Radiation hardness of thin high resistivity FZ silicon detectors in comparison to epitaxial silicon devices

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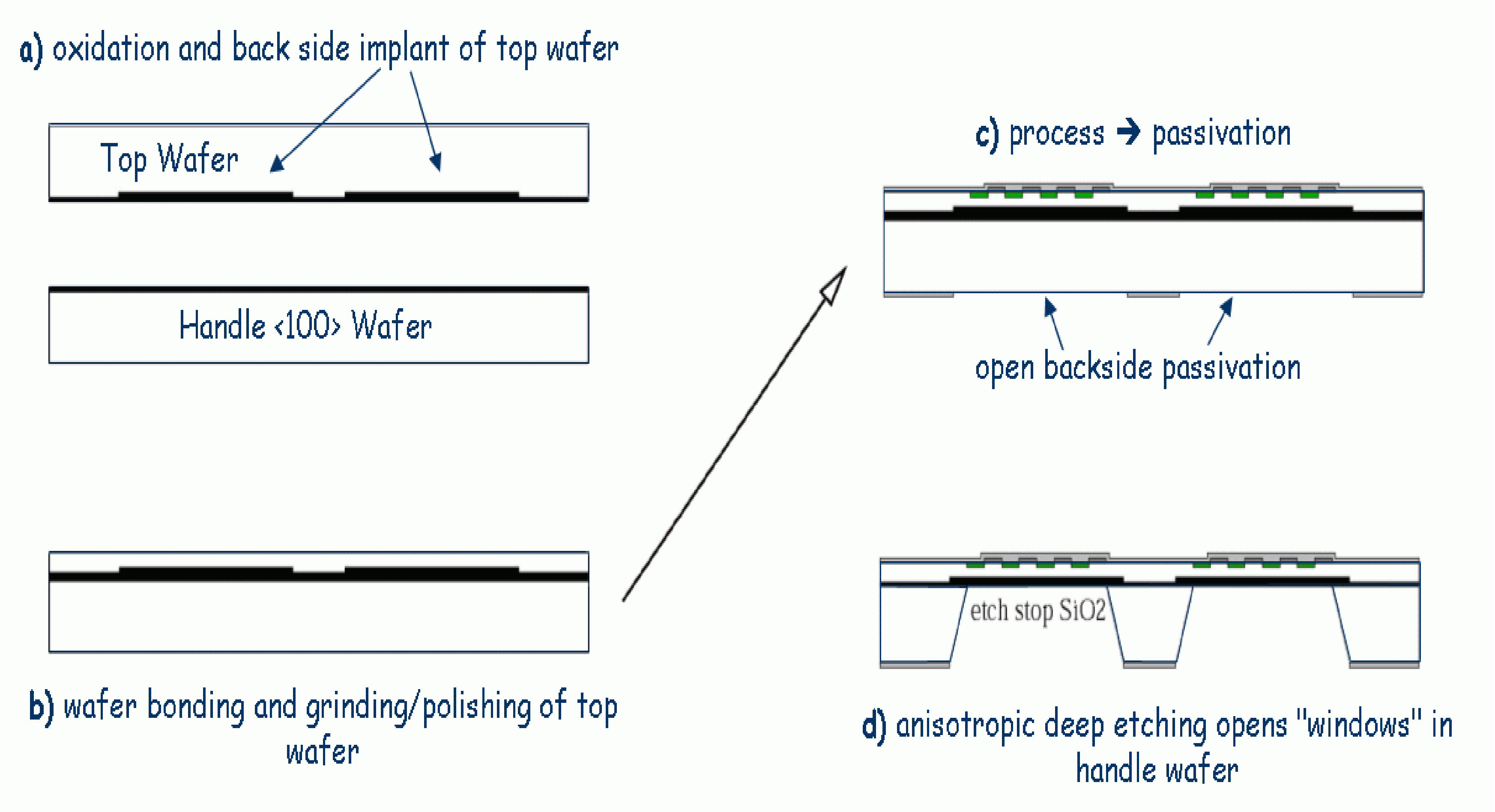
- **MPI device process technology**
- **Irradiation experiments**
- **First results on macroscopic properties**
- **Further investigations**

