Bulk damage effects in standard and oxygen enriched silicon induced by Co-60 gamma radiation

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1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders

CERN 28-30 November 2001

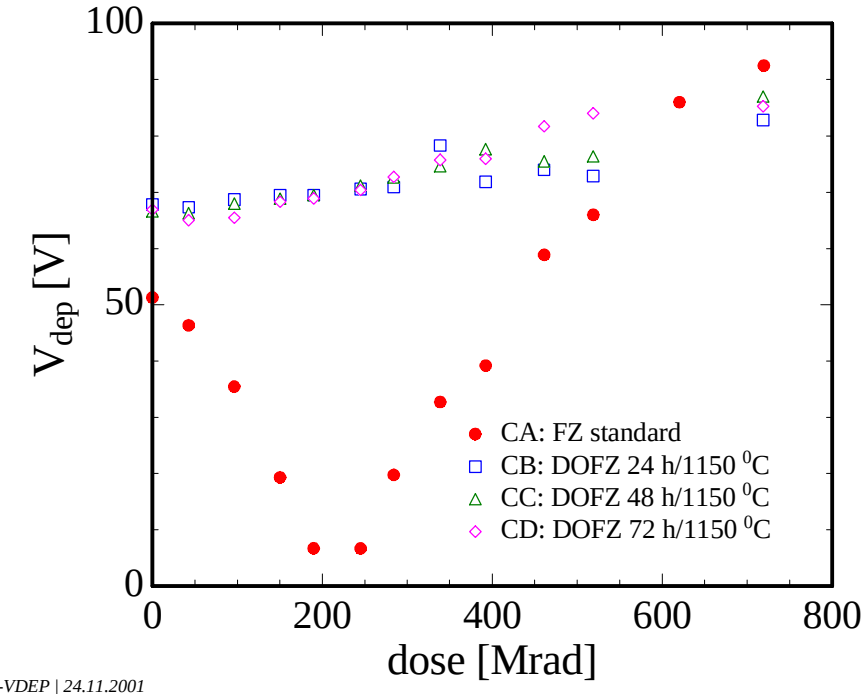
MATERIAL AND IRRADIATION

- **Material:**
  - a) Wacker, FZ n-type, <111>, 4 kΩcm, CIS standard process
  - b) Wacker, FZ n-type, <111>, 4 kΩcm, CIS DOFZ process (24h, 48h, 72h at 1150^{0}C)
  - c) Wacker, FZ n-type, <100>, 4 kΩcm, CIS standard process
  - d) Wacker, FZ n-type, <100>, 4 kΩcm, CIS DOFZ process (24h, 48h, 72h at 1150^{0}C)
  - e) Wacker, FZ n-type, <111>, 15 kΩcm, standard process (Micron)
  - f) Wacker, FZ n-type, <111>, 3 kΩcm, DOFZ process + TD (Micron) (TD: thermal donors)

- **Irradiation:**
  BNL high intensity Co-60 source
  Dose rate: 600 krad per hour
  Dose range: 0 – 720 Mrad
  Irradiation at room temperature

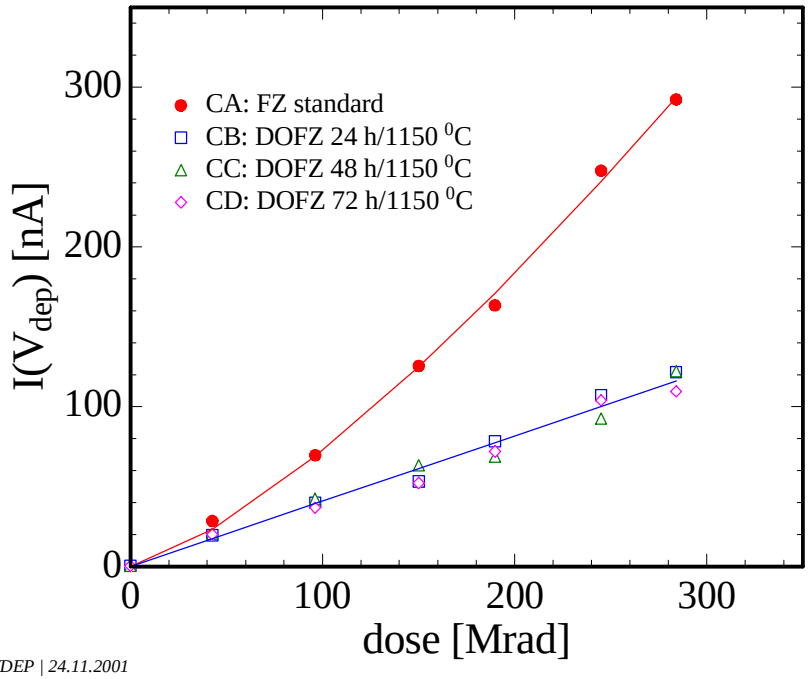
CIS <111> DOSE DEPENDENCE

DEPLETION VOLTAGE



111-VDEP | 24.11.2001

REVERSE CURRENT



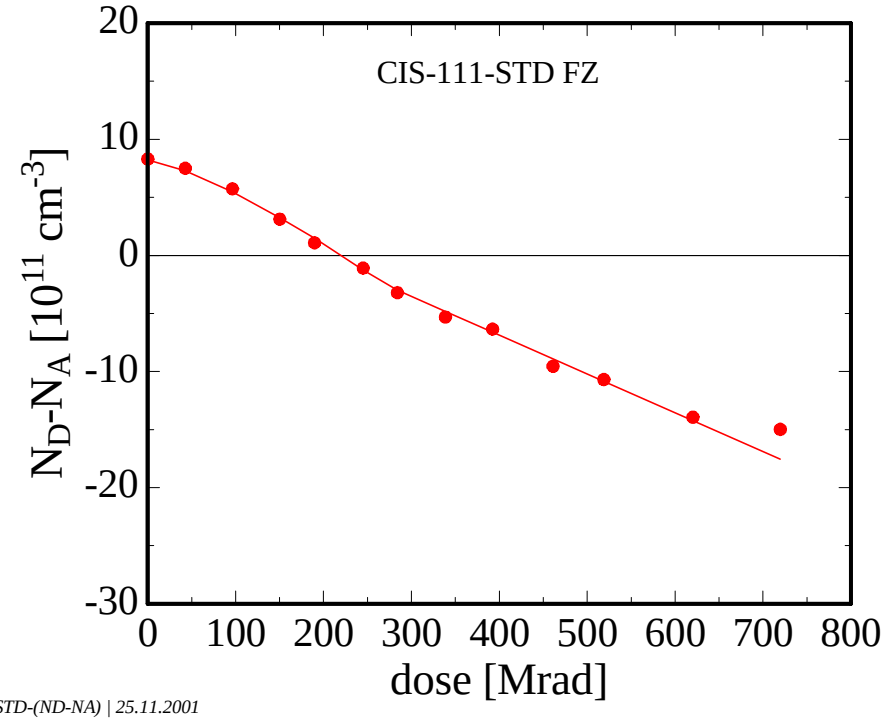
111-IVDEP | 24.11.2001

- **Standard material: inversion at D ≈200 Mrad, V_{dep}(800 Mrad) ≈ 2x V_{dep}(0 Mrad)**
- **DOFZ material: no inversion, small increase of positive space charge with dose**

