Electric Field Modeling by simulations with ISE-TCAD

For the RD50 Simulation Group

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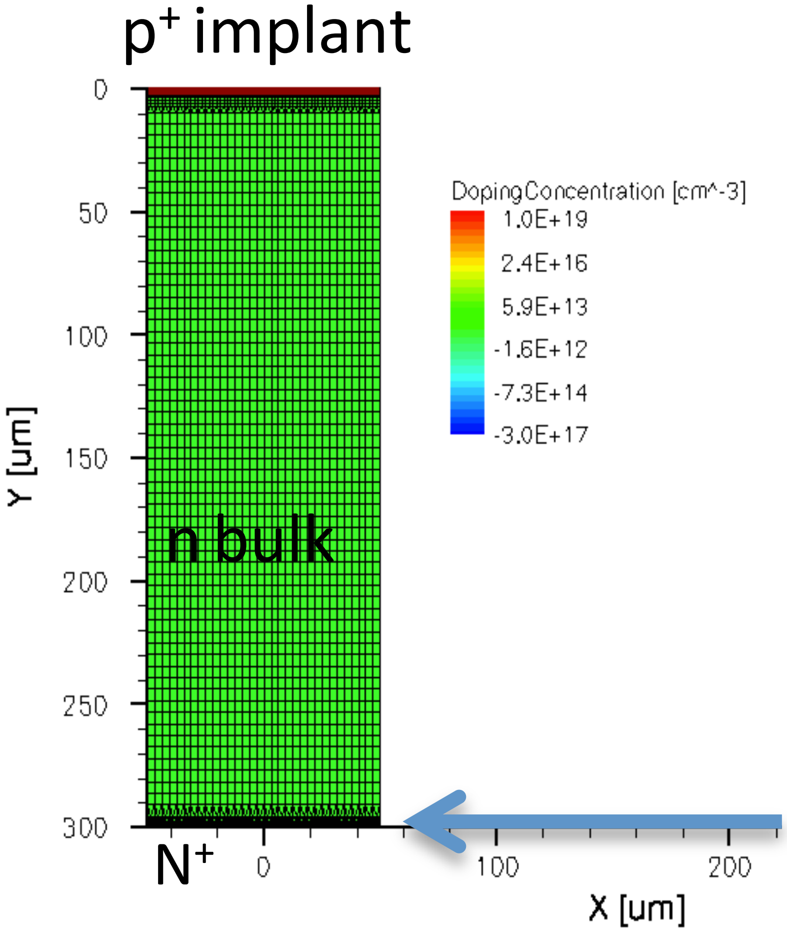
Outline

1. 2D Pad Sensor simulated by ISE-TCAD
    1. 2Defects radiation model
2. Full Depletion Voltage
3. Electric Field Distribution @ 10^{15} cm^{-2}
4. Temperature Effects
5. Electric Field Distribution vs. Fluence
6. Leakage Current
    1. Single level radiation model
7. Summary and next steps

2D Pad Detector



As proposed from the RD50 Detector Simulation Group :

- Simulations by Synopsys ISE-TCAD Version D-2010.03 of a pad sensor has been carried out with the next characteristics:

DOPING PROFILES

$[p^+] = 3 \times 10^{17}$ cm^{-3}
$[n\text{-bulk}] = 6 \times 10^{11}$ cm^{-3}
$[n^+] = 1 \times 10^{19}$ cm^{-3}

Detector thickness ---- d=0.03 cm

Backplane

Radiation induced deep levels

Type of defect	Activation energy, eV	Trapping cross section, cm^2	Introduction rate, cm^{-1}
Deep donor	$E_{DD} - E_V = 0.48$	$\sigma_e = \sigma_h = 1e\text{-}15$	$G_{DD} = 1$
Deep acceptor	$E_{DA} - E_V = 0.595$	$\sigma_e = \sigma_h = 1e\text{-}15$	$G_{DA} = 1$

ISE-TCAD Code used for simulations

Parameters:
Bias Voltage,
temperature
and fluence

```
Electrode {
	{Name="nplus" Voltage=0.0 Material="Aluminum"}
	{Name="pimplant" Voltage=0.0}
	}
```

```
Physics {
Temperature=@<Temperature>@
	Mobility( DopingDep CarrierCarrierScattering HighFieldSaturation Enormal)
	Recombination(SRH(DopingDep) SurfaceSRH)
	EffectiveIntrinsicDensity(Slotboom)                    }
```

Standard physics model for a sensor with no radiation damage

```
Physics (material="Silicon") {
#if @<Fluence==0>@  ##  No Traps
#else
   Traps (
     (Acceptor Level fromValBand  Conc=@<Fluence>@   EnergyMid=0.595
      eXsection=1.0E-15 hXsection=1.0E-15 )
     (Donor Level fromValBand  Conc=@<Fluence>@  EnergyMid=0.48
      eXsection=1.0E-15 hXsection=1.0E-15 )
      )
#endif                  }
```

Radiation model for traps

```
Physics(MaterialInterface="Oxide/Silicon") {
#if @<Fluence==0>@
	Charge(Conc=4e11)
#else
	Charge(Conc=1e12)
	Recombination(surfaceSRH)
#endif            }
```

