Temperature and Frequency Dependence of Electrical Parameters of Irradiated Silicon Diodes

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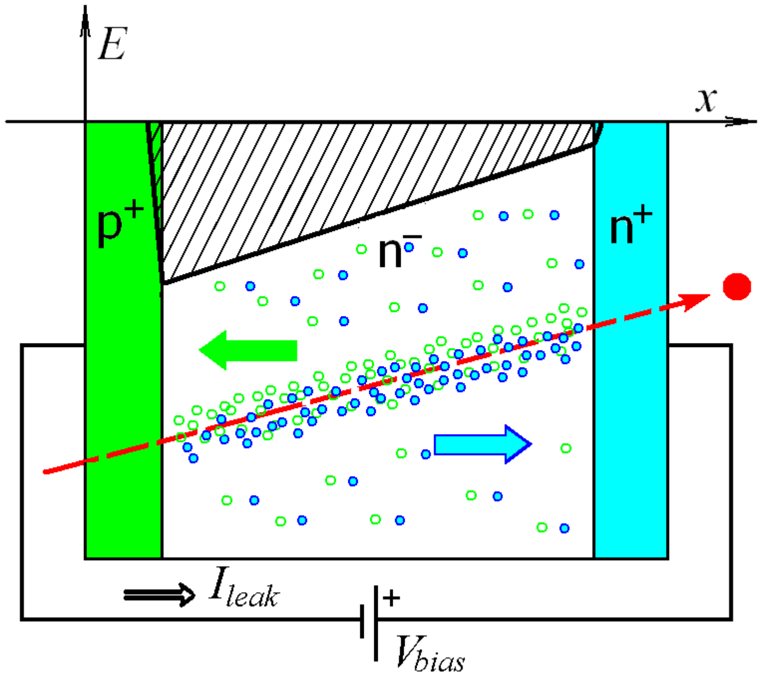
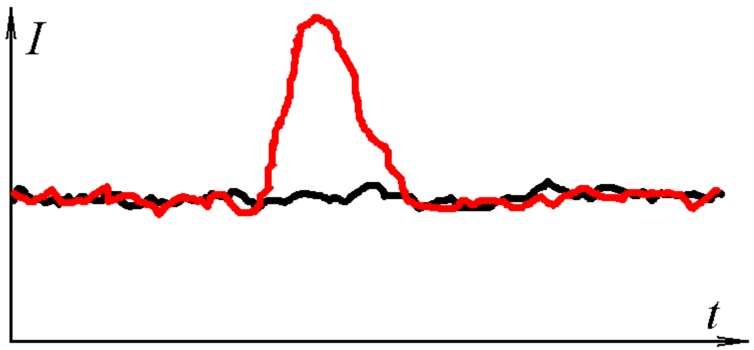
Outline:

- Main detector parameters
- Radiation damage
- Devices under test
- Scaling with temperature:
  - Leakage current
  - Frequency at CV measurement
- Charge collection and its correlation with CV measurement
- Conclusions

Main detector parameters





Fast hadrons (MIP):

$dE/dx \approx 80$ e-h/μm

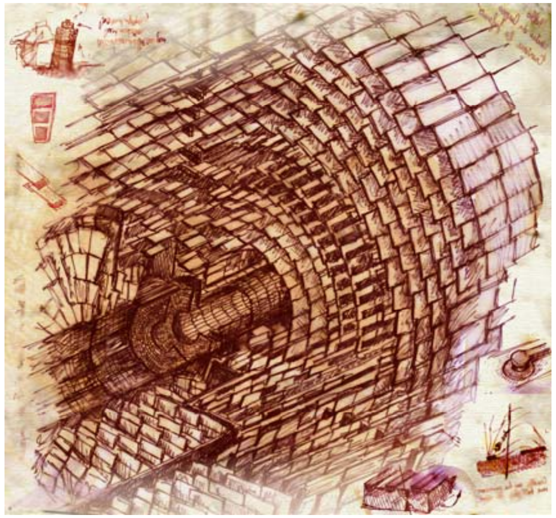
Charge $\propto d \propto \sqrt{V_{bias}} \propto 1/C$

S/N $\propto 1/I_{leak}$

Main parameters – measurement technique:

- Full depletion voltage – CV
- Leakage current – IV
- Collected charge – CCE with MIPs

Radiation damage in silicon



CMS Tracker – Silicon sensors:

- 17 thousand strip modules
- 45 million pixels

Total fluence for innermost layers:

- LHC **$3 \cdot 10^{15}$ cm^{-2}** during 10 years
- Super-LHC **$1.6 \cdot 10^{16}$ cm^{-2}** during 5 years