- **Standard material: current increase $\propto D^{\gamma}$ with $\gamma>1$**
- **DOFZ material: current increase $\propto D$, at 284 Mrad I-STD ≈ 3x I-DOFZ**

CIS <111> DOSE DEPENDENCE

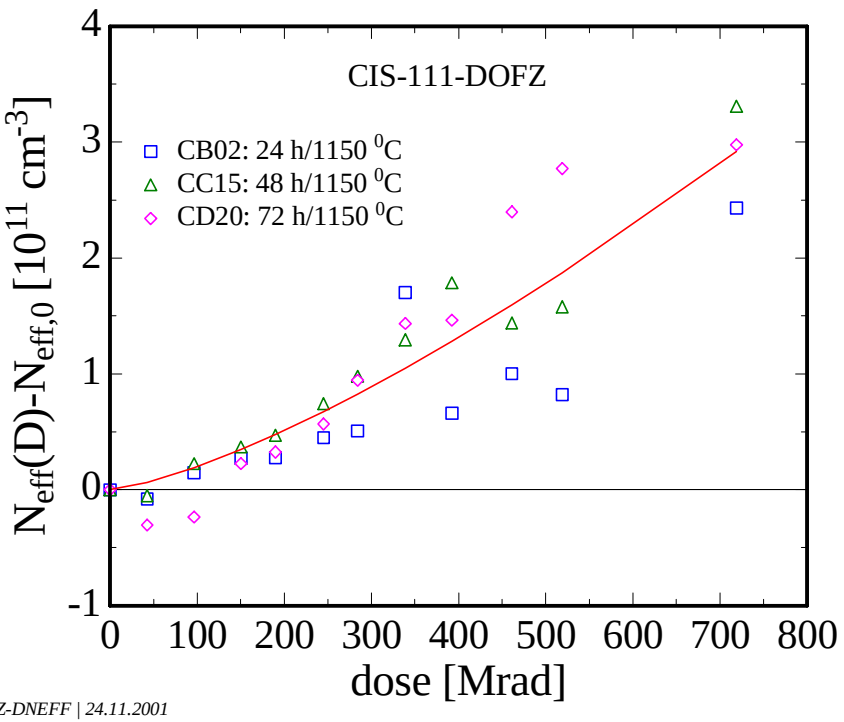
EFFECTIVE DOPING STD MATERIAL



1-STD-(ND-NA) | 25.11.2001

- **Standard material:**
  inversion at D ≈200 Mrad,
  at low dose introduction of negative space charge not linear with dose

EFFECTIVE DOPING DOFZ MATERIAL

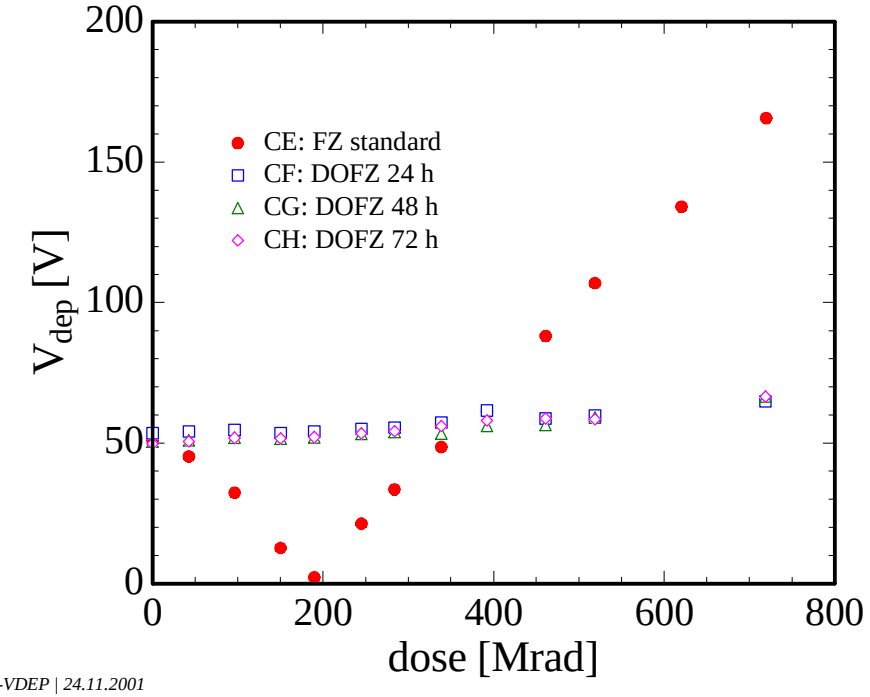


1-DOFZ-DNEFF | 24.11.2001

- **DOFZ material:**
  no SCS inversion in the total dose range,
  small introduction of positive space charge with dose