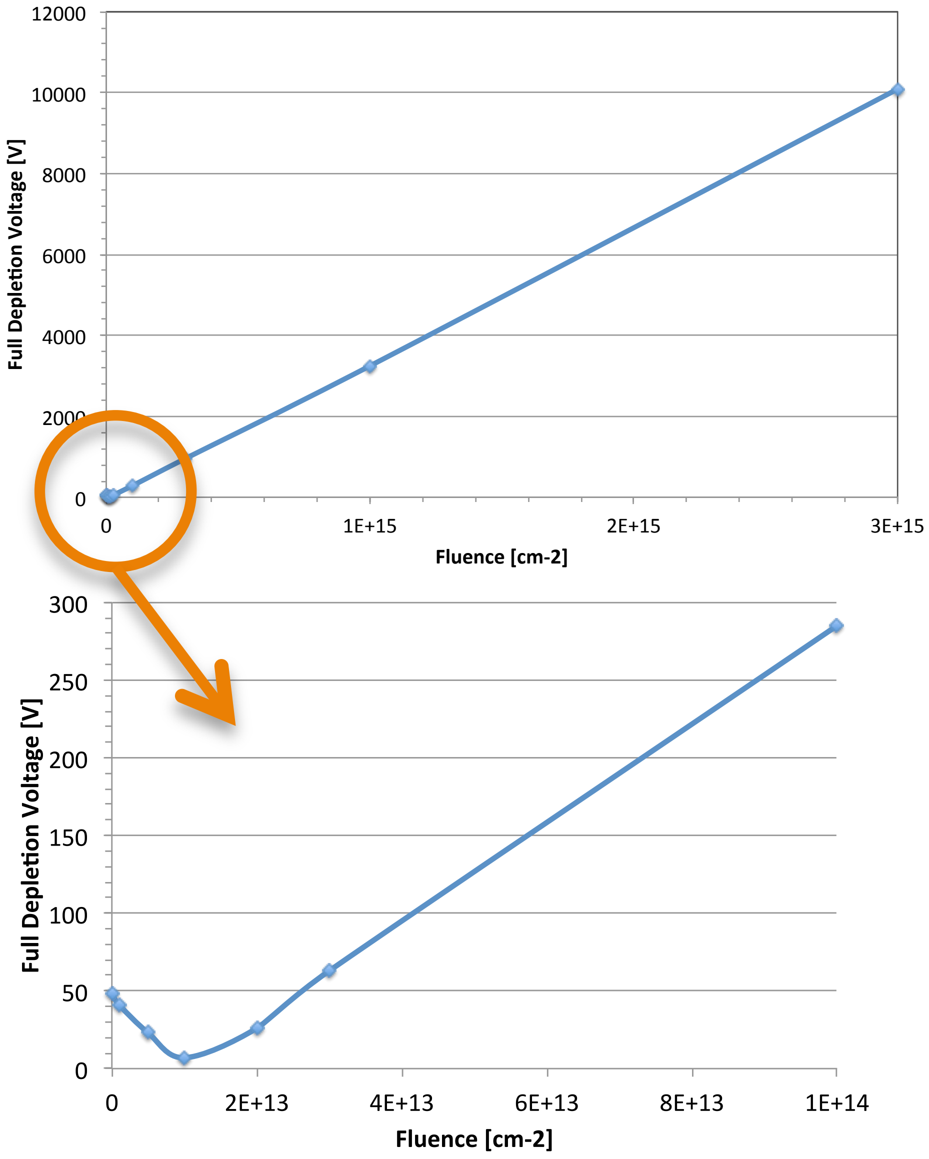
Oxide charge

Full Depletion Voltage

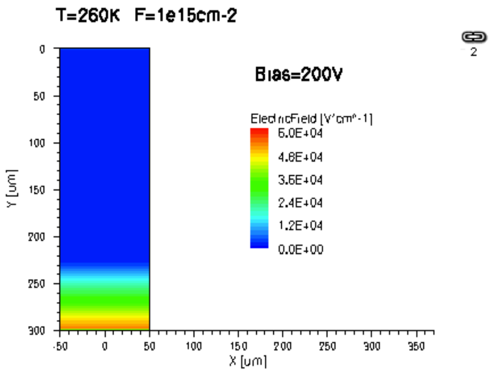
T=290K

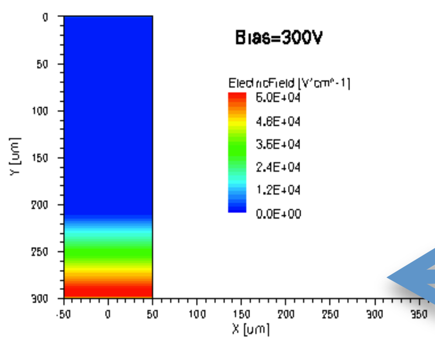
The n-type bulk is inverted to p-type with irradiation at 10^{13} cm^{-2}

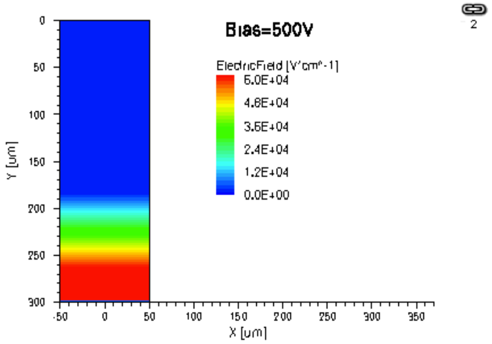
Fluence [cm-2]	Vfd [V]
0	48
1e12	41
1e13	7
1e14	285
3e14	955
1e15	3245
3e15	10086