MPI Device Process Technology



a) oxidation and back side implant of top wafer

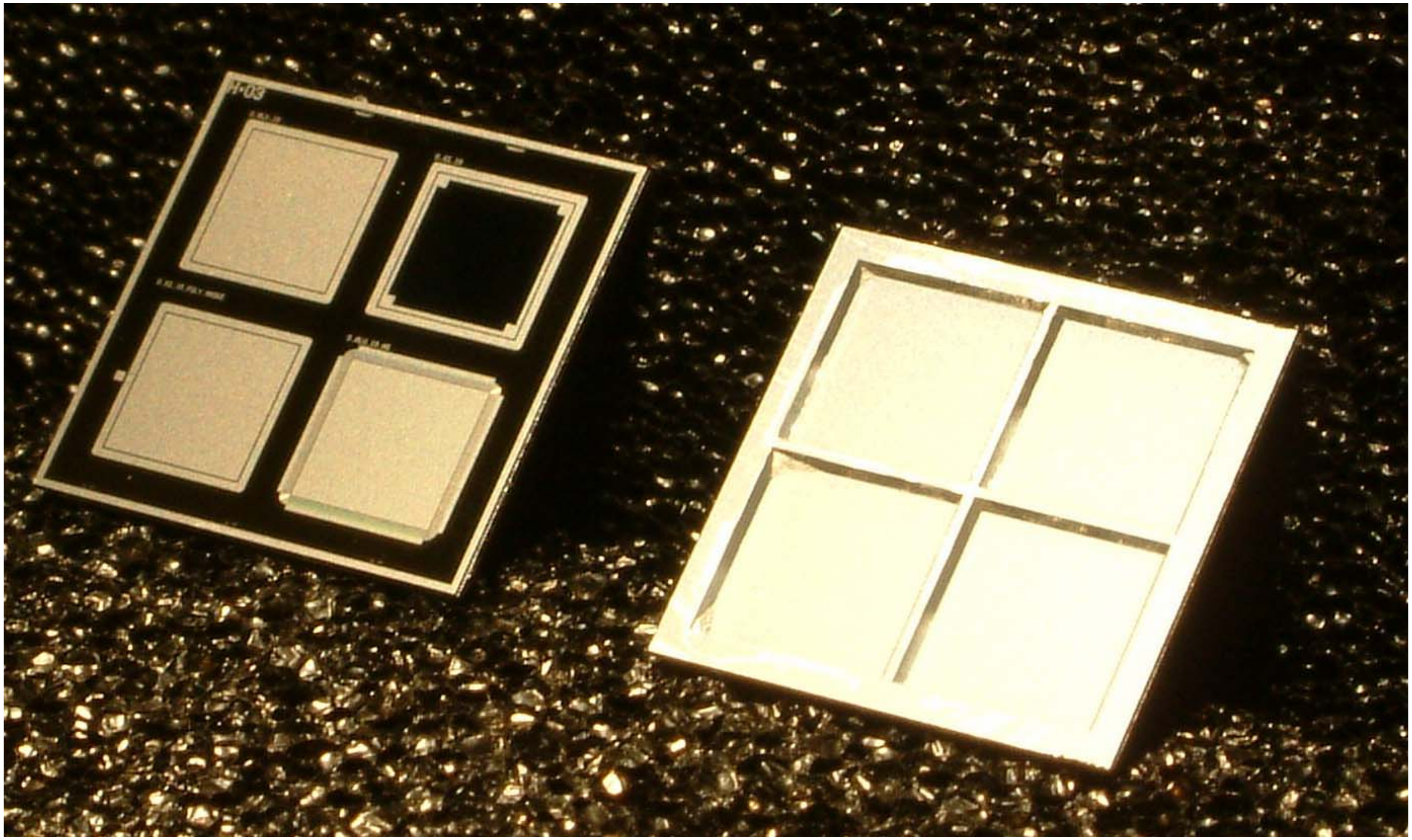
b) wafer bonding and grinding/polishing of top wafer