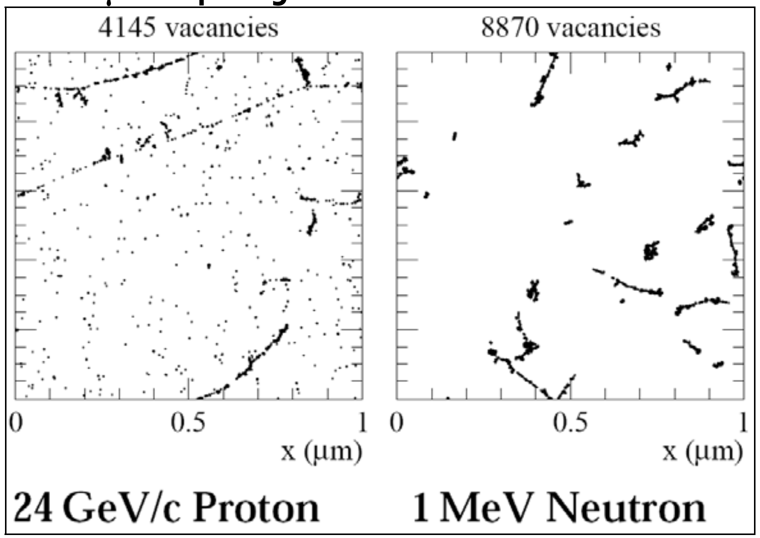
Extremely high radiation damage expected!

Fast hadrons – point defects and clusters:

- Depletion voltage increase
- Leakage current increase
- Signal charge trapping

Cooling is needed to decrease
leakage current →
proper temperature scaling required

1 μm project after 10^{14} cm^{-2}



M. Huhtinen, NIM A491 (2002)

Devices under test and measurement procedures

Type	Thickness [μm]	Resistivity [kΩ·cm]	Fluence [10^{14} cm^{-2}]	
			24 GeV/c protons	reactor neutrons
n-MCz	280	1	2-9	2-10
p-MCz	280	3	2-9	-
n-Epi-DO	100	0.3	-	1-40

CV/IV: at (20, 10, 0, -10)ºC;

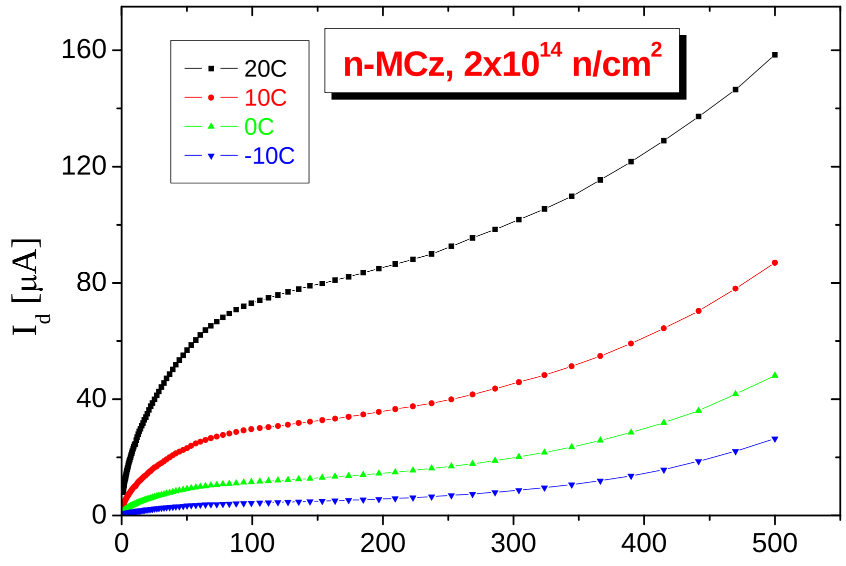
CV:

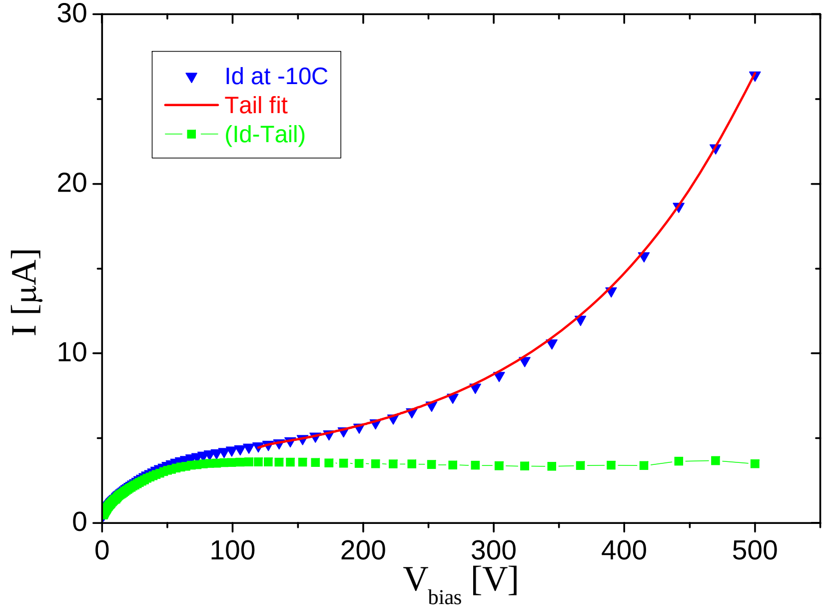
t [ºC]	f [kHz]
20	1-100
10	0.3-30
0	0.3-30
-10	0.1-10

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

MCz: CCE with Sr-90 β-particles

IV scaling: leakage current components





Generally used:

$$I(T) \propto T^2 \exp\left(-\frac{E_a}{kT}\right), \quad E \approx E_g/2$$

- Ratio $I(20^\circ C)/I(-10^\circ C)$:
  16 (expected)
  6 (observed at 500V)
- strong increase after full depletion – "soft breakdown"?