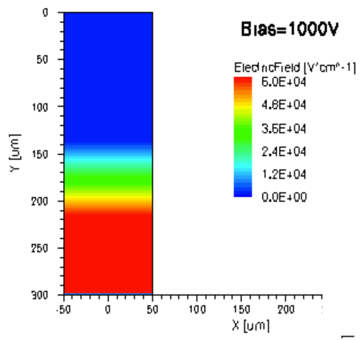


Electric Field Distribution @ 10^{15} cm^{-2}



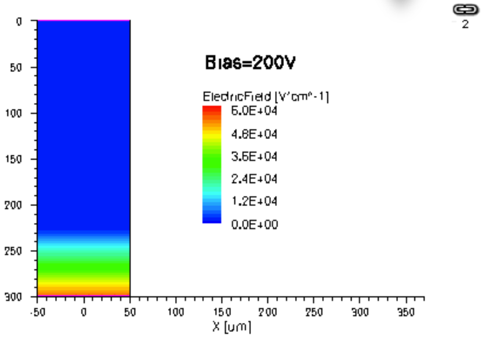


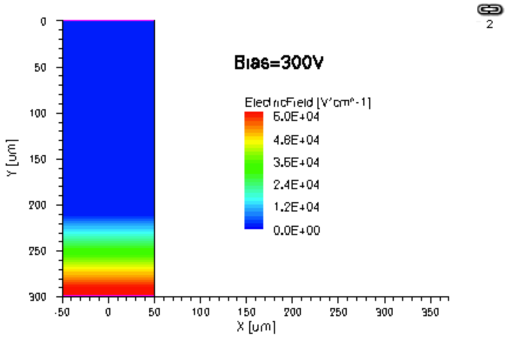


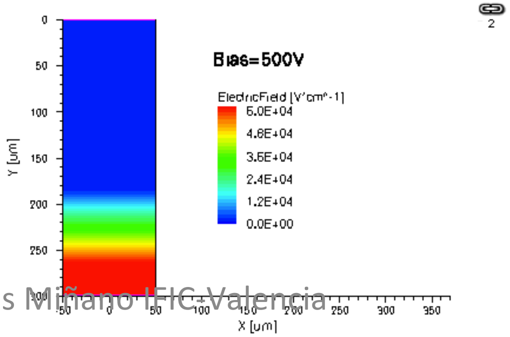


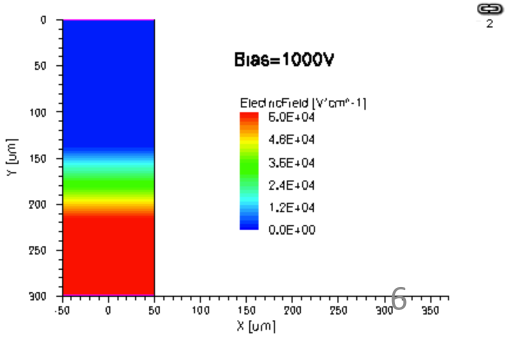
T=260K

