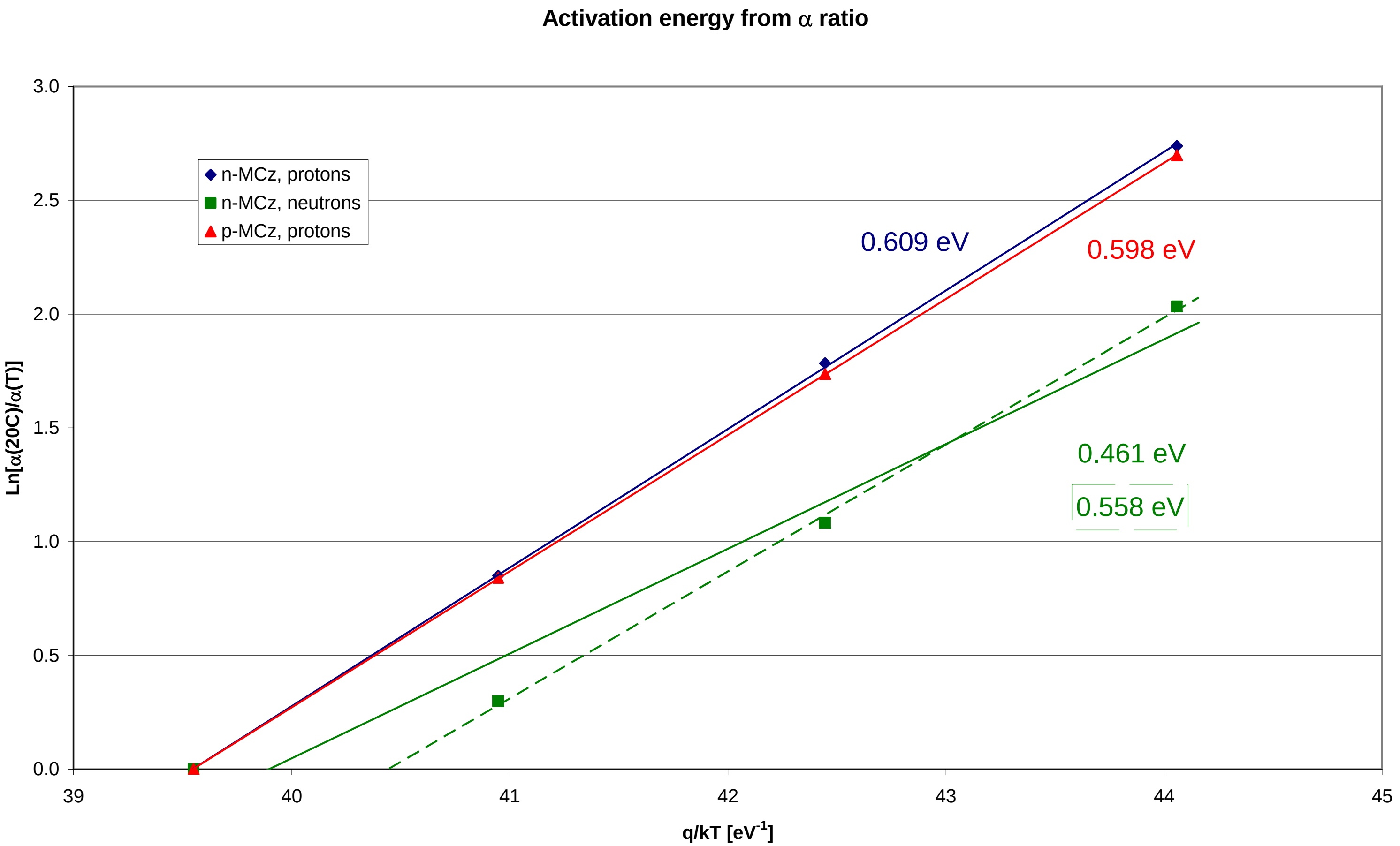






- Subtracted I_d fits linear with fluence
- $= I_d/V_{(olume)}/\Phi_{eq}$;
- good agreement for not annealed samples
  $\alpha(20°C) = (4.8\text{-}5.1)\cdot 10^{-17}$ A/cm