c) process → passivation

d) anisotropic deep etching opens "windows" in handle wafer

L. Andricek, MPI

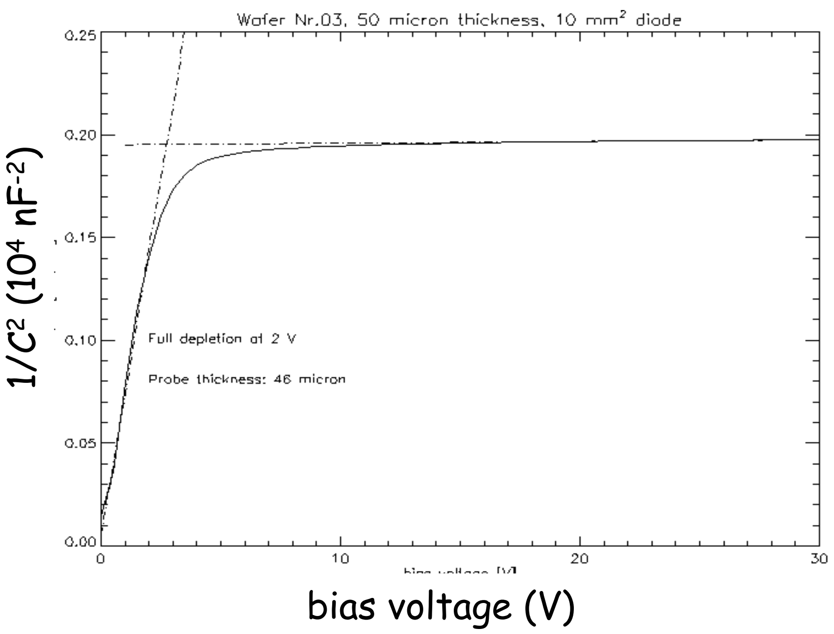
MPI chips after thinning process

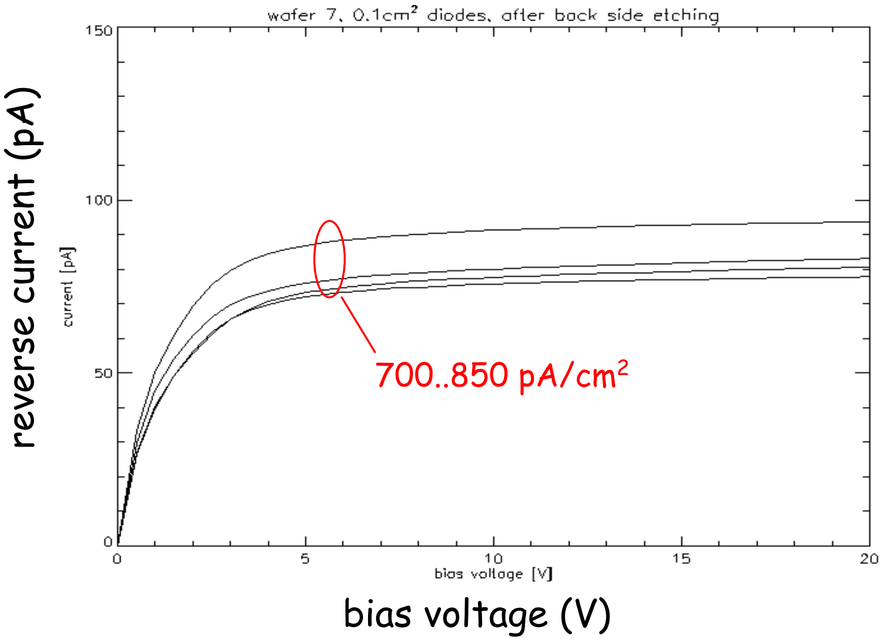


L. Andricek, MPI

Typical C/V and I/V characteristics of MPI chips

50 µm, type I diode, 10 mm²





700..850 pA/cm²

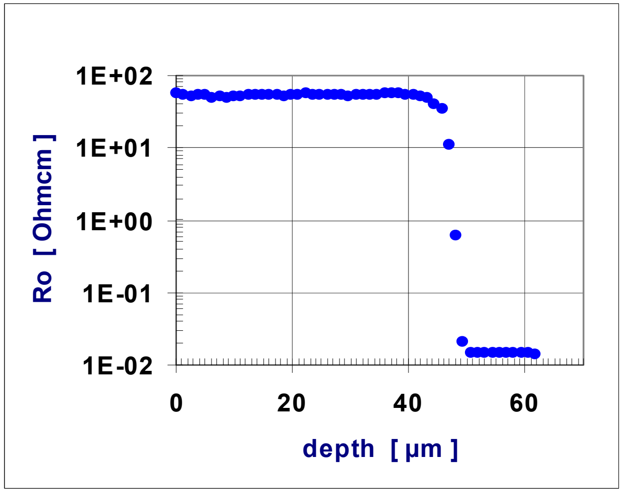
C(30V) ➔ d = 47 µm

ρ ≈ 4 kΩcm

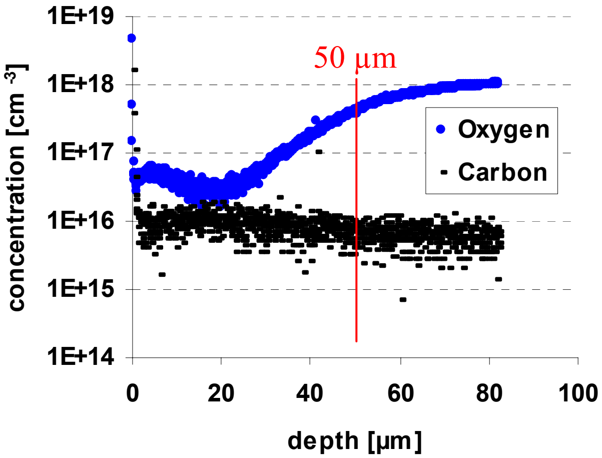
I_{rev}/V ~150 nA/cm³

L. Andricek, MPI

EPI – Silicon: Resistivity and Impurity Profiles



- **EPI-layer: n-type, P doped**
  <ρ> between 0-40 µm: 54.8 ± 2.1 Ωcm
  <ρ> after device process: 62.9 ± 2.8 Ωcm
  Thickness: 49.5 ± 1.6 µm
- **Substrate: n-type, Sb doped, <111>**
  ρ = 0.015 Ωcm
  Thickness: 320 µm