T=290K







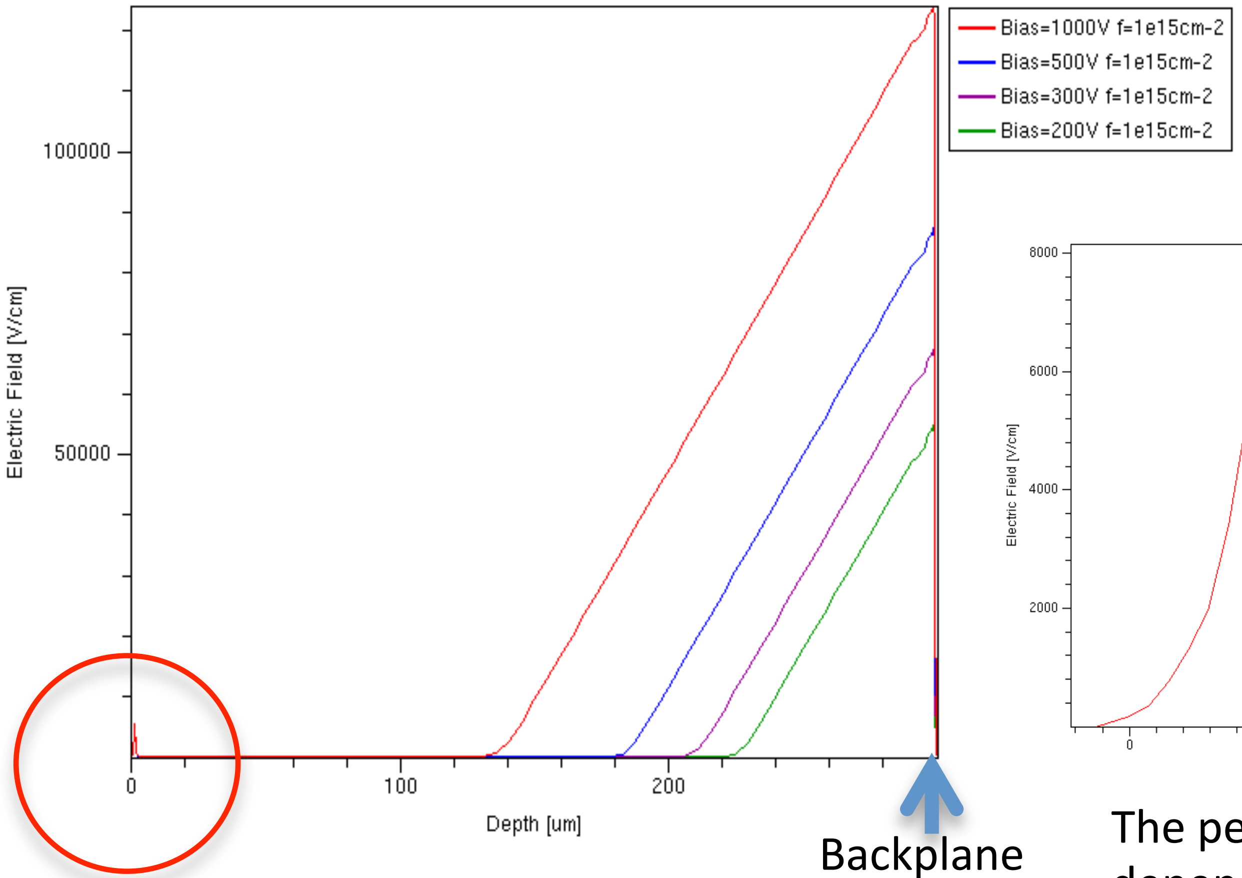


Inverted sensor
N→P bulk

The electric field grows from the sensor backplane

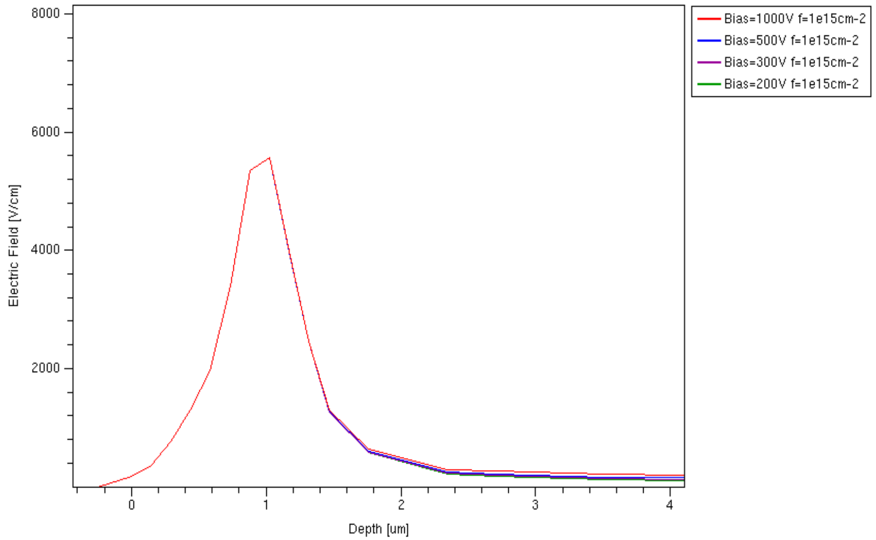
T=290K ϕ = 1 x 10^{15} cm^{-2}

- Electric Field Distribution through sensor depth



Front plane (p+)