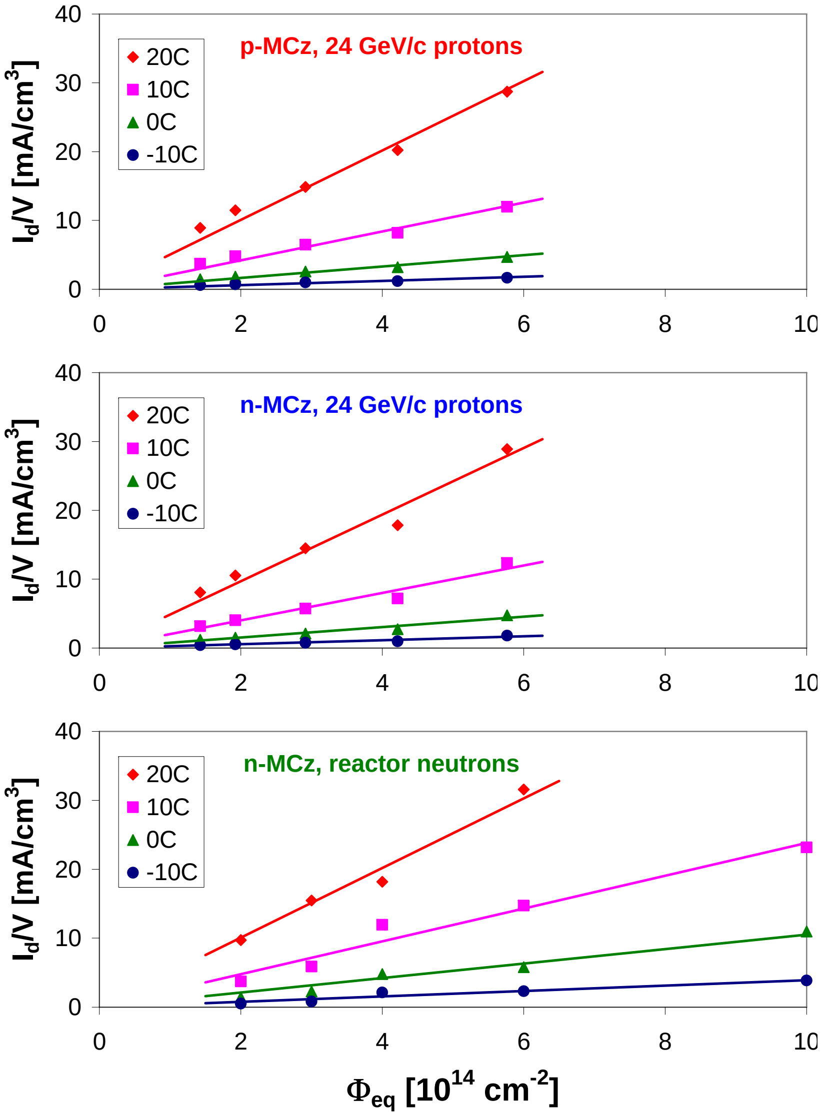
Tail subtraction:

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

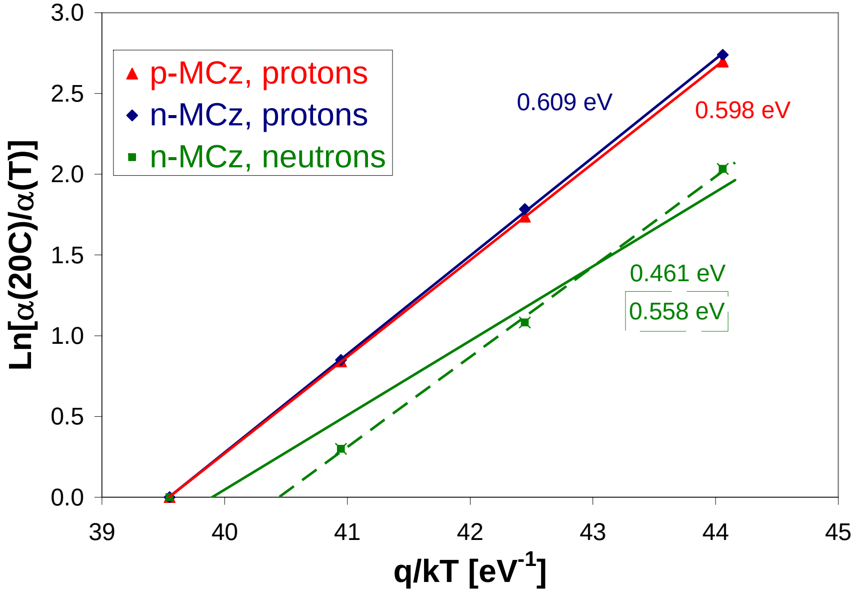
I_{sat} – saturated leakage current,
A and V_0 – tail fitting parameters

