A naïve parametrization of initial acceptor removal

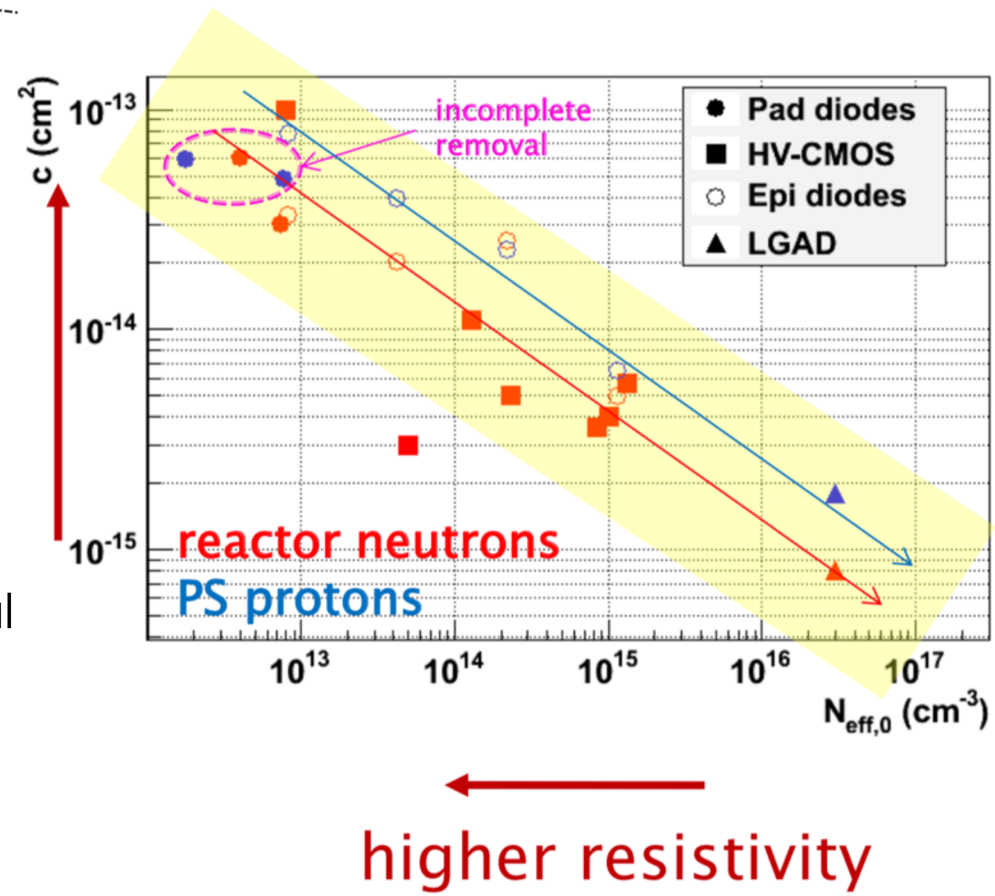
Aide memoire:

$$N(\emptyset)_A = g_c * \emptyset + N(0)_A * e^{-c(N(0)_A)*\emptyset} + N_1 + N_2$$

This is the "initial acceptor removal" term

What is "c(N(0))" [L^2]?

We know it depends on the initial acceptor density: it becomes smaller at larger density



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A naïve parametrization of initial acceptor removal

Let's rewrite the acceptor removal term:

$$e^{-c(N(0)_A)*\emptyset} \rightarrow e^{-\emptyset/\emptyset_o}$$

In this definition, ϕ_o is the fluence needed to have 1/e of the initial doping density left:

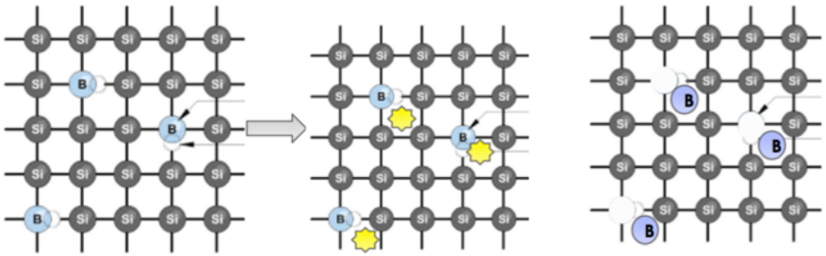
$$N(\emptyset_o)_A = N(0)_A * e^{-\emptyset_o/\emptyset_o} \rightarrow \frac{N(\emptyset_o)_A}{N(0)_A} = e^{-1}$$

ϕ_o is therefore larger for larger initial acceptor densities: you need more irradiation to remove larger values of initial doping.

A two steps process

Initial acceptor removal is believed to be a two steps process:

1. Irradiation knocks out a silicon atom
2. The interstitial silicon atoms trap the Boron (Gallium) dopant



Boron
1. Radiation creates interstitial defects
2. IInterstitials inactivate the Boron:
   Si_i + B_s ➔ Si_s + B_i

$$\emptyset_o * N_{Si} * \sigma = \left(1 - \frac{1}{e}\right) * N(0)_A = N(0)_A^{rem}$$

Φ_o = fluence [cm^{-2}]

N_{si} = silicon atom density 5*E22 [cm^{-3}]

σ = fit parameter [cm^2]: cross section for the 2 steps process

1. ϕ+Si →Si_i
2. Si_i+B_s ➔ Si_s+B_i

$N(0)_A^{rem}$ = removed initial acceptor after a fluence ϕ_o [cm^{-3}]

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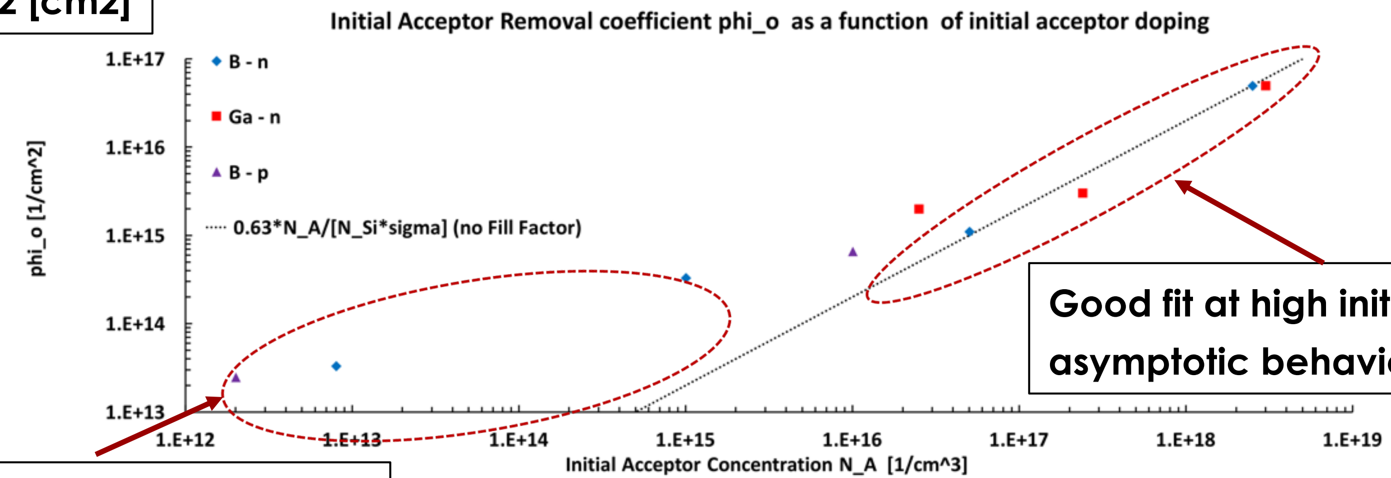
Comparison model - data