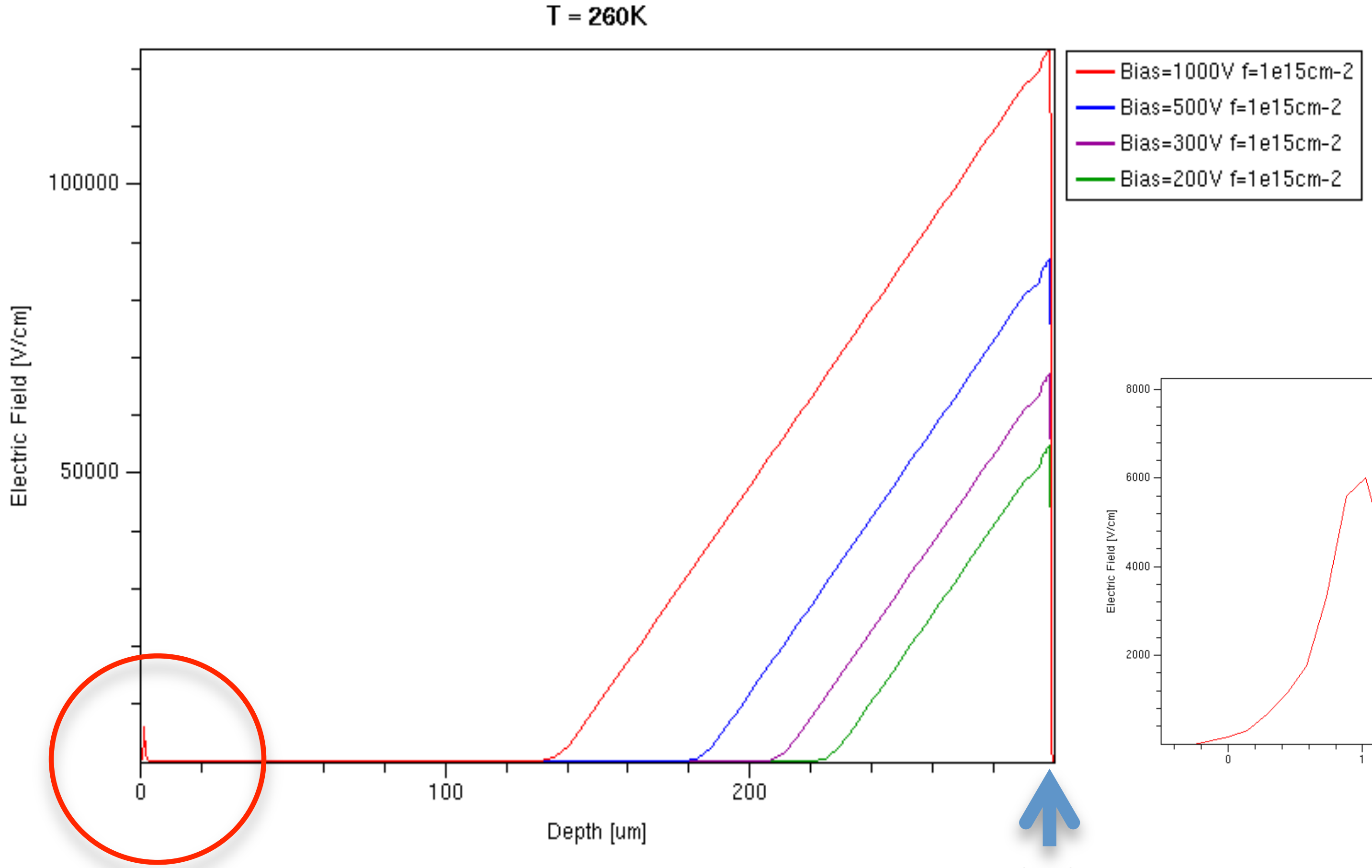
Backplane

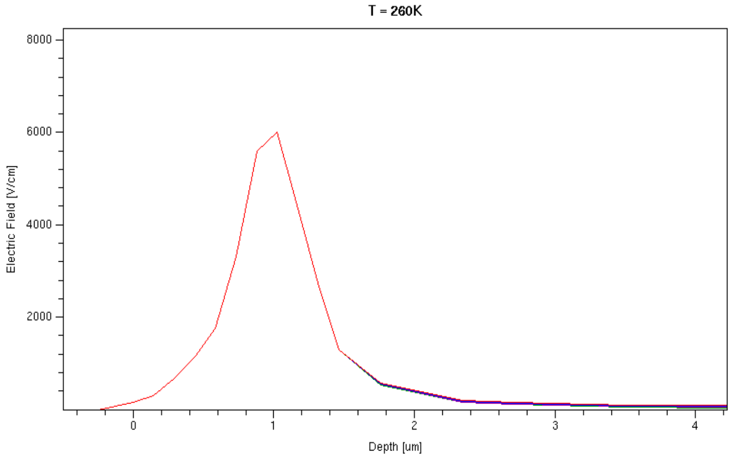


The peak at front contact does not depend on bias voltage

T=260K ϕ = 1 x 10^{15} cm^{-2}

- Electric Field Distribution through sensor depth



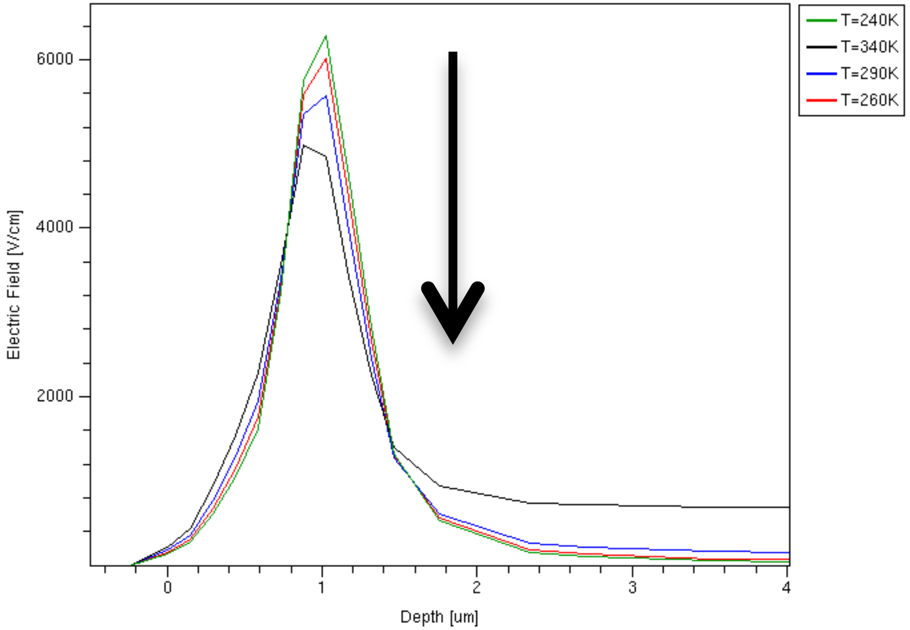


Front plane (p+)