CIS <100> DOSE DEPENDENCE

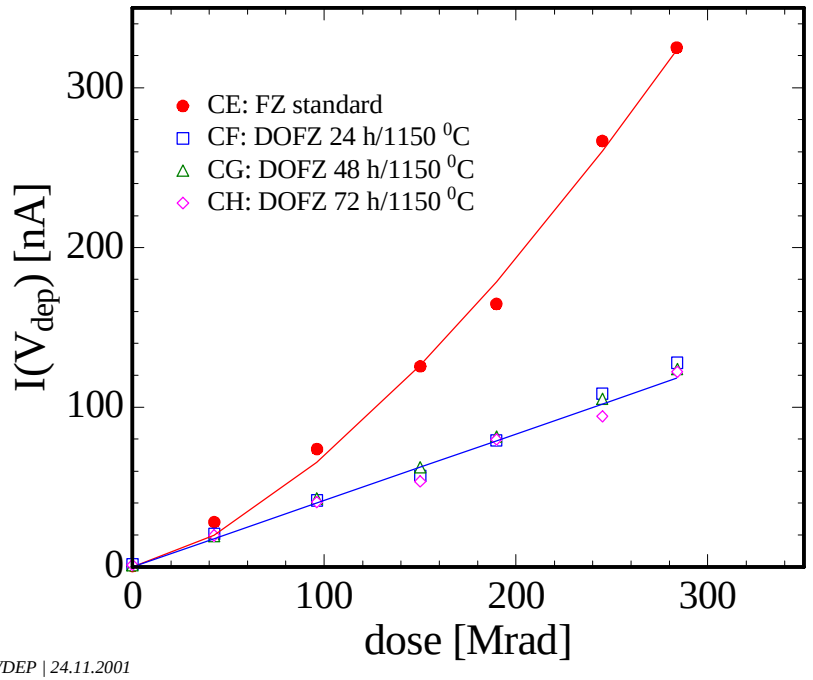
DEPLETION VOLTAGE



00-VDEP | 24.11.2001

- **Standard material: inversion at D ≈200 Mrad, V_{dep}(600 Mrad) ≈ 3x V_{dep}(0 Mrad)**
- **DOFZ material: no inversion, small increase of positive space charge with dose**

REVERSE CURRENT

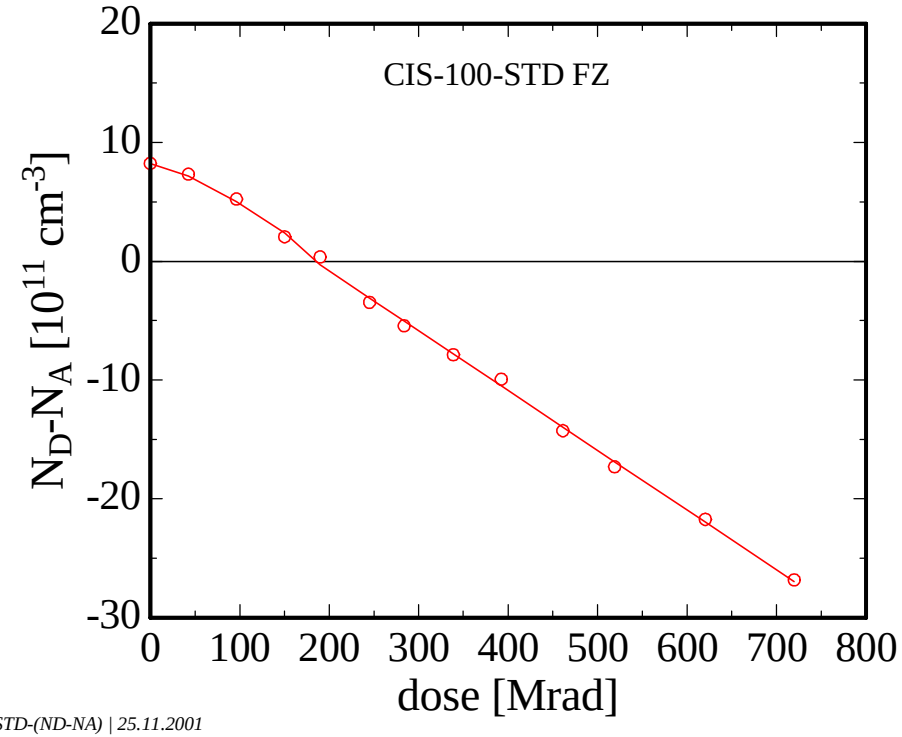


100-IVDEP | 24.11.2001

- **Standard material: current increase $\propto D^{\gamma}$ with γ>1**
- **DOFZ material: current increase $\propto$D, at 284 Mrad I-STD ≈ 3x I-DOFZ**

CIS <100> DOSE DEPENDENCE

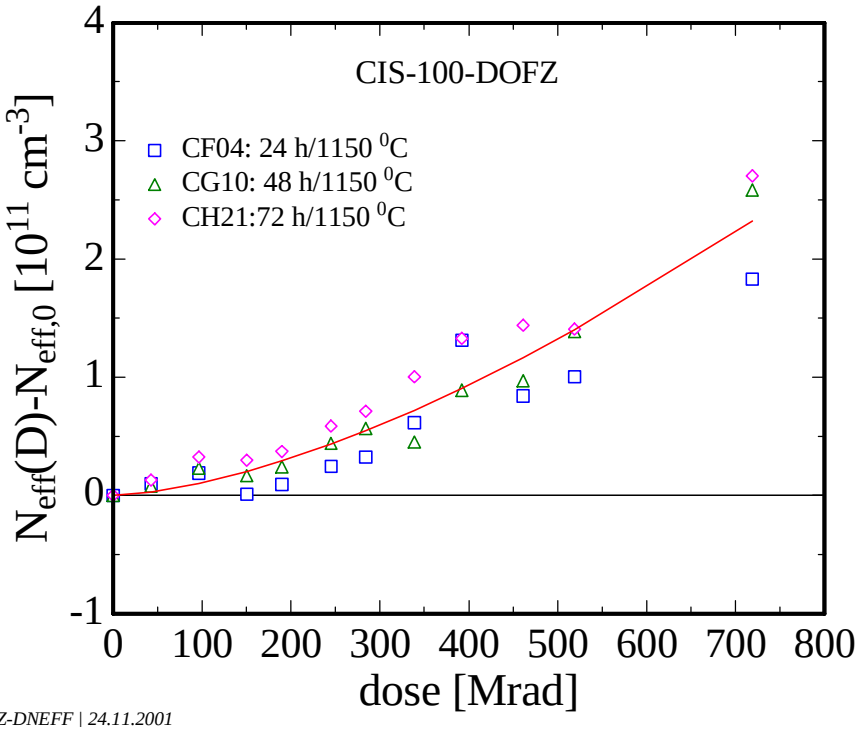
EFFECTIVE DOPING STD MATERIAL



STD-(ND-NA) | 25.11.2001

- **Standard material:**
  inversion at D ≈200 Mrad,
  at low dose introduction of negative space charge not linear with dose
  at high dose increase > compared to <111>