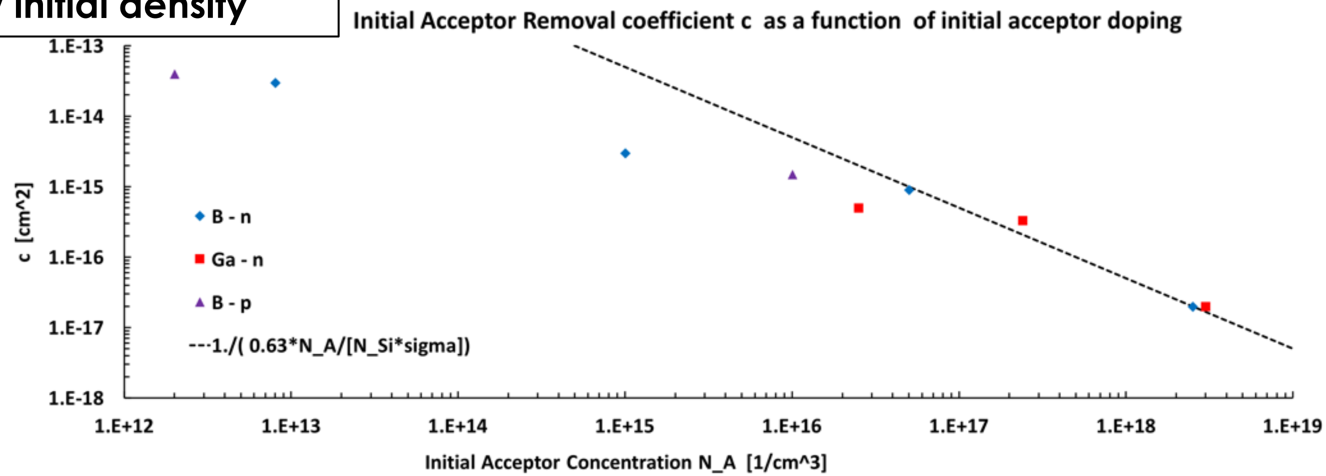
$$\emptyset_o * N_{Si} * \sigma = N(0)_A^{rem}$$

Fit parameter
σ = 8.3E-22 [cm2]



Good fit at high initial density: asymptotic behavior = linear

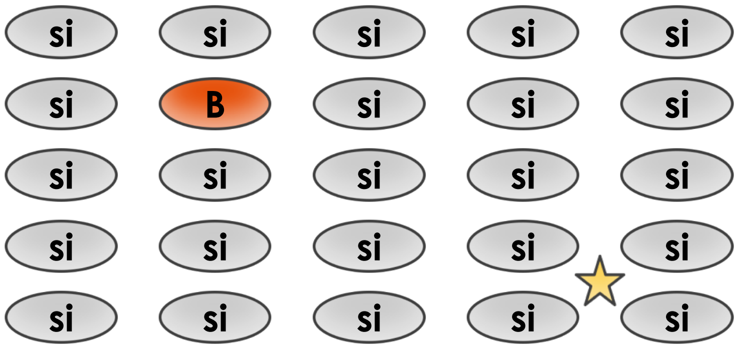
bad fit at low initial density



Need to have a "Density factor" that takes into account density effects

Initial acceptor density factor

$$\emptyset_o * N_{Si} * \sigma = N(0)_A^{rem}$$



At low initial acceptor densities:

Si-interstitials do not find the Boron

➔ a higher fluence is needed to remove low density Boron

Density factor: probability of Si-interstitials to be in the proximity of Borons substitutional.