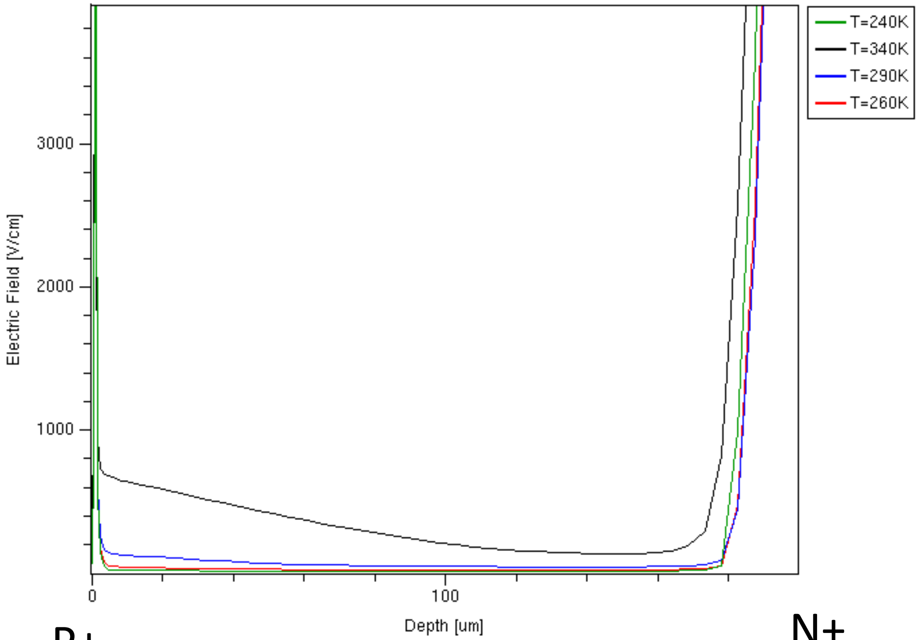
Backplane

Temperature Effects

@500V and irradiated at 10^{15} cm^{-2}



P+



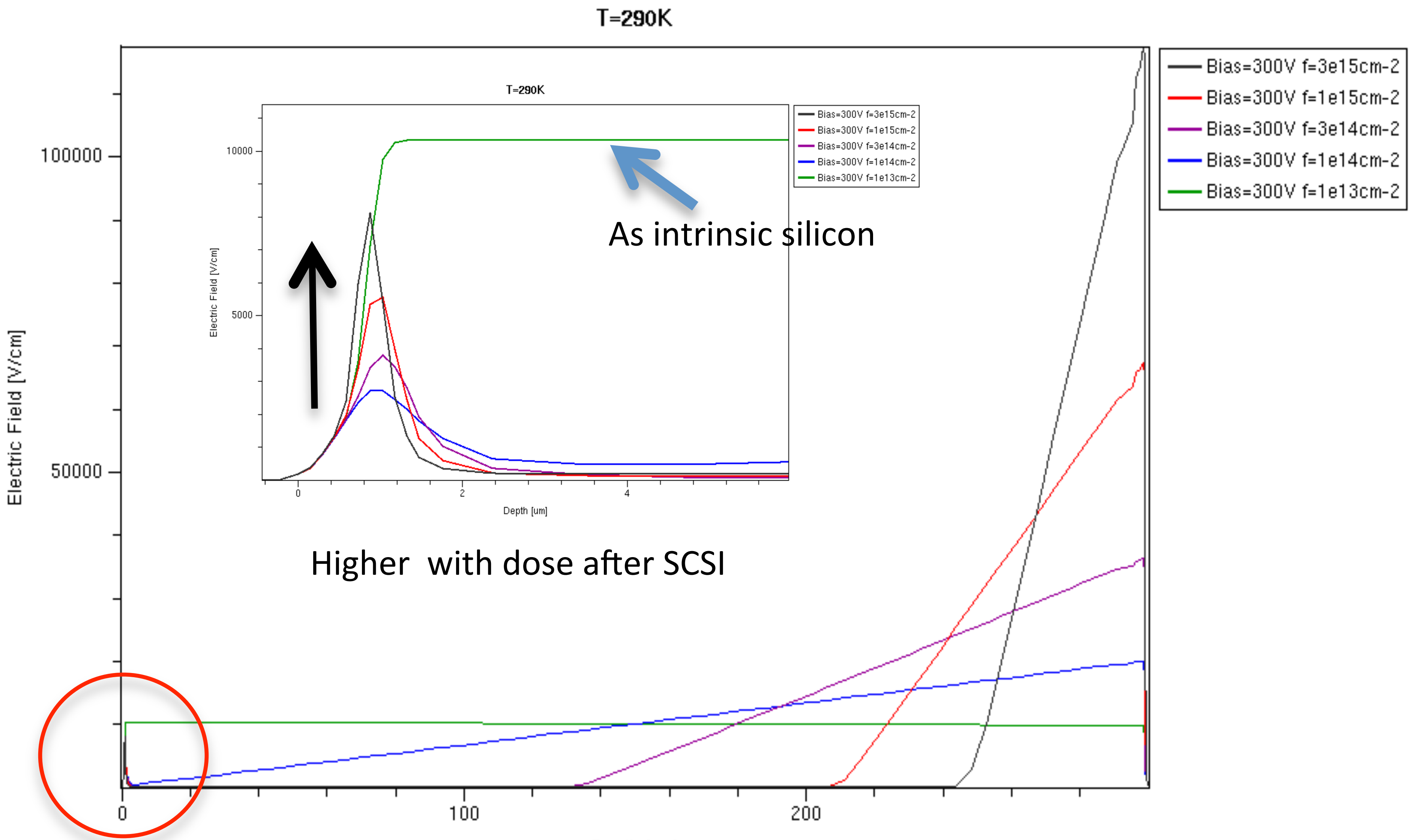
P+

N+
backplane

The peak at p+ contact decreases as temperature increases, whereas a double junction effect is more evident.