EFFECTIVE DOPING DOFZ MATERIAL

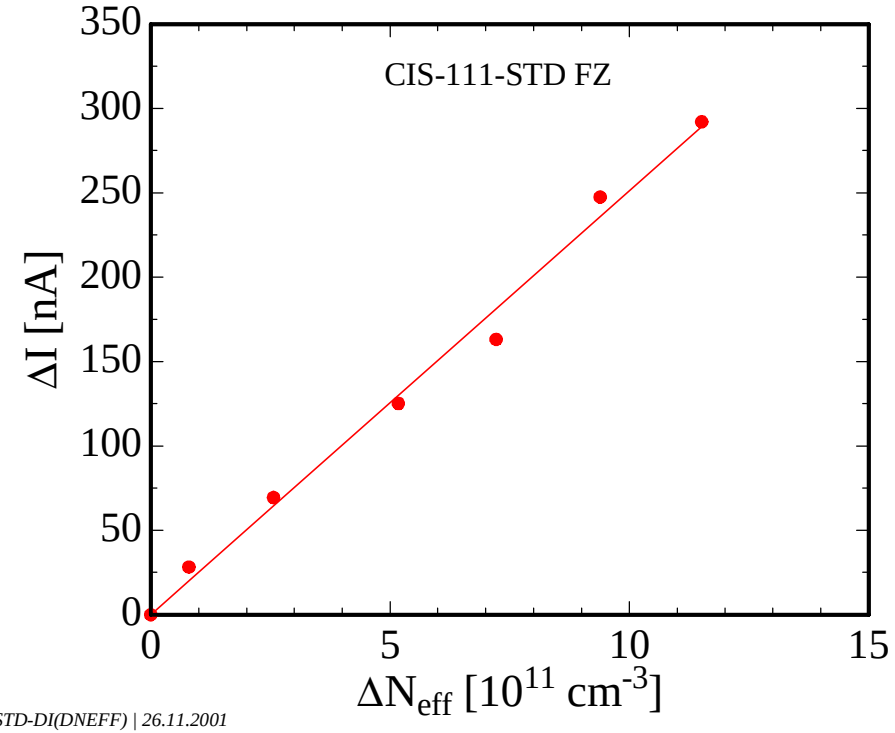


DOFZ-DNEFF | 24.11.2001

- **DOFZ material:**
  no SCS inversion in the total dose range,
  small introduction of positive space charge with dose,
  increase comparable with <111>

