Replacing Boron with Gallium

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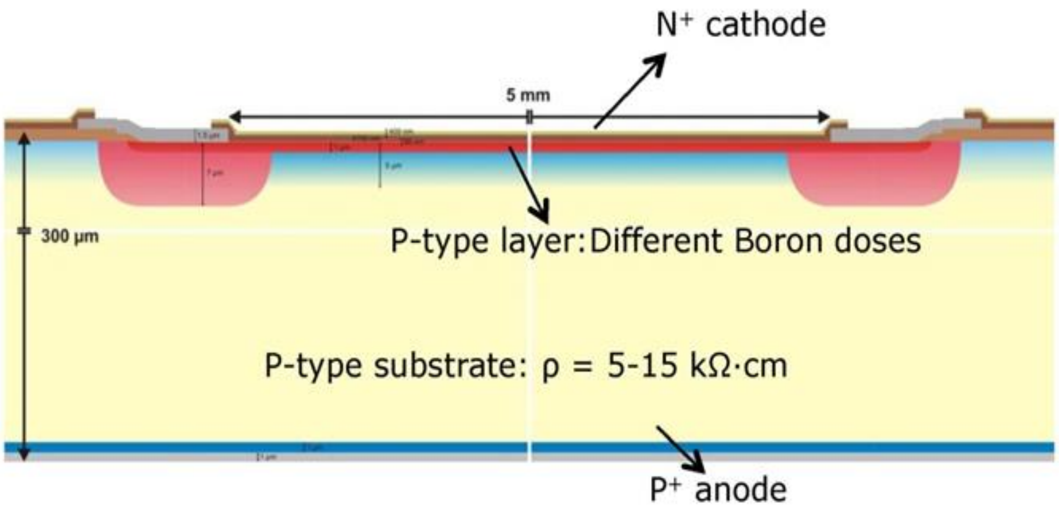
LGAD: Stack



Doping
p bulk: FZ Np=1e12 cm^-3
n cathode: Phosphorus Nn~1e19 cm^-3

Surface passivation
bi-layer (from silicon surface to top: 800 nm thermal oxide + 40 nm deposited alumina).