Limiting behaviors:

$$\lim_{N(0)_A \to 0} Dn = 0$$

impossible to find B atoms

$$\lim_{N(0)_A \to \infty} Dn = 1$$

Very easy to find B atoms

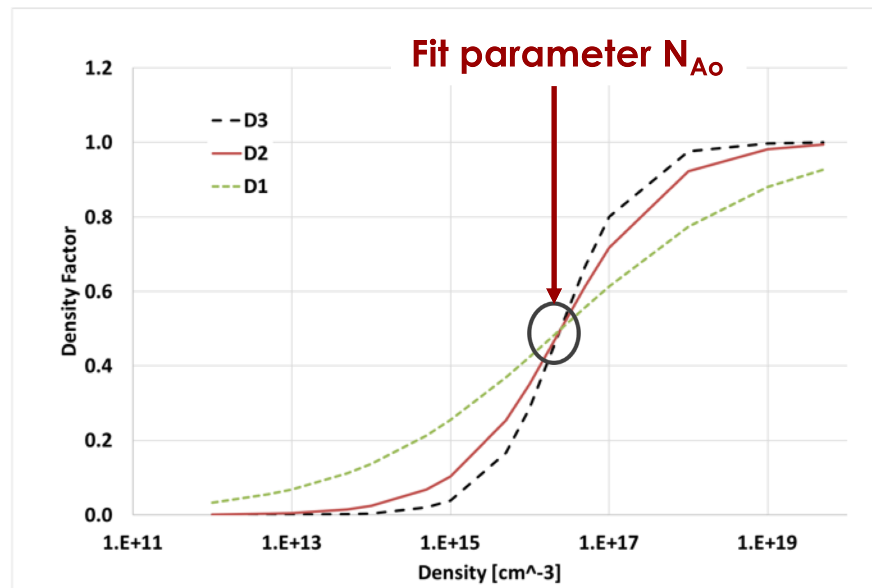
$$Dn = \frac{1}{1+\left(\frac{N_{Ao}}{N(0)_A}\right)^{n/3}}$$