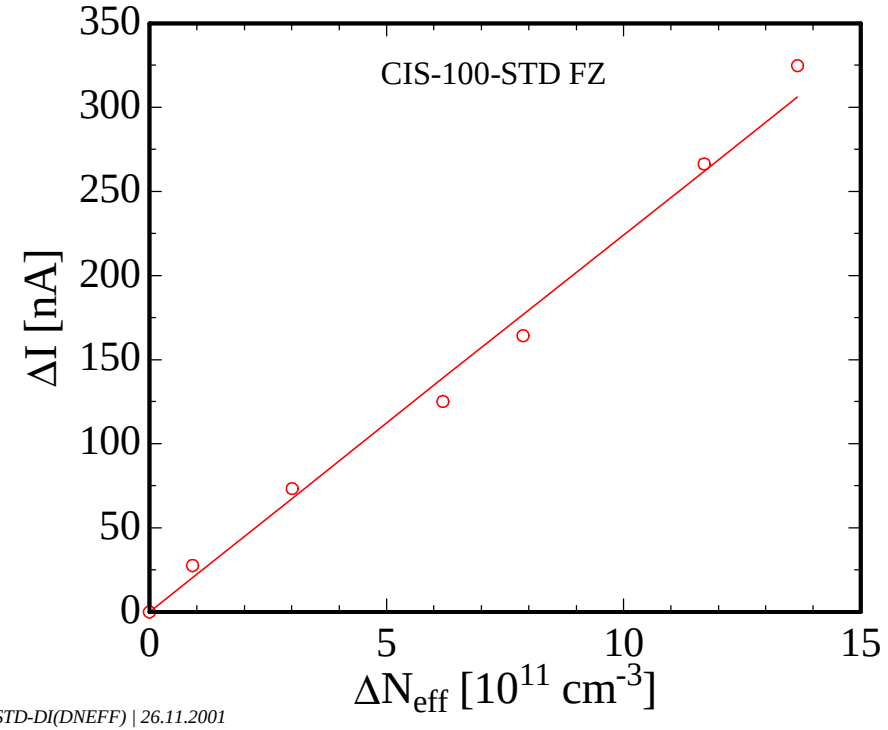
CORRELATION OF CURRENT WITH EFFECTIVE DOPING

CIS <111> STD material



-STD-DI(DNEFF) | 26.11.2001

CIS <100> STD material



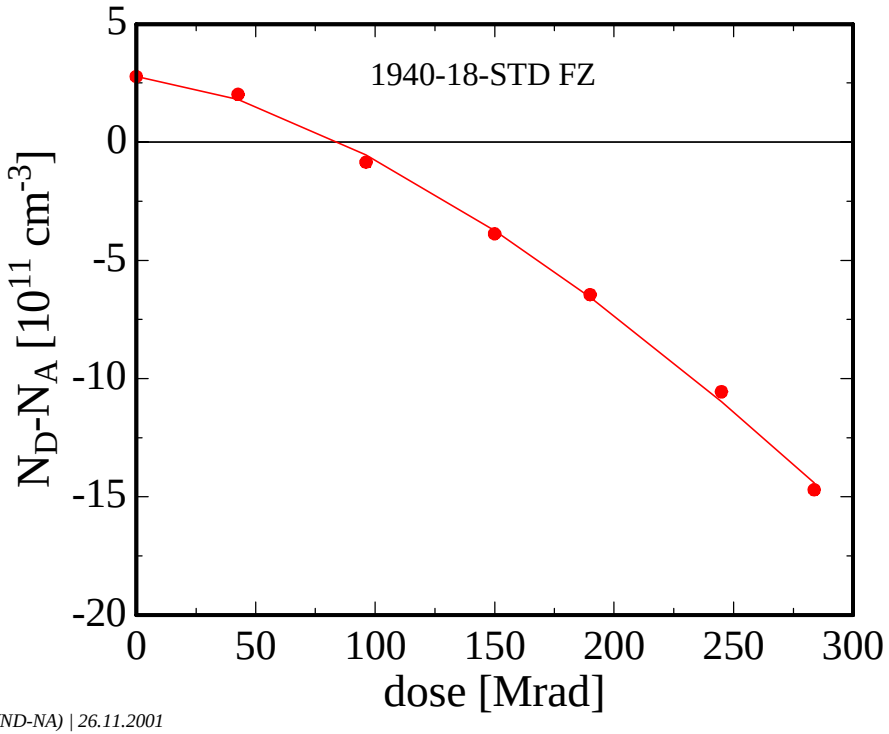
STD-DI(DNEFF) | 26.11.2001

- **for both <111> and <100> standard material:**

  current increase ∝ change of effective doping concentration

MICRON-BNL STD and DOFZ/TD MATERIAL

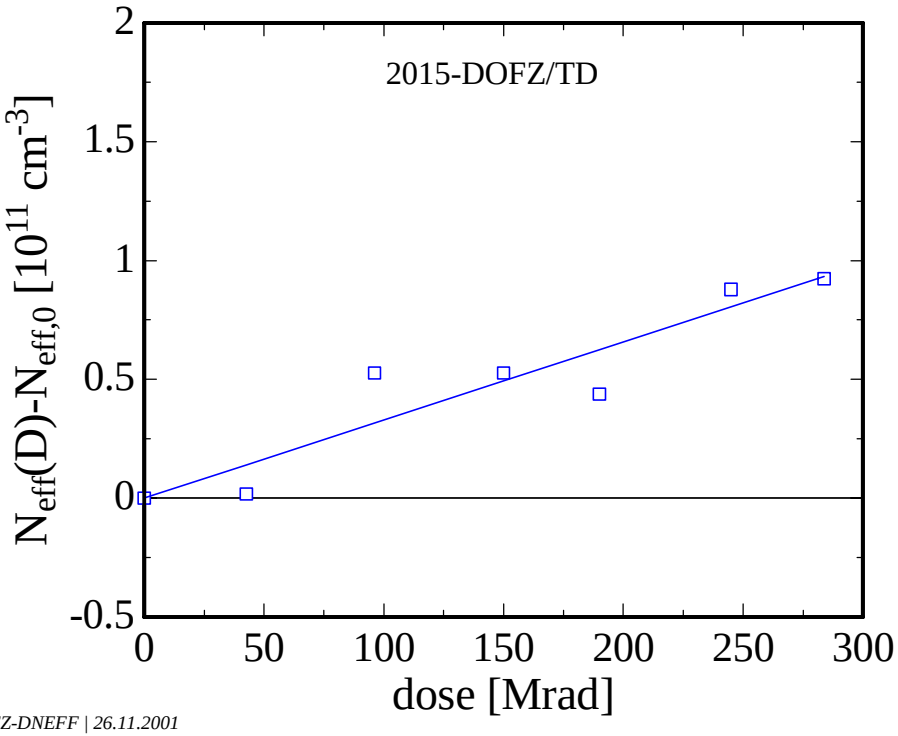
EFFECTIVE DOPING STD MATERIAL



D-(ND-NA) | 26.11.2001

- **Standard material:**
  inversion at D ≈ 100 Mrad,
  the introduction of negative space charge is not linear with dose

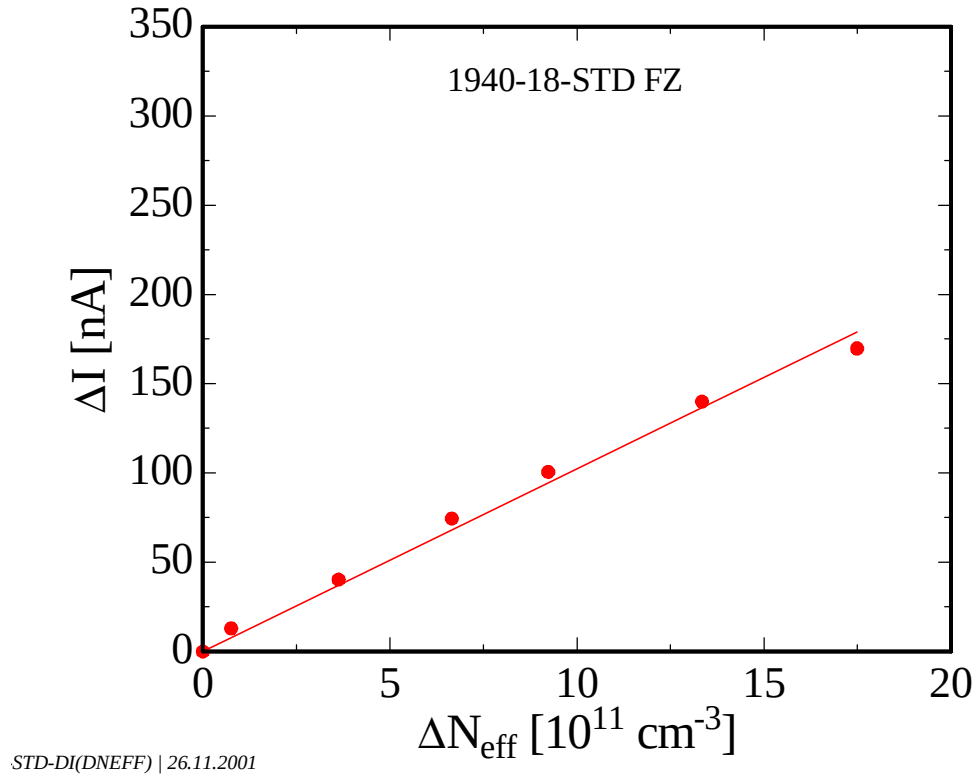
EFFECTIVE DOPING DOFZ MATERIAL



OFZ-DNEFF | 26.11.2001

- **DOFZ material:**
  no SCS inversion in the total dose range,
  small introduction of positive space charge with dose

CORRELATION OF CURRENT WITH EFFECTIVE DOPING



- **for BNL-1940 standard material:**

current increase ∝ change of effective doping concentration

REVERSE CURRENT RESULTS

CIS DOFZ material:

$$\Delta I/V = \alpha_I \times D$$

Material	α_I (10^{-12} $Acm^{-3}Gy^{-1}$)
CIS <111>	5.7±0.5
CIS <100>	5.9±0.4
References:	
MacEvoy 96	21
Li 96	33
Feick 97	39
Moll 98	14

CIS standard material:

$$\Delta I/V = \alpha_{SI} \times D^{\gamma}$$

Material	α_{SI} (10^{-12} $Acm^{-3}Gy^{-1}$)	γ
CIS <111>	2.1	1.34
CIS <100>	1.2	1.46