IV scaling: MCz material

Current density vs. Φ_{eq}



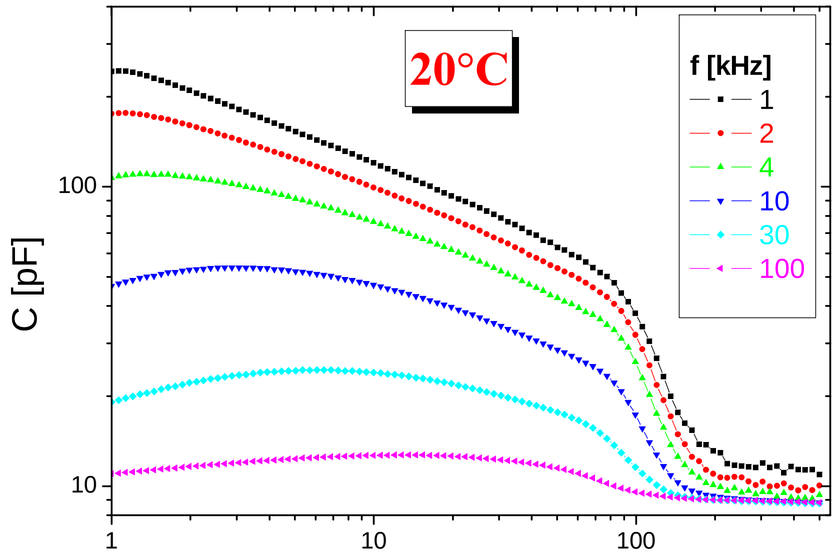
Arrhenius plot for α(T)

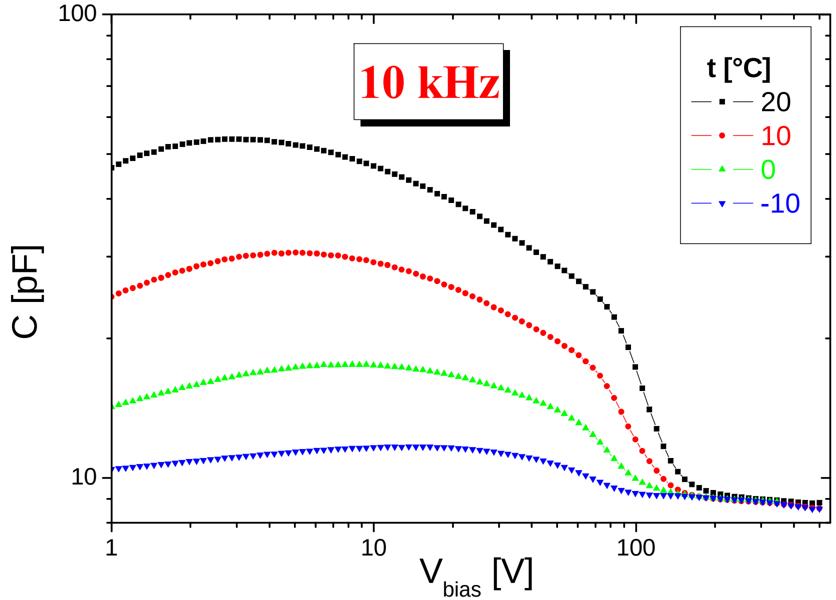


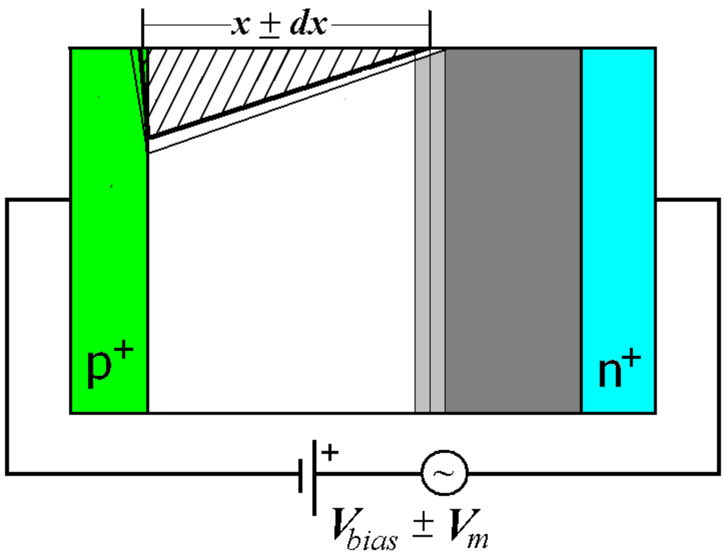
- I_d – linear with fluence;
- Good agreement for α at 20°C: $(4.8–5.1)\cdot 10^{-17}$ A/cm

Sample/ Irradiation	$\alpha = I_d/V_{(olume)}/\Phi_{eq}$ [10^{-17} A/cm] 20°C	10°C	0°C	-10°C	E_a [eV]
p-MCz/protons	5.04	2.10	0.83	0.30	0.598
n-MCz/protons	4.84	2.00	0.76	0.28	0.609
n-MCz/neutrons	5.05	2.38	1.05	0.39	0.558