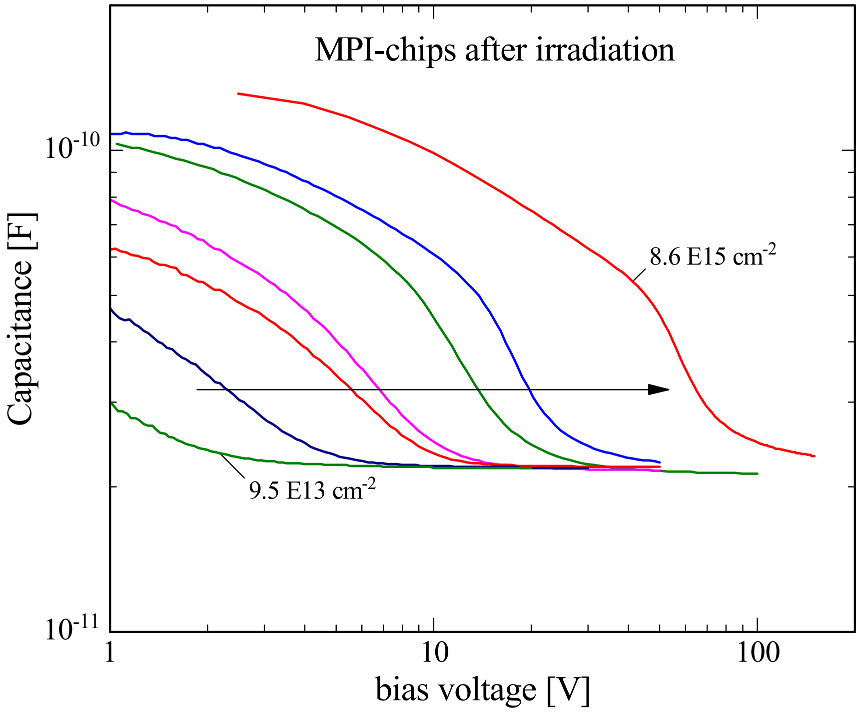


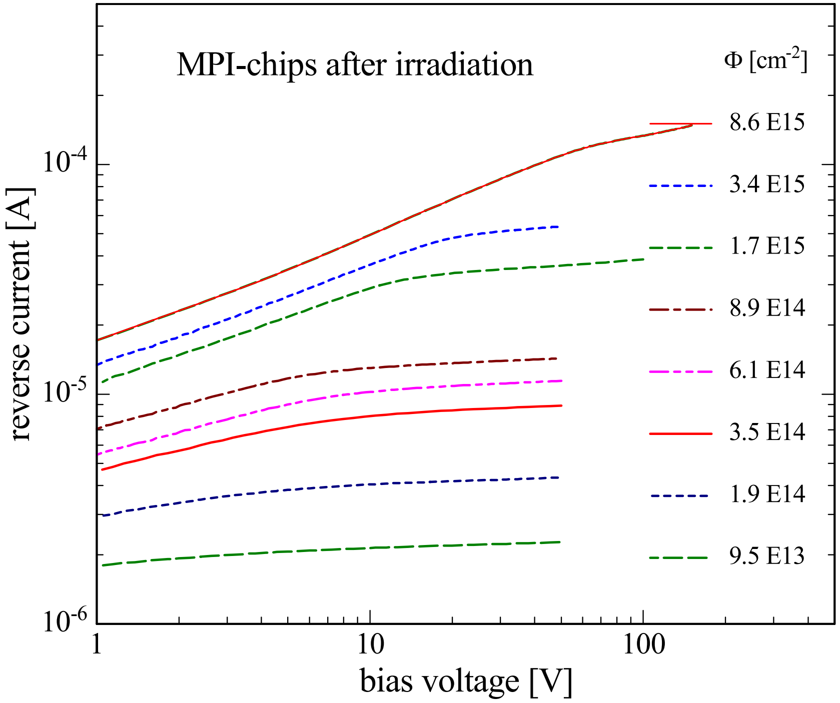
- **Oxygen diffusion from Cz-substrate into epi-layer**
  <[O]> ≈ 9×10^{16} cm^{-3} in epi-layer
- **Carbon concentration near detection limit**
  <[C]> ≈ 9×10^{15} cm^{-3}

Irradiation Experiment

- CERN PS irradiation period 2003
- Beam energy 20 GeV
- Fluence range: 10^{14} up to 10^{16} p/cm^2
- Multiple exposures in different runs