n = 1 linear

n = 2 surface

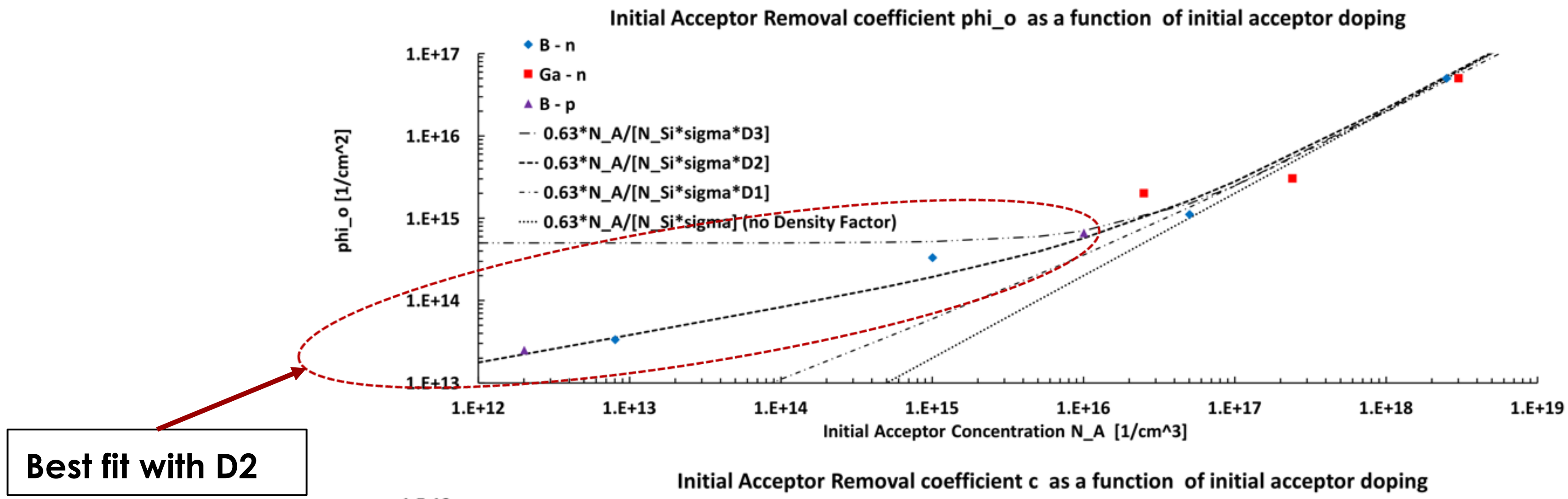
n = 3 volume

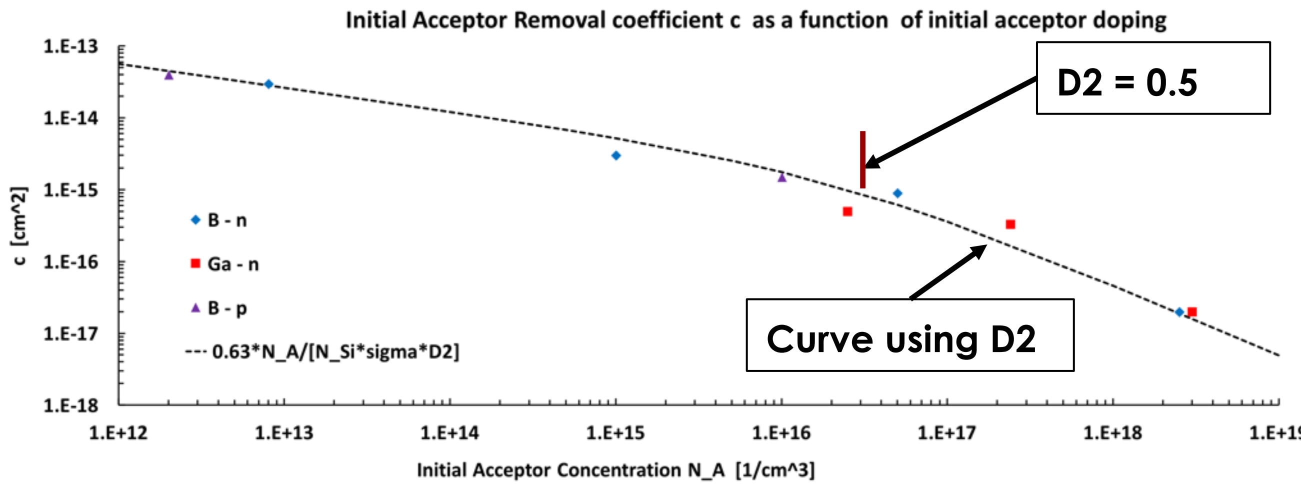
N_{Ao} = 2.5 E16 [cm^{-3}]