CV scaling: approach







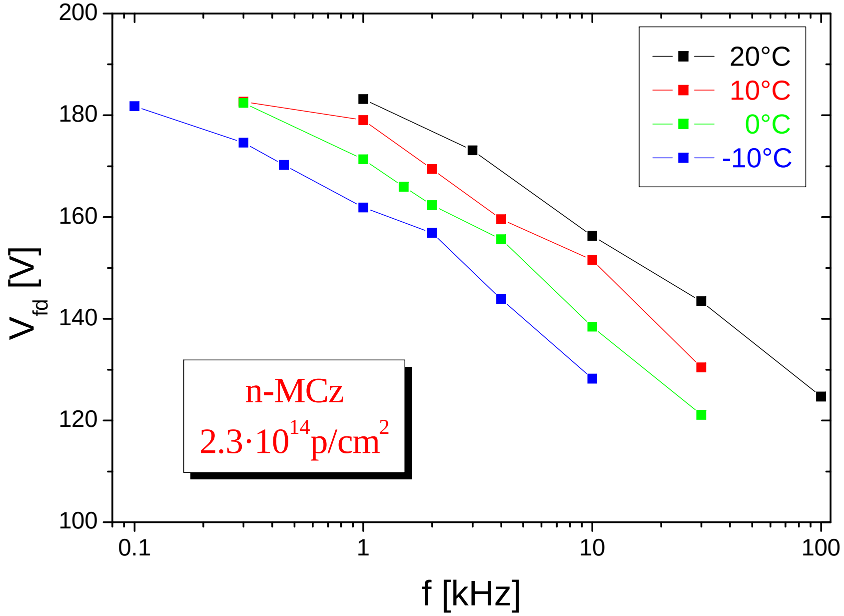
$$\mathbf{V = V_{bias} + V_m e^{i\omega t}}$$

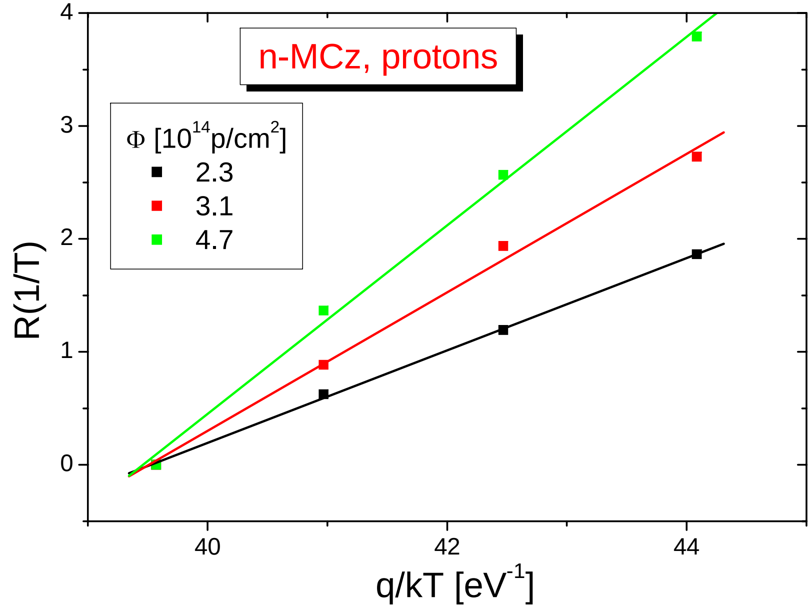
Defect response should depend not only on temperature, but also on frequency

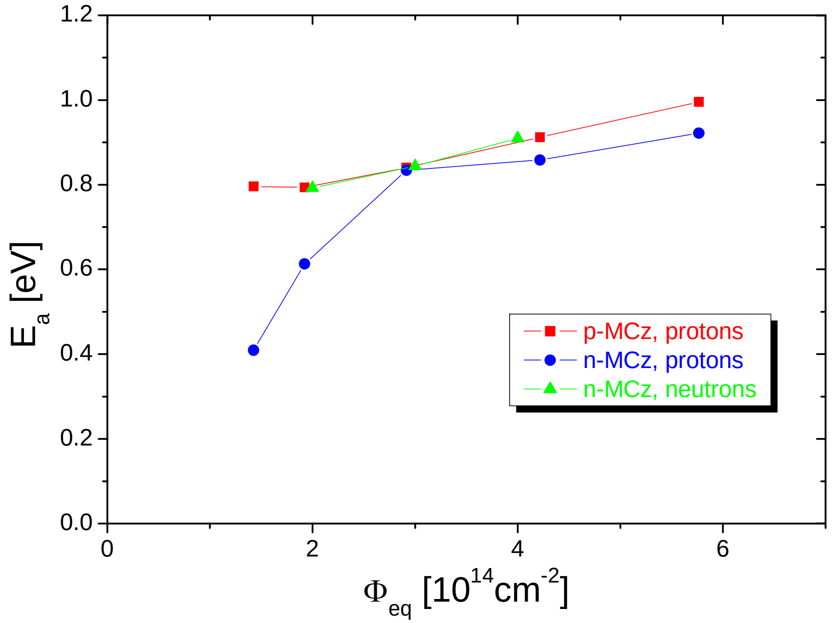
Petterson et al. (NIM A583):