Typical I/V and C/V characteristics after irradiation





C/V presented in serial mode

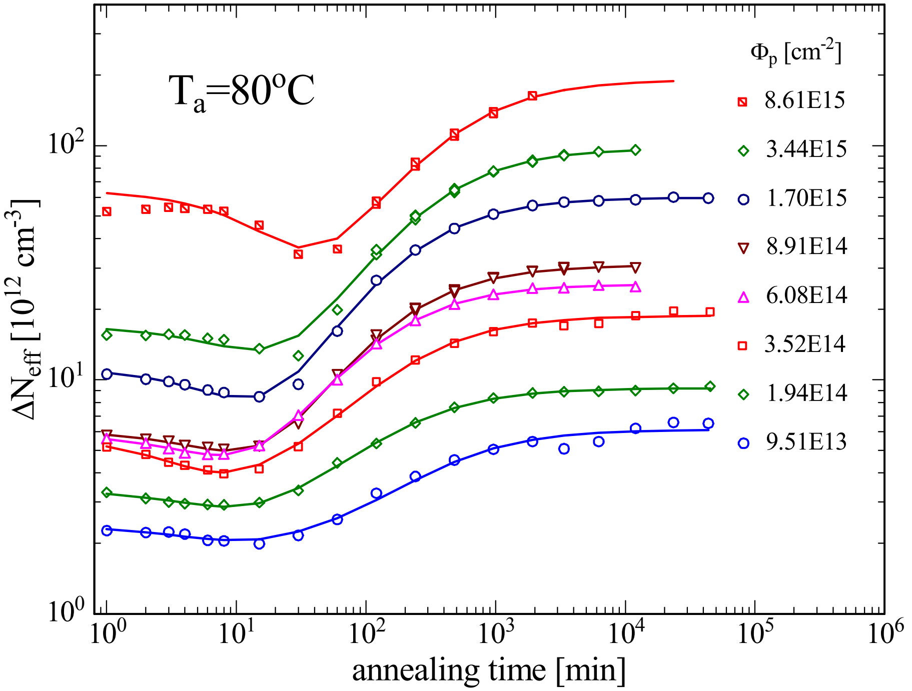
Frequency: 10 kHz

I/V measured with guard ring connected to ground, T≈ 21 °C

Annealing of ΔN_{eff} at 80°C

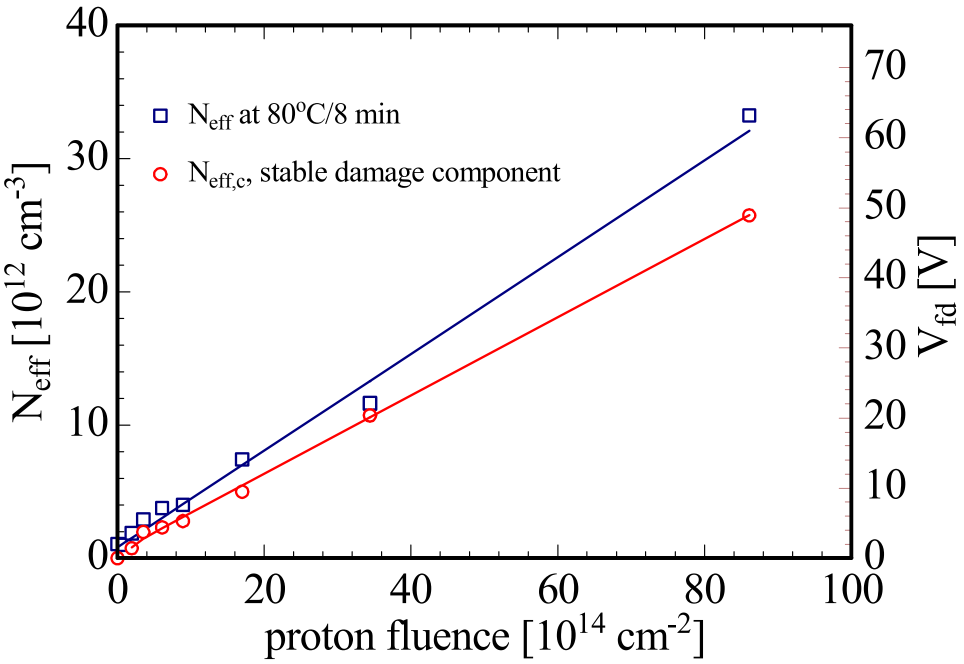
Standard parameterization: $\Delta N_{eff} = N_A(\Phi,T,t) + N_C(\Phi) + N_Y(\Phi,T,t)$

- **Minimum of annealing curve shifts for high fluences to larger annealing times**
- **Short term annealing component strongly suppressed in case of long exposures**
- **Time constant of long term annealing component (reverse annealing) increases with increasing fluence**
- **Stable damage component N_C and reverse annealing amplitude $N_{Y,inf}$ increases with increasing fluence**



N_{eff} at 80°C for 8 min and stable damage component N_C

20 GeV/c protons, fixed fluence values



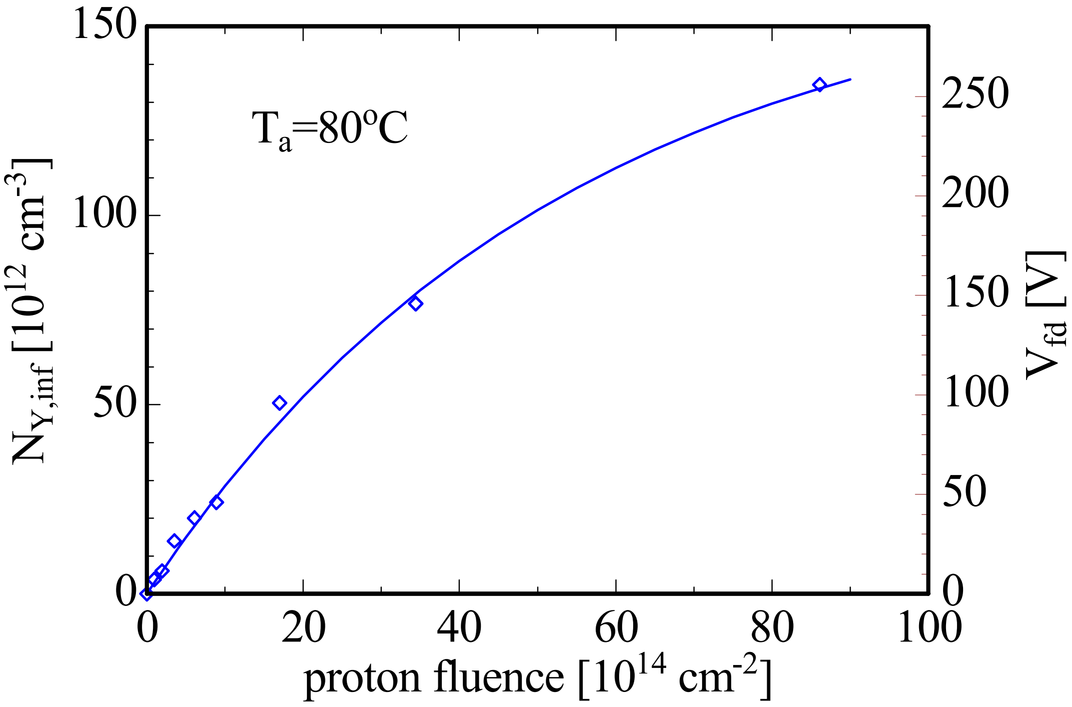
- Type inversion for all fluence values achieved ($\Phi_{min} = 9.5 \times 10^{13}$ p/cm²)
- $N_{eff}(\Phi) = N_{eff,0} \times \exp(-c \times \Phi) + \beta_{eff} \times \Phi$, $\beta_{eff} = \beta_{acceptor} - \beta_{donor}$