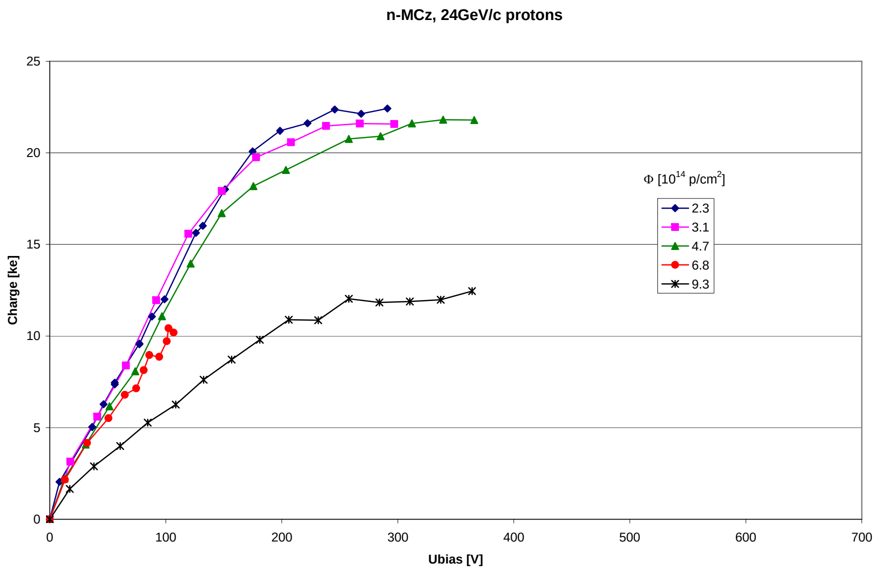
IV measurements: E_a for current scaling