$$f(T) \propto e_n(T) \propto T^2 \exp\left(-\frac{E_a}{kT}\right)$$

CV scaling: MCz material



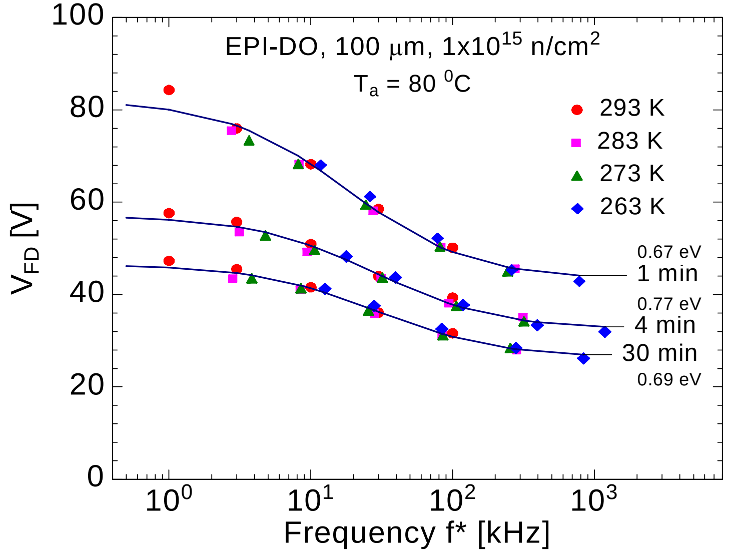


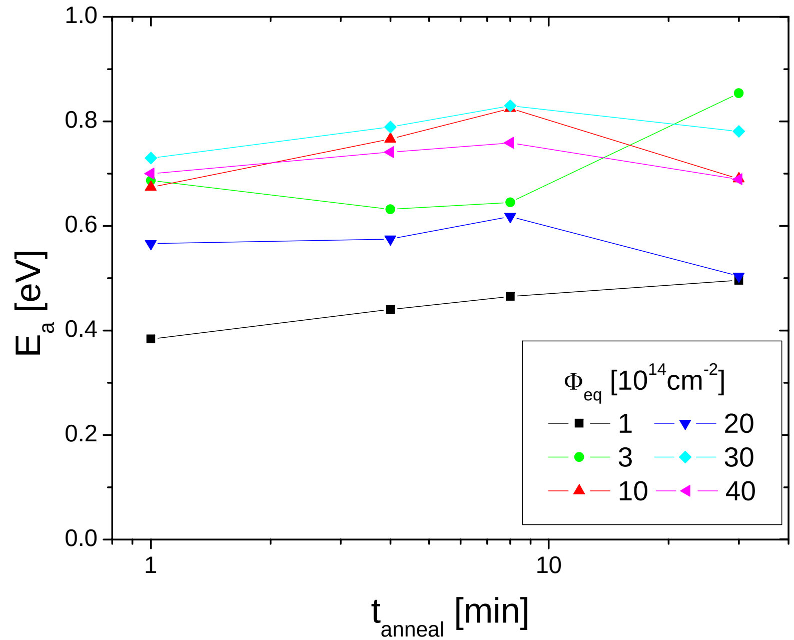


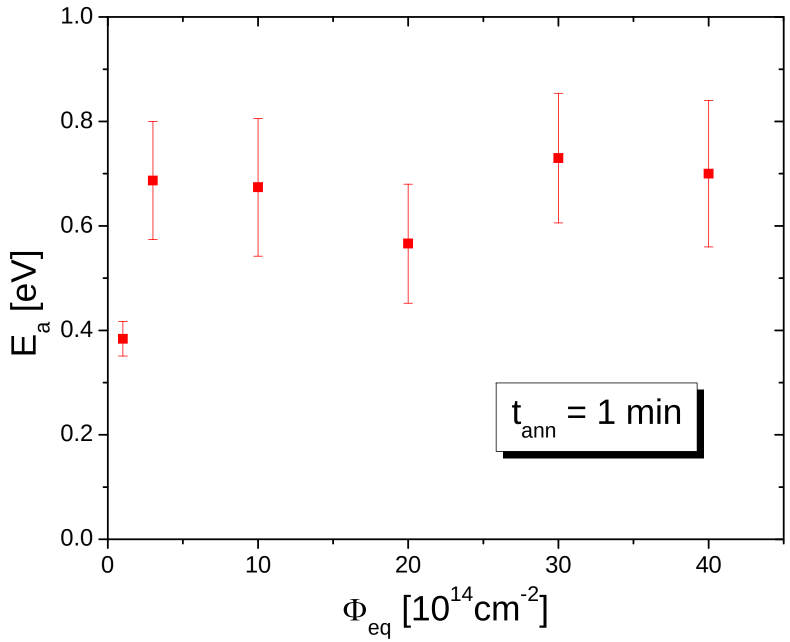
$$R\left(\frac{1}{T}\right) = \ln\left(\frac{f_{293K}}{f_T}\cdot\left(\frac{T}{293}\right)^2\right) = \frac{qE_a}{k}\left(\frac{1}{T} - \frac{1}{293}\right)$$