$\beta_{eff} = 3.6 \times 10^{-3}$ cm^{-1} , comparable with DOFZ

$g_C = 2.9 \times 10^{-3}$ cm^{-1}

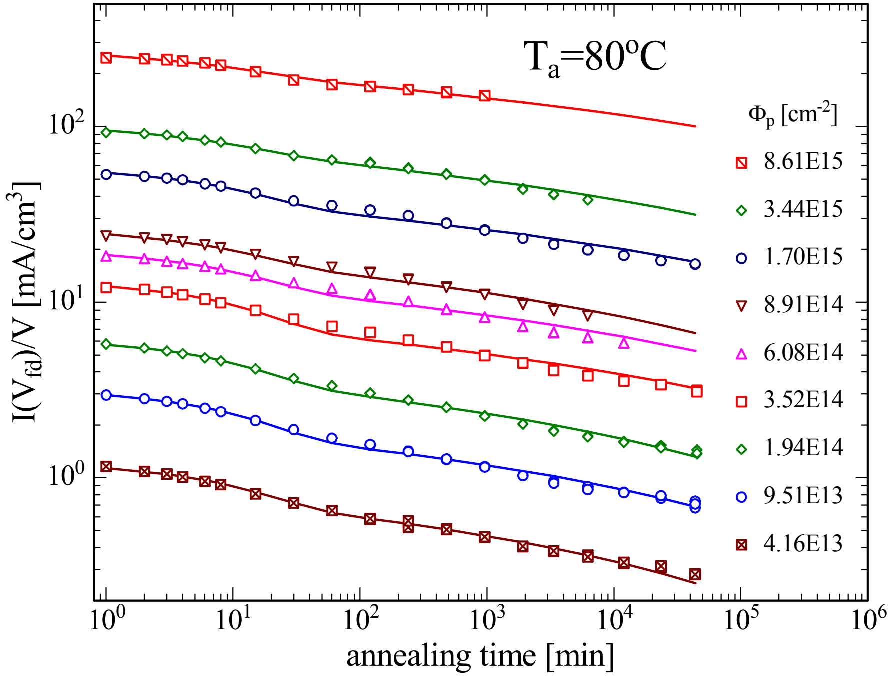
Reverse annealing amplitude N_Y

20 GeV/c protons, fixed fluence values



- Reverse annealing amplitude shows saturation effect at very high fluences like DOFZ silicon
- $N_Y(\Phi) = N_{Y,inf} \times \{1 - \exp(-c_y \times \Phi)\}$: $c_y = 1.87 \times 10^{-16}$ cm^2, $N_{Y,inf} = 1.67 \times 10^{14}$ cm^{-3}

Reverse current annealing at 80°C



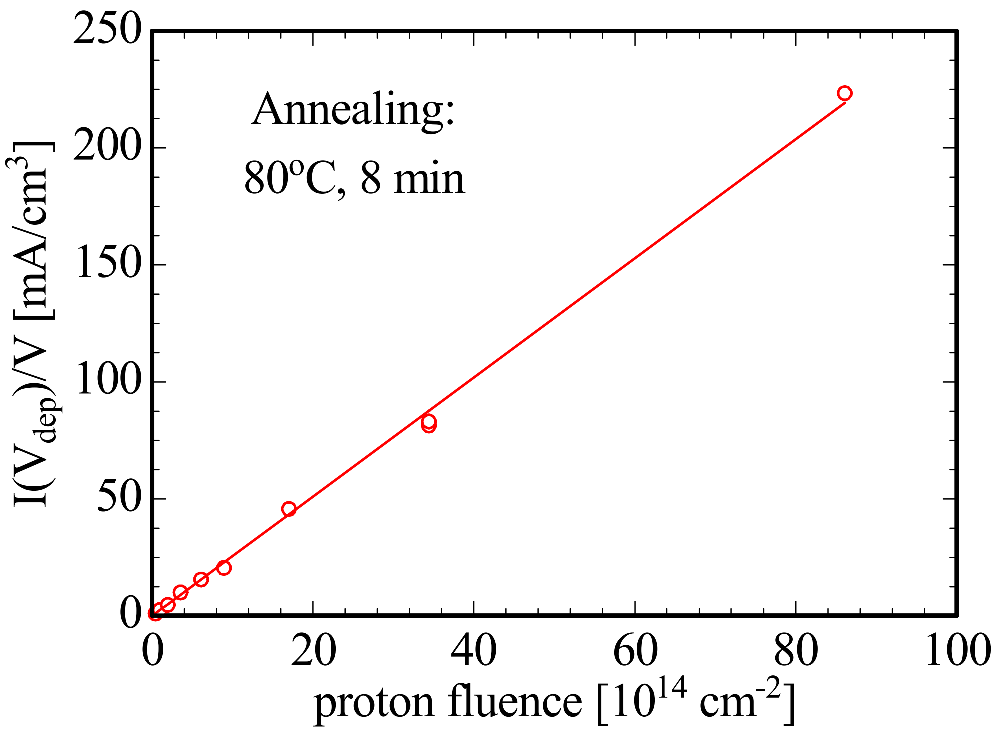
- **Time dependence of I_{rev} annealing quite similar for all fluences**
- **Short term annealing region:** **at high fluences short term annealing amplitude suppressed**
- **Long term annealing region:** **time dependence independent of fluence**