RESULTS FOR ΔN_{eff}

Standard material, low dose range (<300 Mrad):

$$\Delta N_{eff} = g_A \times D^{\gamma}$$

Material	g_A (10^4 cm^{-3}Gy^{-1})	γ
CIS <111>	6.9	1.31
CIS <100>	6.8	1.35
BNL <111>	3.2	1.52

CIS standard material, high dose range:

$$\Delta N_{eff} = N_c + g_A \times D$$

Material	g_A (10^5cm^{-3}Gy^{-1})
CIS <111>	3.3
CIS <100>	5.0

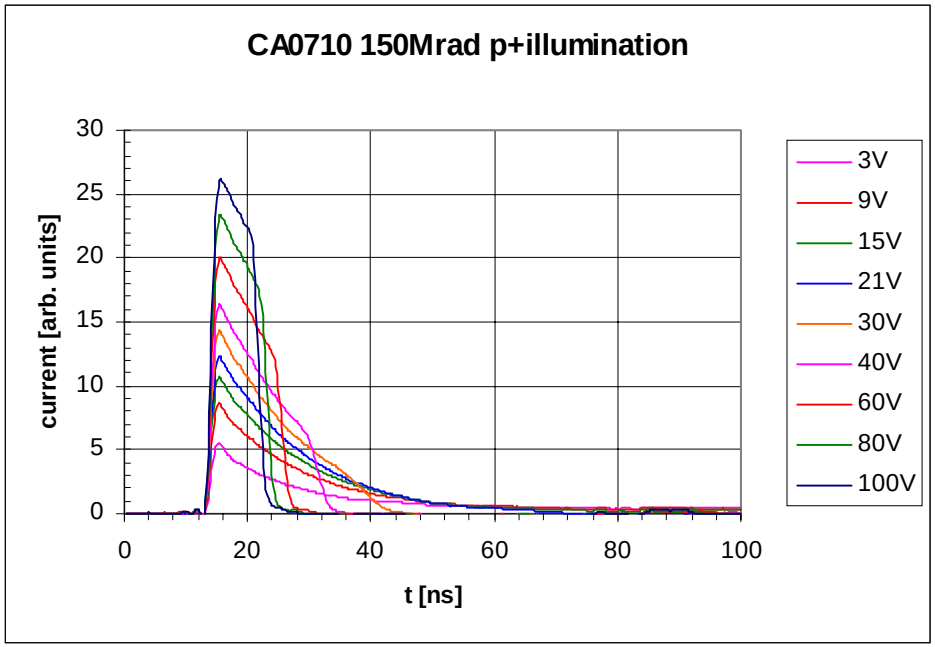
CIS DOFZ material:

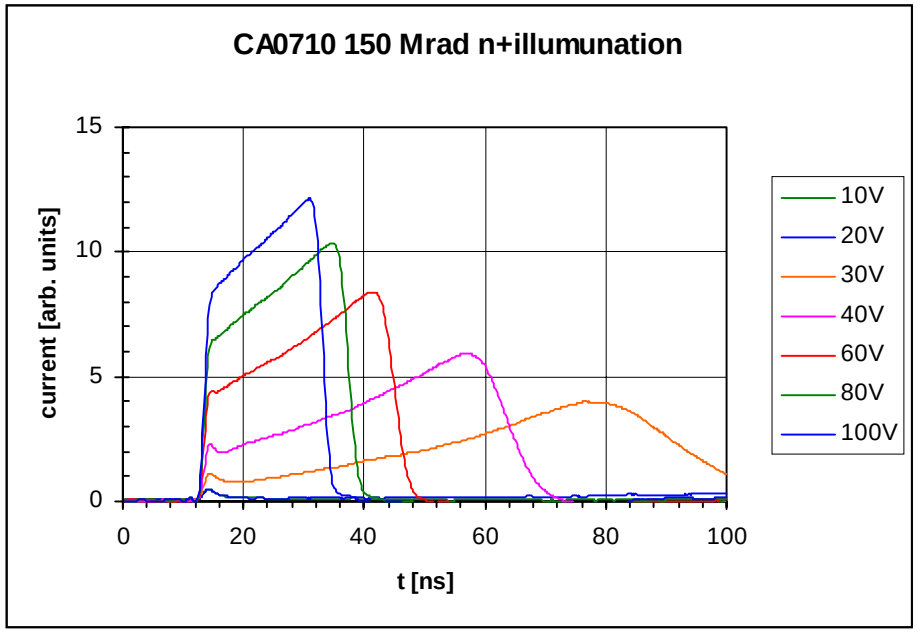
$$\Delta N_{eff} = g_A \times D^{\gamma}$$