- E_a depends on: material, irradiation, fluence
- Generally larger (~ 0.8eV) then for current scaling (~0.6eV)

CV scaling: Epi-DO 100µm

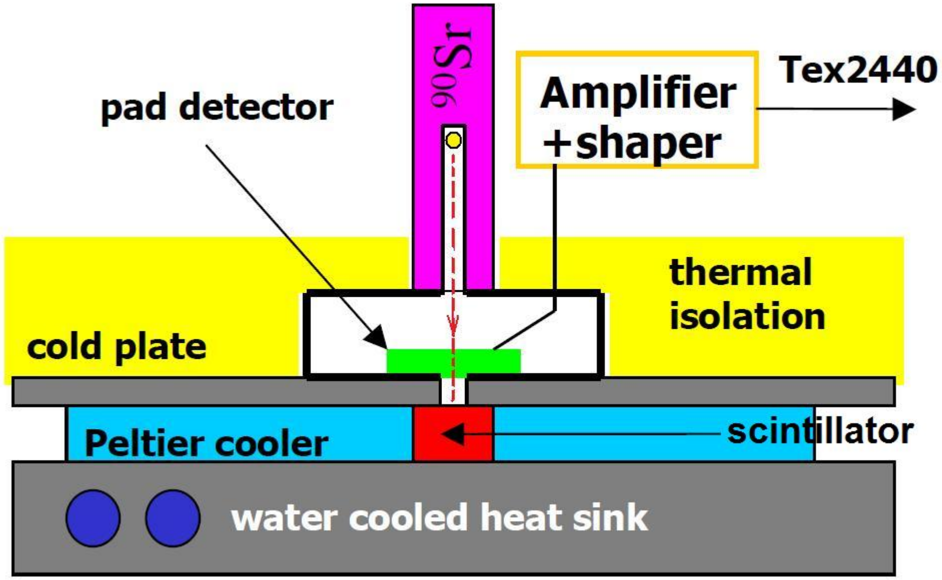


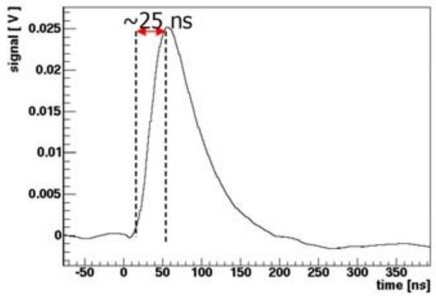




- $E_a(\Phi)$ is similar to MCz;
- $E_a(t_{ann})$ is different before ($<10^{15}cm^{-2}$) and after SCSI;
- Correlation with short-term annealing?