Parameterization:

$$I(V_{fd})/V(\Phi,T,t) = \alpha(T,t)\times\Phi = a_I(\Phi,T) \times \exp(-t/\tau_I) + \{a_0(\Phi,T) - b(\Phi,T) \times \ln(t/t_0)\}$$

short term annealing + long term component

Reverse current after annealing at 80°C for 8 min

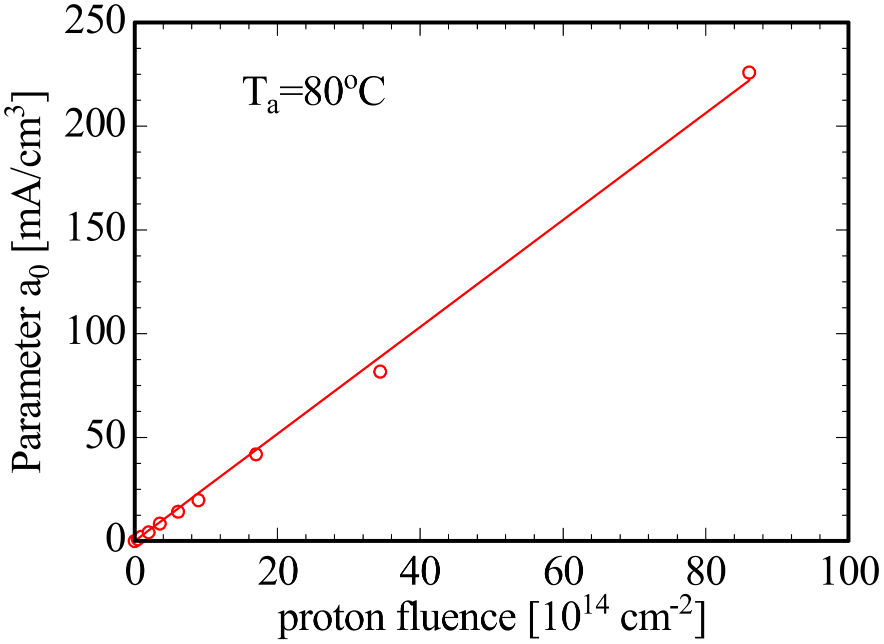


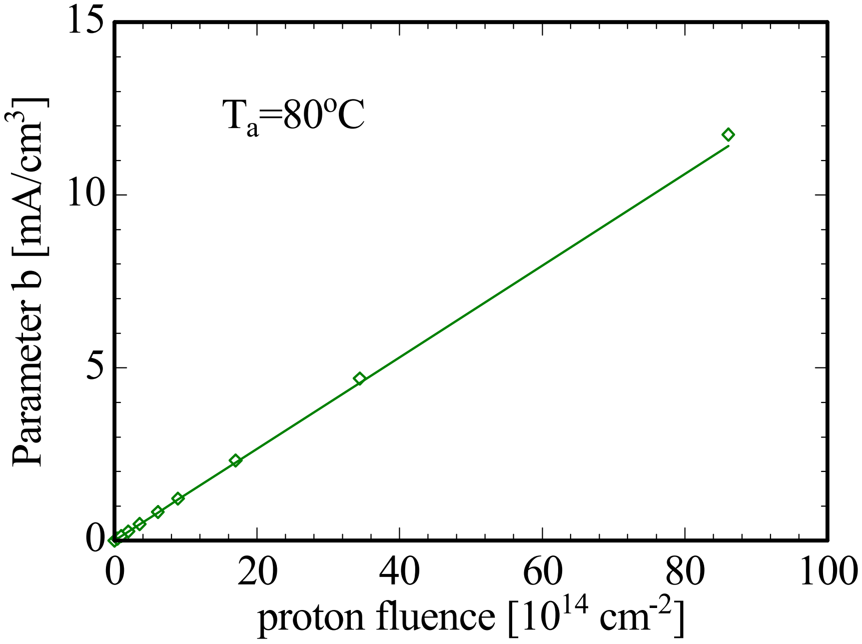
Reverse current increase universal for all silicon materials

- **Parameterization:** $I(V_{fd})/V = \alpha(T=80°C, t=8min) \times \Phi$

$\alpha = 2.43 \times 10^{-17}$ **A/cm** → $\alpha_{eq} = 3.91 \times 10^{-17}$ **A/cm (1 MeV neutron eq.)**