Material	g_A (10^3 cm^{-3}Gy^{-1})	γ
CIS <111>	3.8	1.36
CIS <100>	0.84	1.56

CURRENT PULSE SHAPES BEFORE INVERSION

CIS-<111> standard material
Laser light wave length: 670 nm



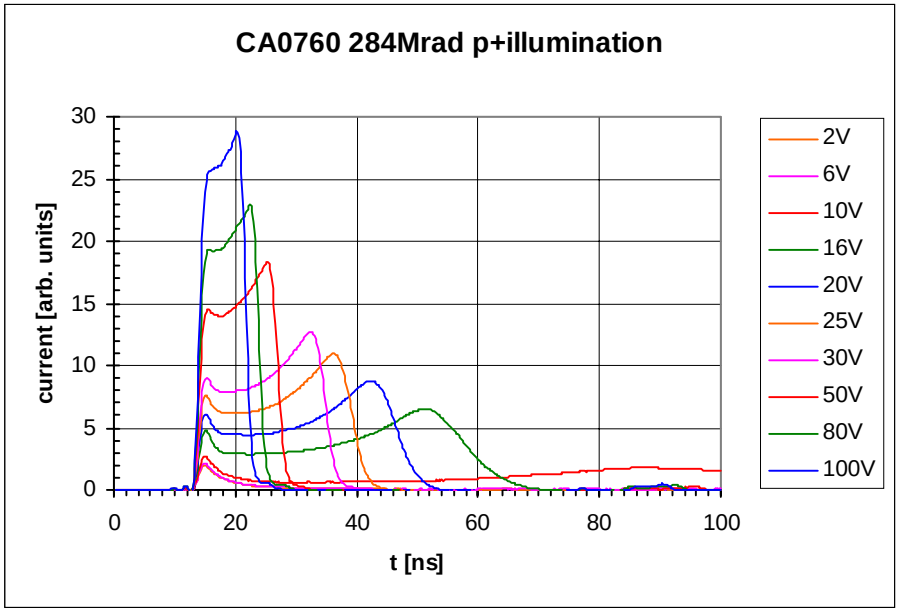


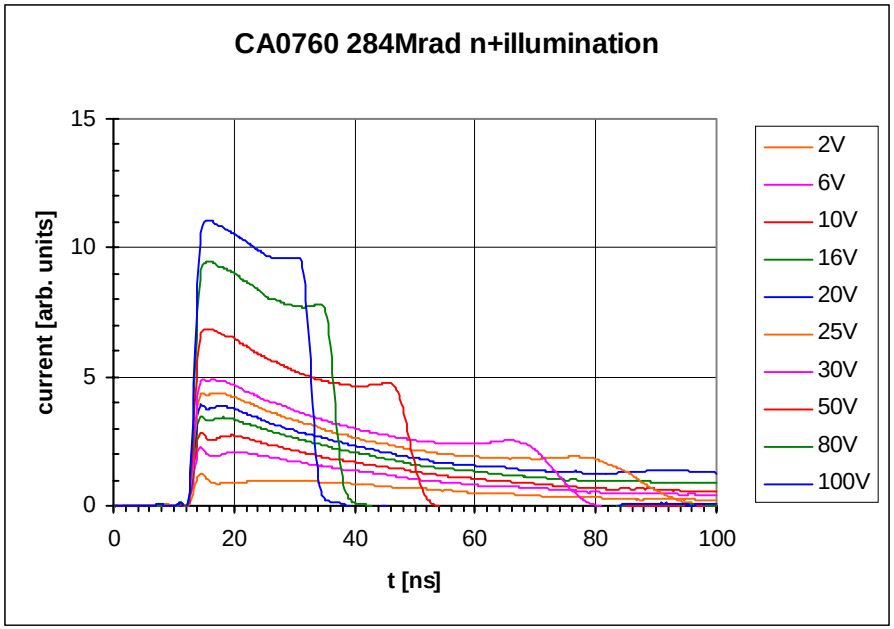
- **illumination p^+-contact: high field side**
  current pulse shape dominated by electron transport

- **illumination n^+-contact: low field side**
  current pulse shape dominated by hole transport

CURRENT PULSE SHAPES AFTER SCS INVERSION

CIS-<111> standard material
Laser light wave length: 670 nm

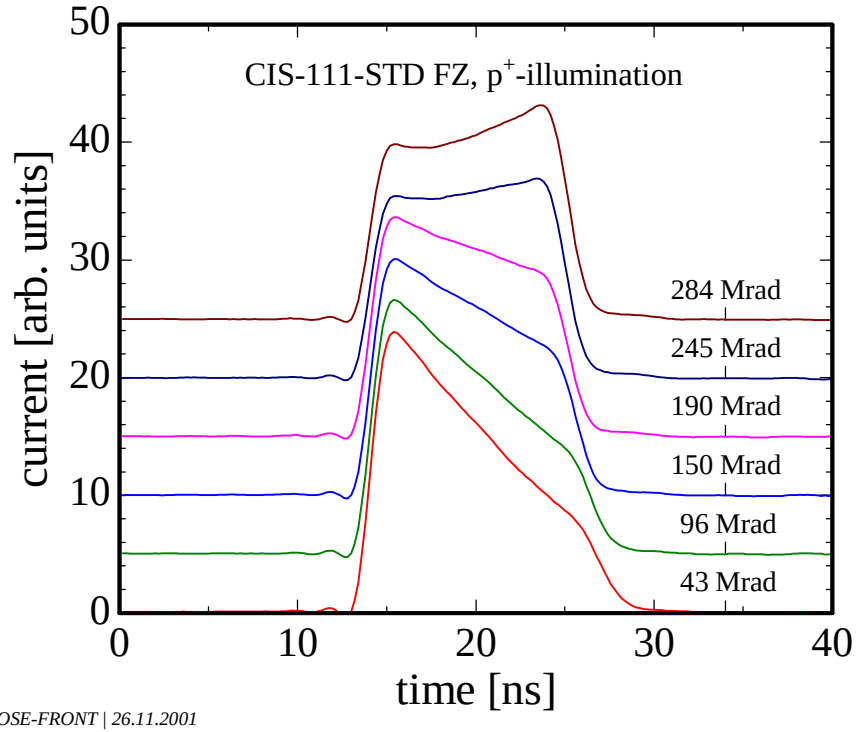




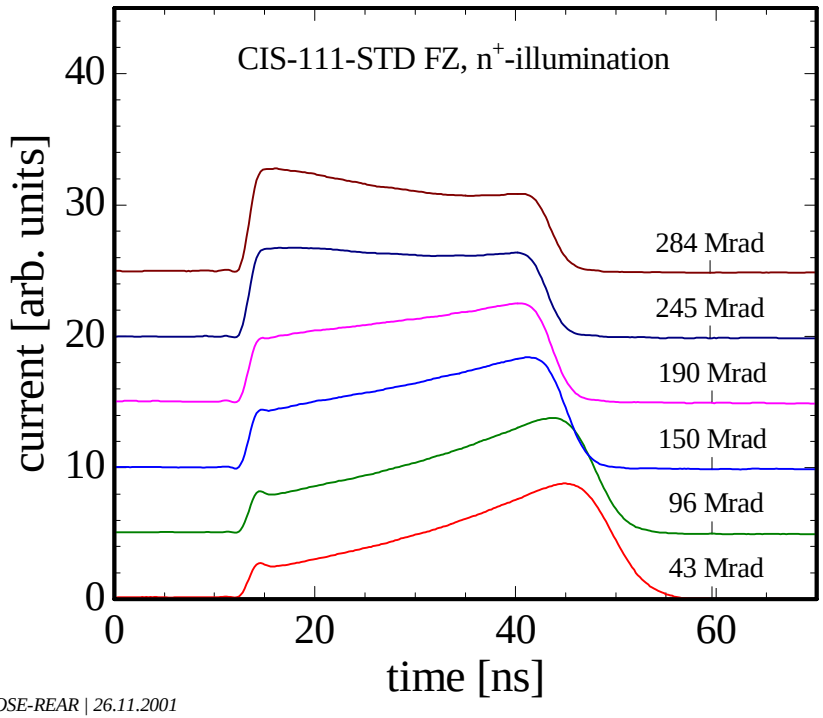
- illumination p^+-contact: low field side
  current pulse shape dominated by electron transport
- illumination n^+-contact: high field side
  current pulse shape dominated by hole transport
- main depletion zone starts at n^+-contact
- junction at p^+-contact indicated by both pulse shapes