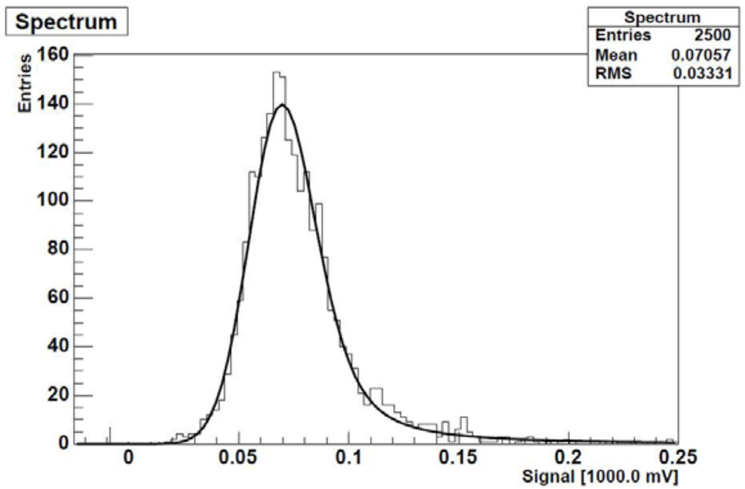
Charge collection with beta-particles



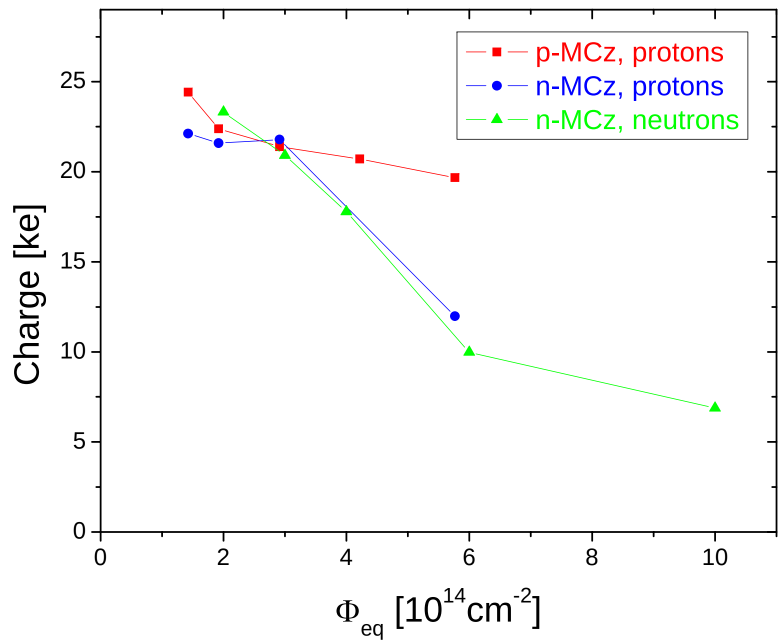


- 25 ns shaper;
- triggered by scintillator;
- cooling to -30°C

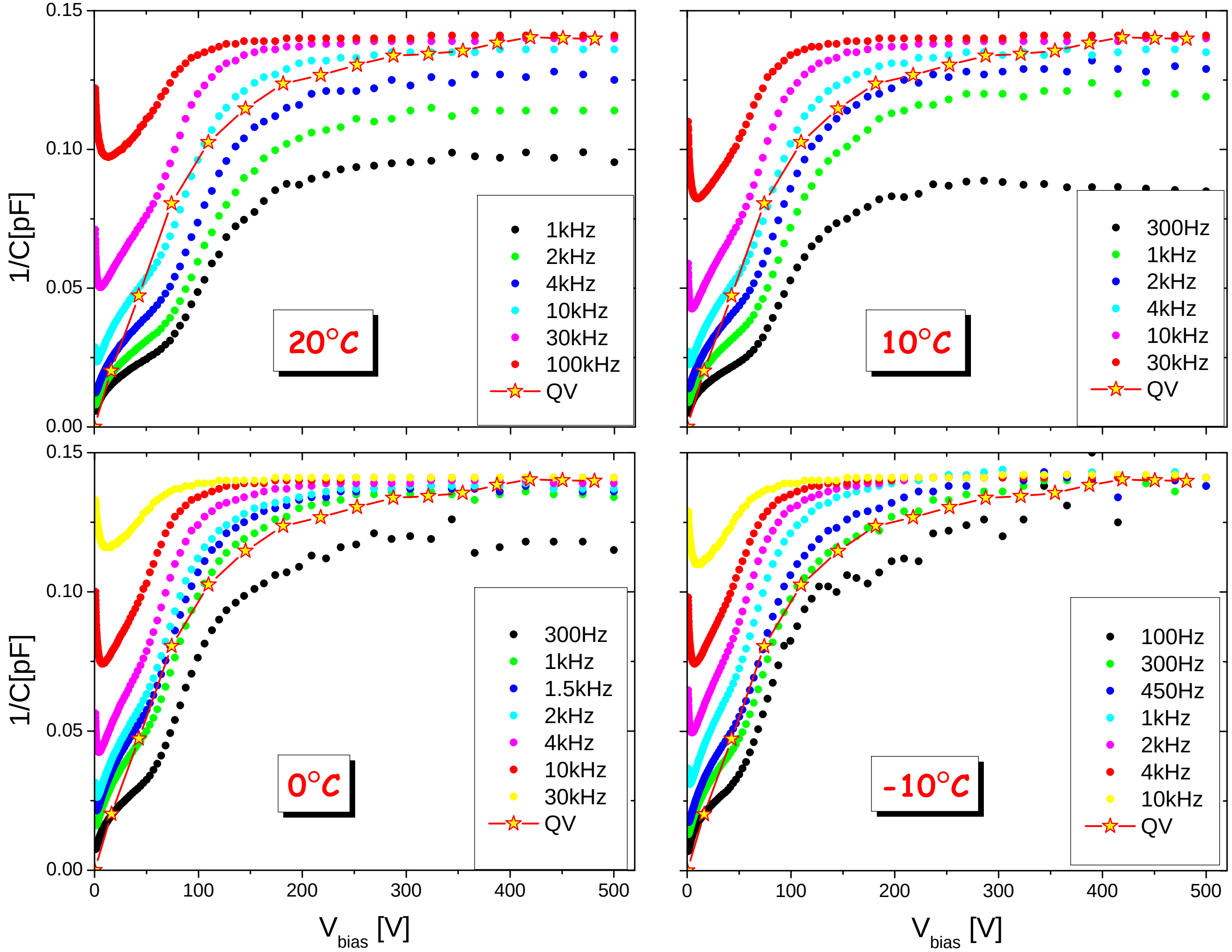
Landau-Gaussian convolution



CCE degradation with fluence



Correlation between Q(V) and 1/C(V)



p-MCz
$3.1 \cdot 10^{14} p/cm^2$
E_a = 0.793eV

t[°C]	f1[kHz]	f2[kHz]
20	10	10
10	4	3.1
0	1.5	0.87
-10	0.45	0.22

f1 – Petterson et al.
f2 – for given E_a

It works better!

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

They may be scaled with temperature using activation energy (E_a) concept

I(V) scales well with temperature if “soft breakdown” exponential tail is subtracted

For C(V) frequency scaling E_a values depend on material, irradiation type and fluence

Nevertheless, using proper E_a value Q(V) scales well with 1/C(V) measured at different temperature