T=290K Bias=300V

- **Electric Field Distribution**



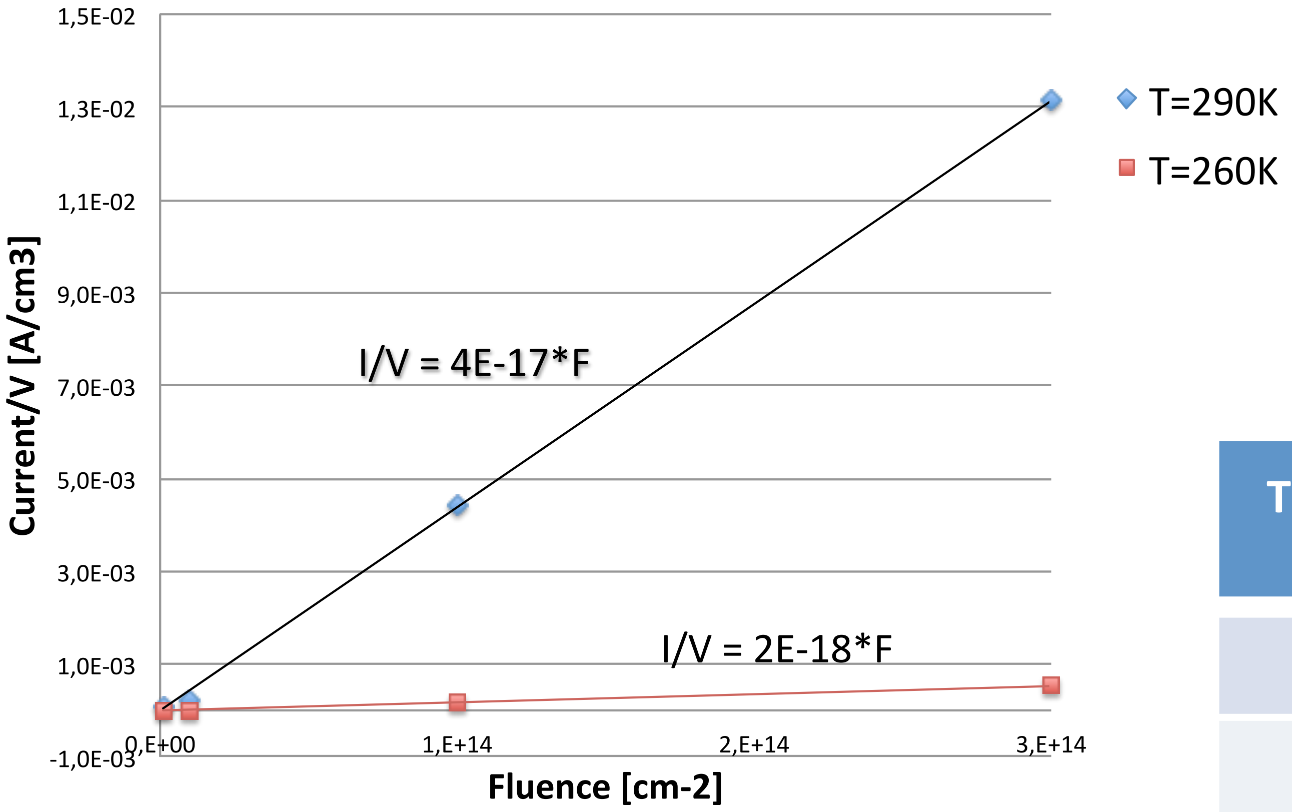
As intrinsic silicon

Higher with dose after SCSI

Leakage Current

Bulk generated current calculated from a single level model:

```
Traps (
   (Donor Level fromCondBand  Conc=@<Fluence>@  EnergyMid=0.65
    eXsection=1.0E-13 hXsection=1.0E-13 )
    )
```



V = 100 µm² x 300µm

Current related damage rate

$$\Delta I / V = \alpha \cdot \Phi$$

T [K]	α [x10⁻¹⁷ A/cm]
290	4
260	0.2

measured after 80min at 60°C :

$\alpha_{80/60} = (3.99 \pm 0.03)10^{-17}$ A/cm

Moll's Thesis →

Summary

- Following the Vladimir's proposals, simulations with ISE-TCAD have been carried out in order to perform a cross-test of the software.
- The results are focused in Electric Field distribution in irradiated sensors (2 midgap level model) and some conclusions can be extracted:
  - After bulk inversion an asymmetric double peak is seen at both sides of the sensor.
  - The peak at p+ contact seems to depend on:
    - Temperature
    - Irradiation dose

- Full depletion voltage and leakage current (single level model) characteristics are also presented.

Next Steps

- Charge collection efficiency
- Implementation of avalanche effect
- Trap configuration
- Geometrical dependence
- …
- …
- Any suggestion is wellcome

Back Up

Physics Models

$$\varepsilon \nabla^2 \psi = -q\,(p - n + N_{D^+} - N_{A^-})$$

Poisson Equation

$$\nabla \cdot \vec{J_n} = q\,R_{net} + q\,\frac{\partial n}{\partial t}$$

$$-\nabla \cdot \vec{J_p} = q\,R_{net} + q\,\frac{\partial p}{\partial t}$$

Transport Equations

$$R_{net}^{SHR} = \frac{np - n_{i,eff}^2}{\tau_p(n + n_1) + \tau_n(p + p_1)}$$

Shockley-Read-Hall
Model

	electrons	holes	units
τ_{min}	0	0	s
τ_{max}	1×10^{-5}	3×10^{-6}	s
N_{ref}	1×10^{16}	1×10^{16}	cm^{-3}
γ	1	1	1

Table 5.2: Default parameters for doping-dependent SRH lifetime.