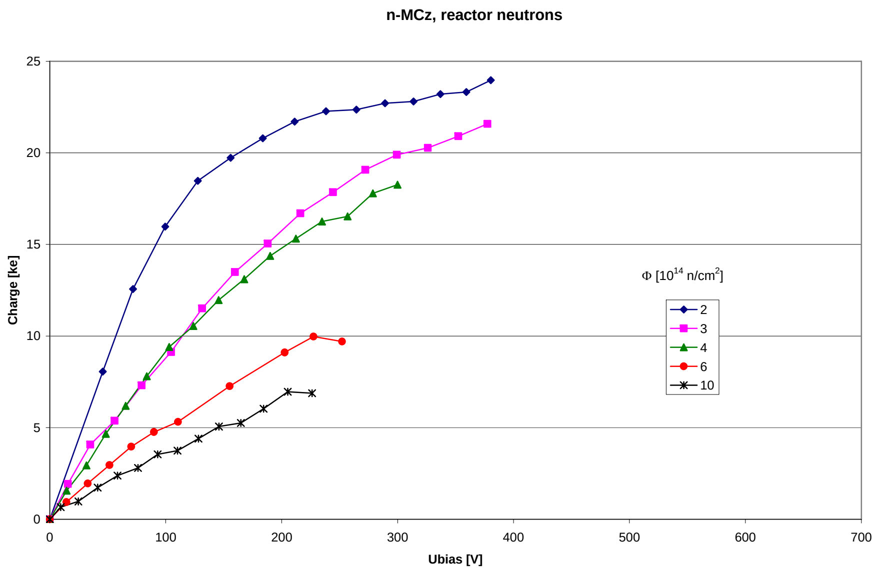


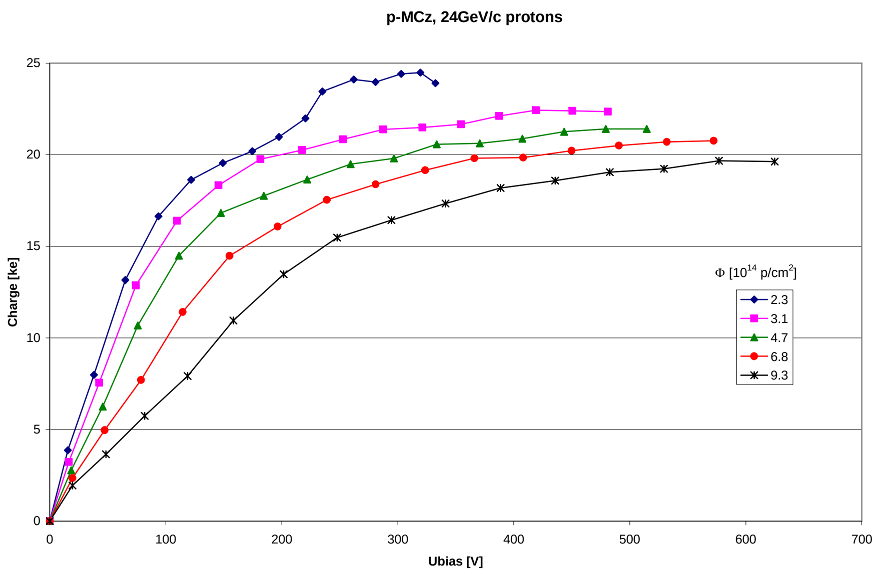
✓ Good linearity;

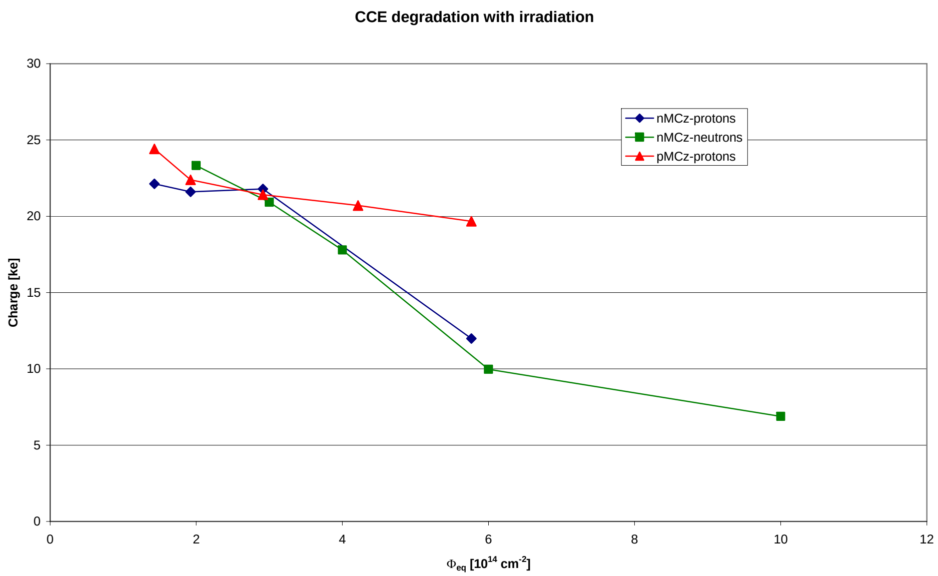
✓ E_a ~0.6 eV – as expected

Charge collection with beta-particles









Conclusions:

Electrical parameters of silicon diodes based on different type materials (n-MCz, p-MCz and n-Epi) and irradiated with charged particles and neutrons were studied at different temperature and frequency values

For CV the correspondence between T and f is not smooth

At least, from CV scaling it seems that Ea depends on material and irradiation type and fluence

For IV current rise due to “soft breakdown” can be successfully subtracted. Obtained generation current values scale well with the temperature