Comparison model - data

$$\emptyset_o = \frac{N(0)_A^{rem}}{N_{Si} * \sigma * Dn}$$





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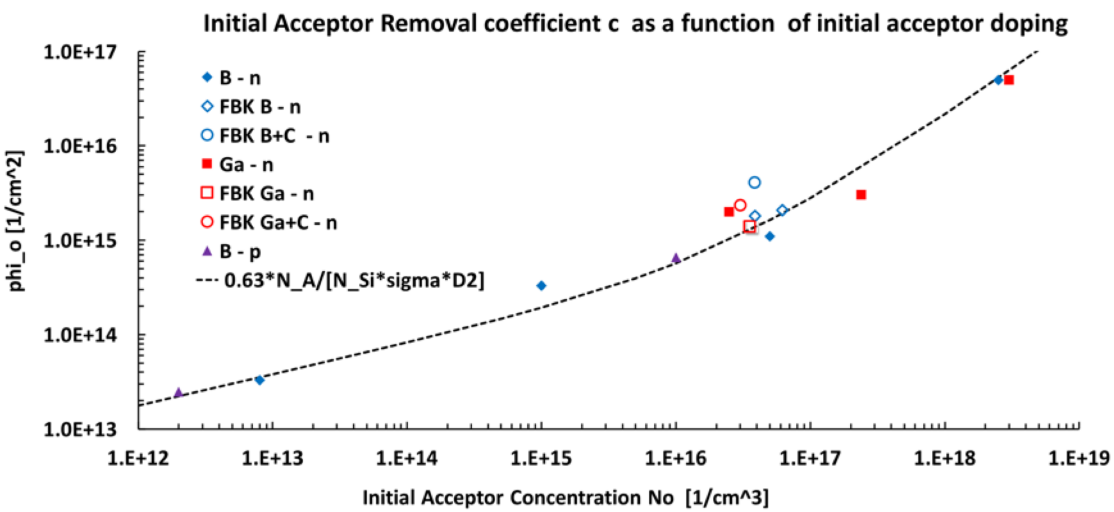
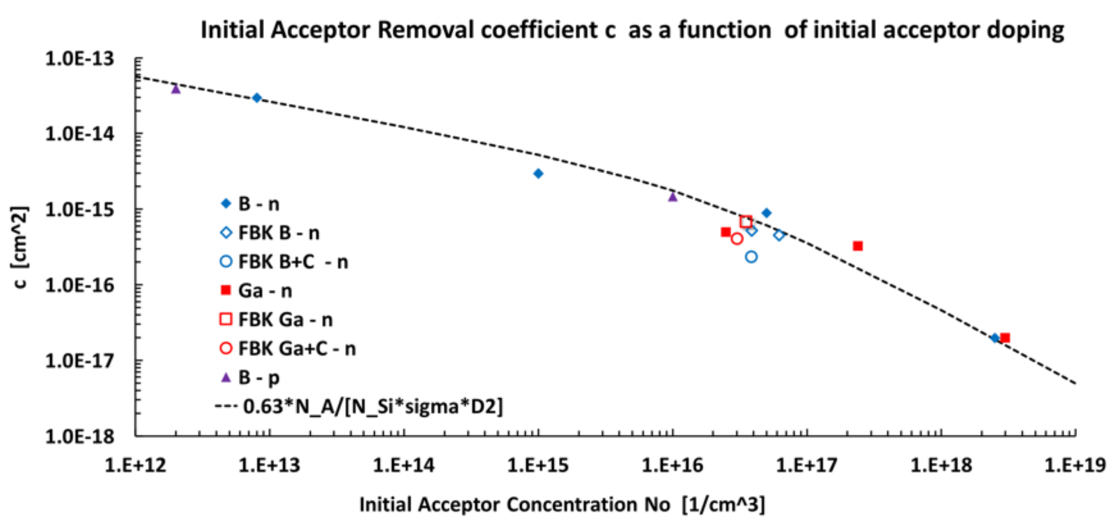
Comparison model – data with UFSD2

$$\emptyset_o = \frac{N(0)_A^{rem}}{N_{Si} * \sigma * Dn} = \frac{N(0)_A^{rem}}{N_{Si} * \sigma}\left(1 + \left(\frac{N_{Ao}}{N(0)_A}\right)^{2/3}\right)$$



N_{Ao} = 2.5 E16 [cm^{-3}]

σ = 8.3E-22 [cm2]