PULSE SHAPES - DOSE DEPENDENCE

CIS-<111> standard material
Laser light wave length: 670 nm



*-DOSE-FRONT | 26.11.2001



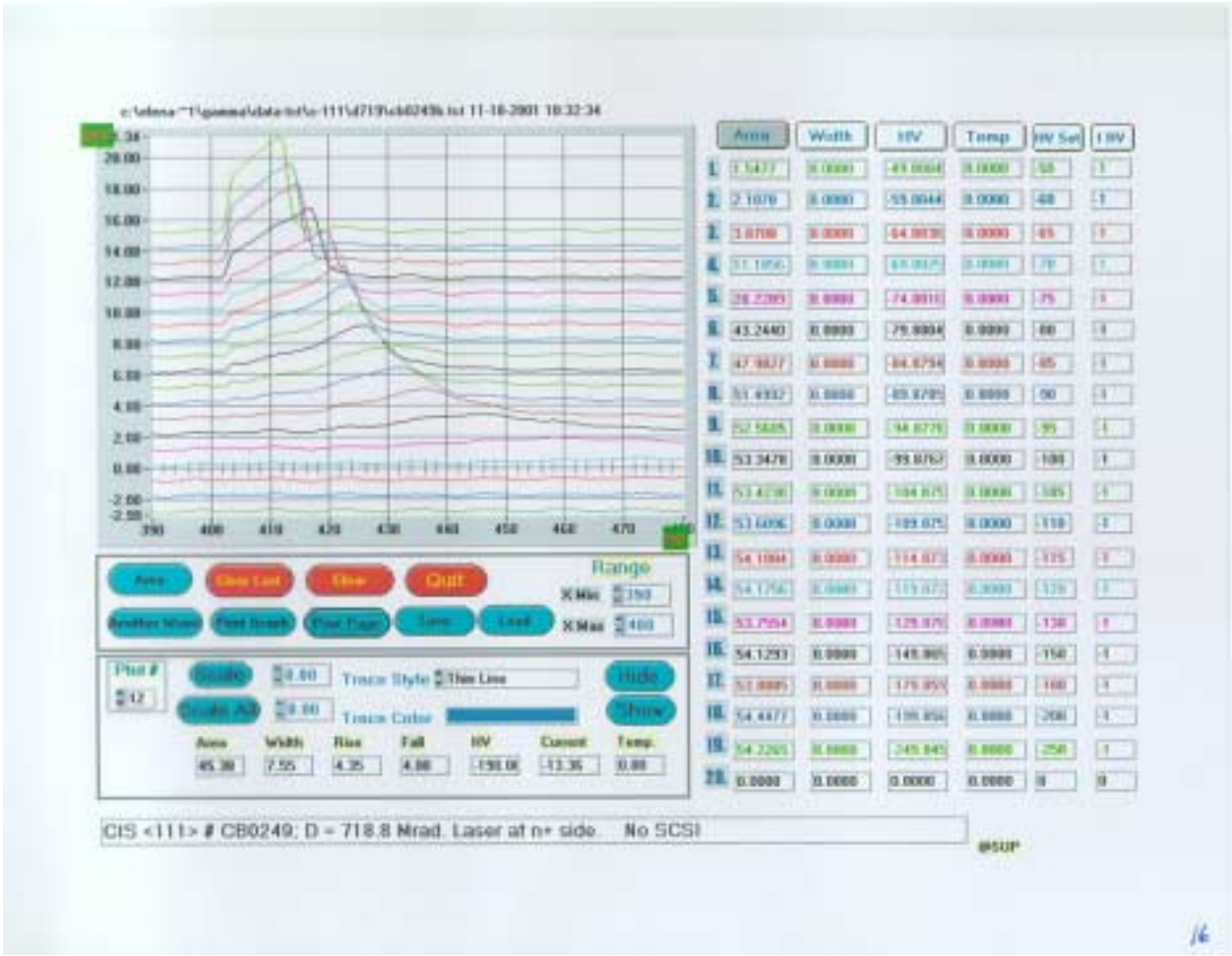
DOSE-REAR | 26.11.2001

➢ **Development of pulse shapes versus dose at constant V_{bias} = 60 V**

CURRENT PULSE SHAPES AFTER 719 MRAD

CIS-<111> DOFZ material: 24h 1150^{0}C

- **Illumination: n^+-side hole transport**
- **Laser light: 670 nm**
- **V_{bias} range: 50 V – 250V**
- **Transient slope: positiv**
- **No SCS inversion**



CURRENT PULSE SHAPES AFTER 719 MRAD

CIS-<100> DOFZ material: 24h 1150^{0}C

- **Illumination: n^+-side hole transport**
- **Laser light: 670 nm**
- **V_{bias} range: 50 V – 250V**
- **Transient slope: positiv**
- **No SCS inversion**

CONCLUSIONS

Oxygen enriched material:

- More radiation hard with respect to ΔN_{eff} and leakage current ΔI compared to STD material
- N_{eff} increases slightly with dose $\rightarrow$ creation of donor like defects
- No obvious dependence of ΔN_{eff} and ΔI on oxygen concentration above 5×10^{16} cm^{-3}
- Leakage current increase linear with dose ($\alpha_I \approx 6\times10^{-12}$ Acm^{-3} Gy^{-1} is a factor 2-5 smaller compared to values reported by different authors)

Standard material:

- In the dose range 0 – 300 Mrad $\rightarrow \Delta N_{eff} = g_A \times D^{\gamma}$ with $\gamma = 1.3 – 1.5$, for dose values > 300 Mrad $\rightarrow \Delta N_{eff} \propto D$
- Space charge sign inversion clearly seen in laser induced current pulse shapes
- Dose values for SCS-inversion depends on initial doping concentration and “background” oxygen concentration
- Leakage current increase in the dose range 0-300 Mrad $\rightarrow \Delta I/V = \alpha_I \times D^{\gamma}$, $\gamma = 1.3 – 1.5$
- ΔI is proportional to ΔN_{eff}