with

$$n_1 = n_{i,eff}\, exp\left(\frac{E_{trap}}{\kappa T}\right) \tag{5.14}$$

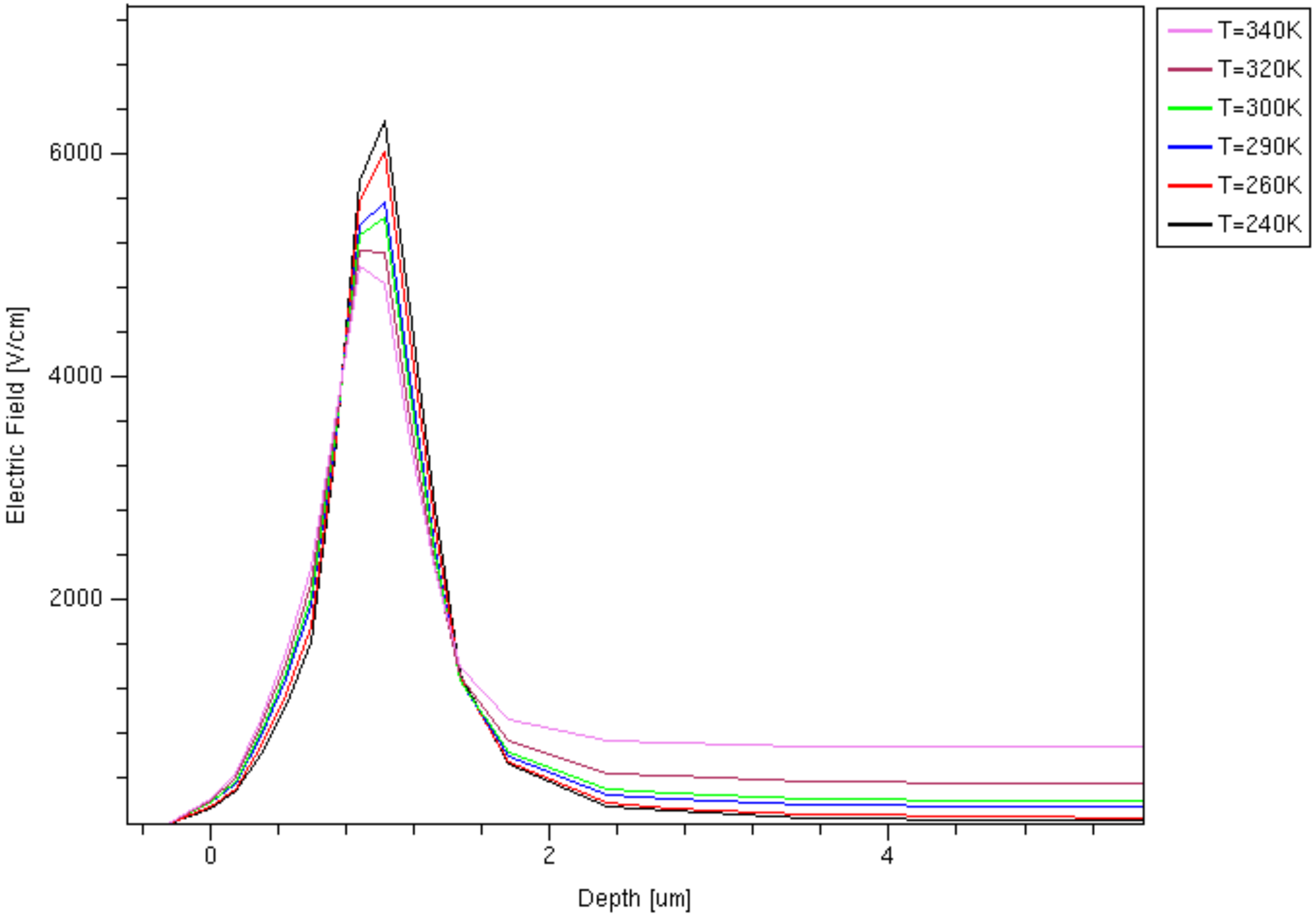
$$p_1 = n_{i,eff}\, exp\left(-\frac{E_{trap}}{\kappa T}\right) \tag{5.15}$$

where E_{trap} is the difference between the defect level and intrinsic Fermi level. The silicon default value is $E_{trap} = 0$.

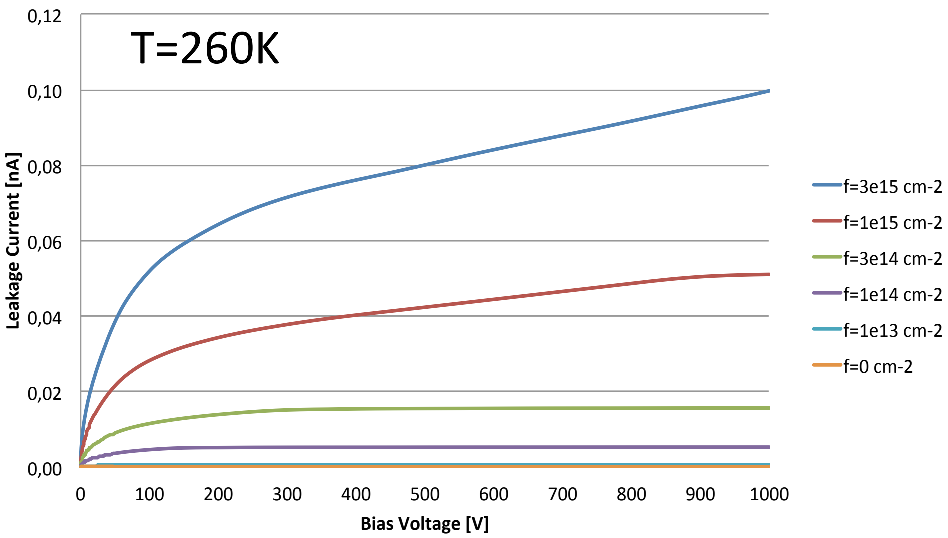
The minority lifetimes τ_n and τ_p are modelled as doping-dependent factors [101] with the *Scherfetter* relation given by the equation 5.16 and with the default parameter values listed in Table 5.2.

$$\tau_{n,p} = \tau_{min} + \frac{\tau_{max} - \tau_{min}}{1 + (\frac{N_A+N_D}{N_{ref}})^{\gamma}} \tag{5.16}$$

Electric Field
500V – 10^{15} cm^{-2}



Leakage Current



Temperature dependence:

$$I \propto \exp\left(-E_g / 2k_B T\right)$$