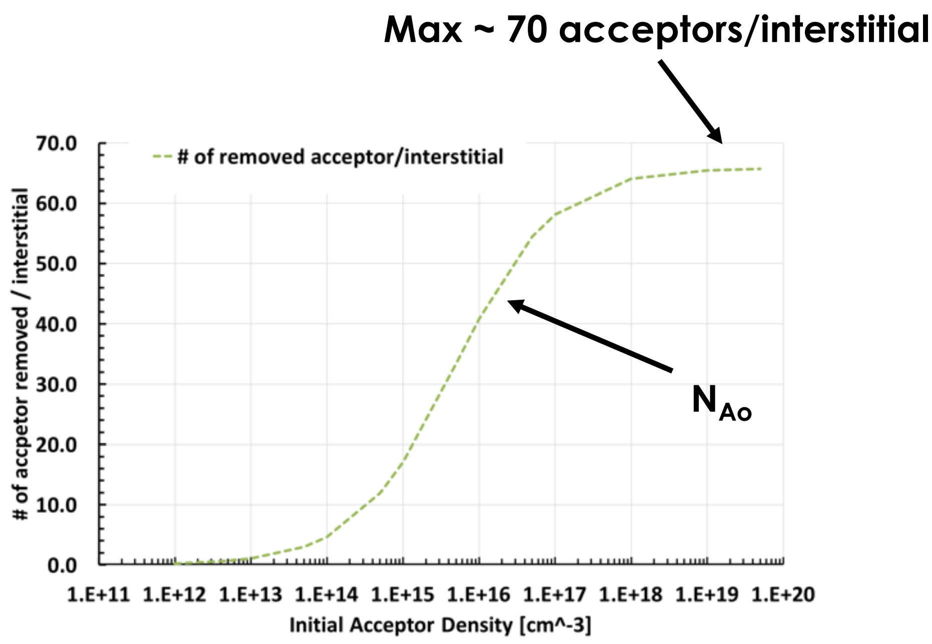
A few comments on acceptor removal

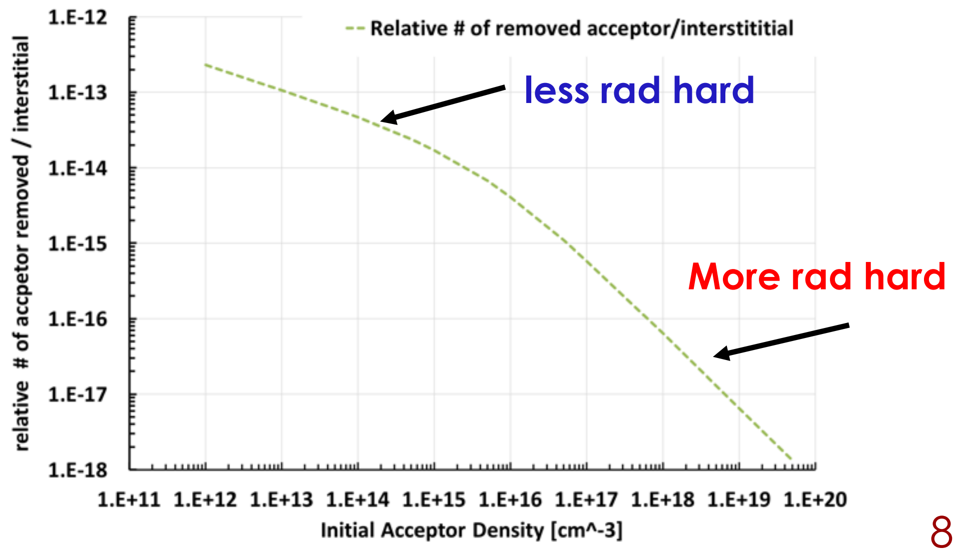
At very high acceptor density, **an interstitial can remove at most ~70 acceptors**

N_{Ao} = density at which an interstitial removes 50% of its maximum

Even though at low density less acceptors are removed, the relative change is much higher at low densities:

Rad-hard designs need to use heavily doped silicon





Formalism

We now use:

$$\emptyset_o = \frac{1}{c}$$

In order to maintain a similar nomenclature we can write:

$$\emptyset_o = \frac{1}{c}\,\frac{N(0)_A^{rem}}{N_{Si^*}\sigma_o}\left(1+\left(\frac{N_{Ao}}{N(0)_A}\right)^{2/3}\right) = \frac{1}{c}\,D2(N(0)_A)$$

specific to B, B+C, Ga, Ga+C

Common to all doping type

Summary

$$\phi_o = \frac{1}{c}$$

The inverse of the "c" coefficient has a simple meaning:
the fluence needed to reduce initial acceptor to 1/e

From this definition, a simple model of the evolution of ϕ_o with initial acceptor density is proposed:

- At high $N(0)_A$: ϕ_o grows linearly with $N(0)_A$
  → Each impinging particle removes at most ~ 70 acceptors
- At low $N(0)_A$: ϕ_o needs a Density factor to account for initial acceptors low density
- The Density factor that fits the data best is a ratio of area (D2)