Reverse current annealing parameter





- **Parameter a_0 and b: linear dependent on fluence**

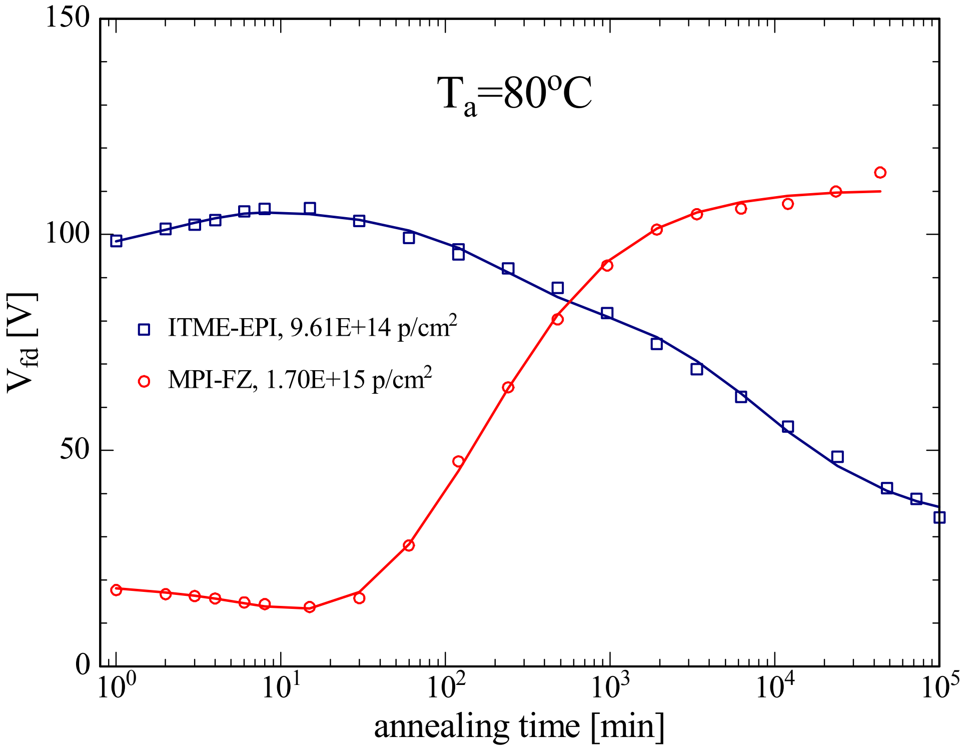
  Corresponding normalized values:

  $$\alpha_0 = a_0/\Phi = 2.6\times10^{-17}\ \text{A/cm} \quad \rightarrow \quad \alpha_{0,eq} = 4.2\times10^{-17}\ \text{A/cm}$$

  $$\beta = b/\Phi = 0.13\times10^{-17}\ \text{A/cm} \quad \rightarrow \quad \beta_{eq} = 0.21\times10^{-17}\ \text{A/cm}$$

Annealing behavior of V_{fd}

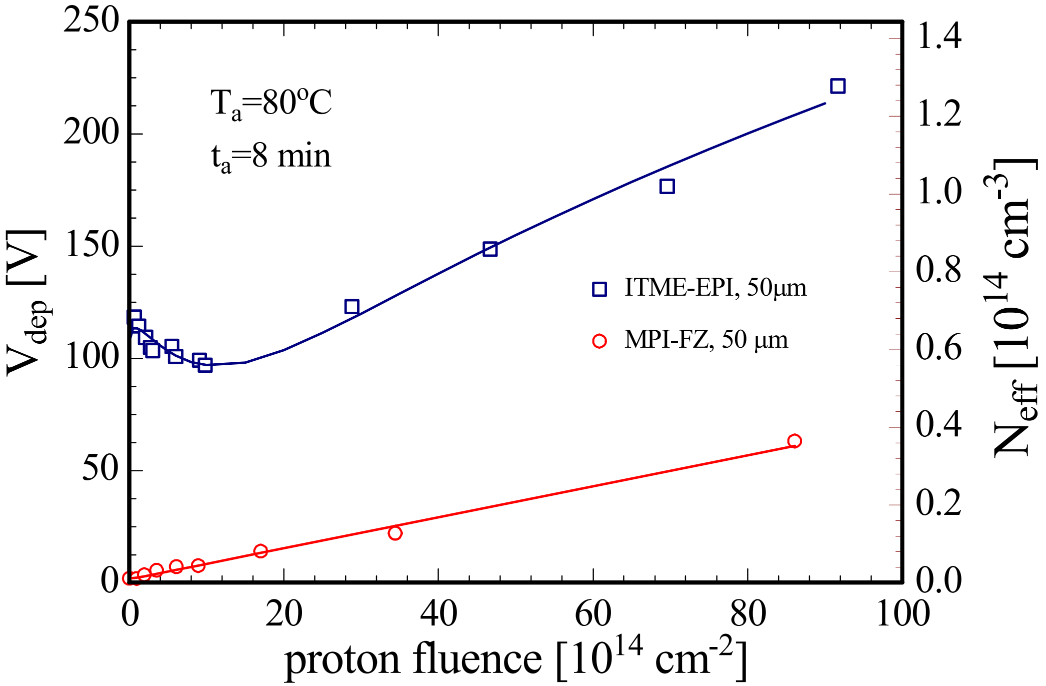
MPI-chip in comparison with EPI device



- **MPI chip: short term decrease, long term increase → type inverted**
- **EPI device: short term increase, long term decrease → not type inverted**

Fluence dependence of V_{fd} for MPI-chips and EPI devices

Annealed at 80°C for 8 min



- **Effective introduction rates at high fluences:**

for MPI: β_{eff} = 0.0036 cm^{-1}, type inverted , β value comparable with DOFZ-Si
for EPI: β_{eff} = 0.0084 cm^{-1}, not type inverted, shallow donor creation

FURTHER INVESTIGATIONS

- **Studies on Charge Collection Efficiency (CCE)**
  Understanding of trapping effects at very high damage levels

- **Studies on possible non-uniformities in thin FZ and EPI-silicon**
  Space charge density (shallow n-type layer at the p-n junction),
  Thermal donor profile, is hydrogen involved?
  What is the reason for the time shift in the reverse annealing?

  ***Microscopic studies*:**
  Understanding of radiation induced generation of shallow donors (type of TD´s) and deep acceptors responsible for detector performance
  Correlation of trapping with defects

- Next steps:
  Irradiation and investigation of 25µm & 75µm thick 50 Ωcm EPI-layers
  Processing and investigation of 50µm EPI-layer on low resistivity FZ-Si