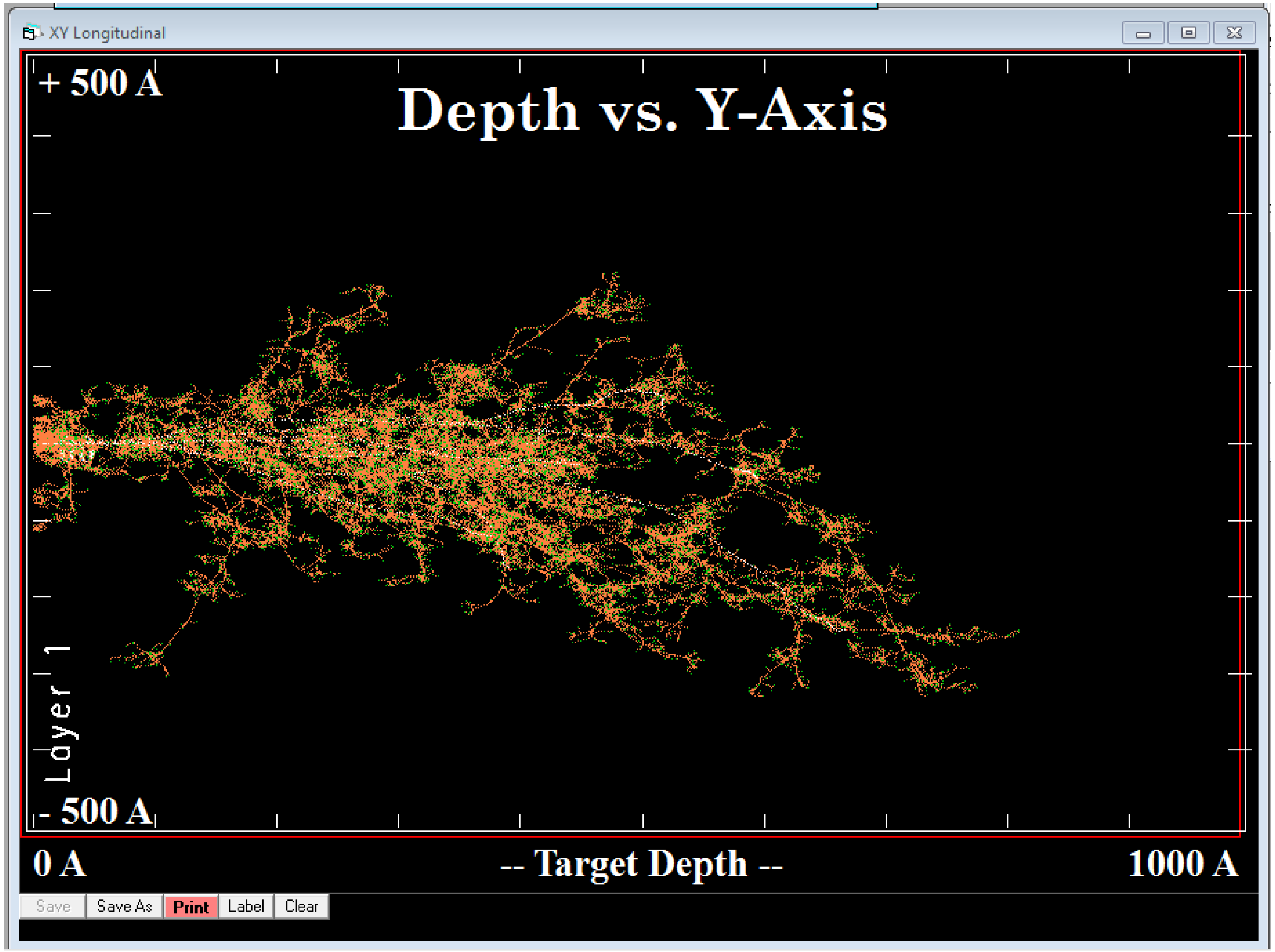
Phosphorous implantation:
First: Energy: 70 KeV. Dose: 1E15 atm/cm2; Second: Energy: 150 KeV. Dose: 5E14 atm/cm2
Post P implant anneal: 1000 Celsius degrees for 44 min

A few wafers had Boron replaced by Gallium

C-V on Ga implanted structures reveal the absence of the gain-layer
Maureen Petterson performed simulations with SRIM 2013 using two implantation energies (including 400 nm thermal oxide)

Original Gallium implantation:	**Energy: 60 KeV**. Dose: 1.4E13 atm/cm2
Alternative Gallium Implantation:	**Energy: 1500 KeV**. Dose: 1.4E13 atm/cm2

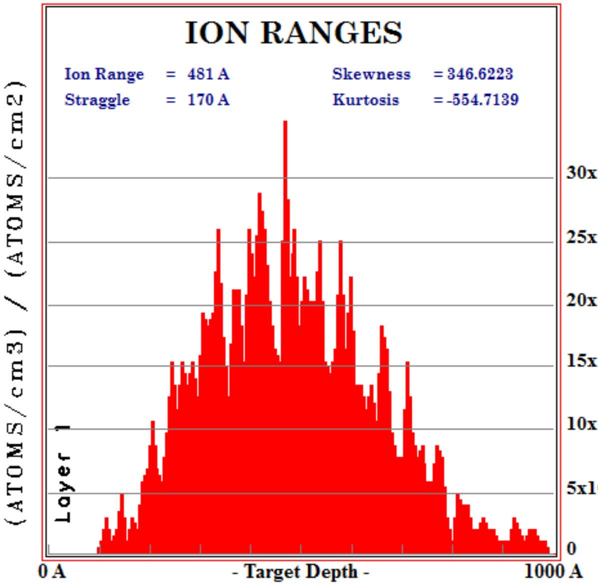
60keV Ga into Si: Cascades



A few selected events shown

SRIM 2013: Stopping Ranges of Ions in Matter
Damage Calculation: Full Cascades

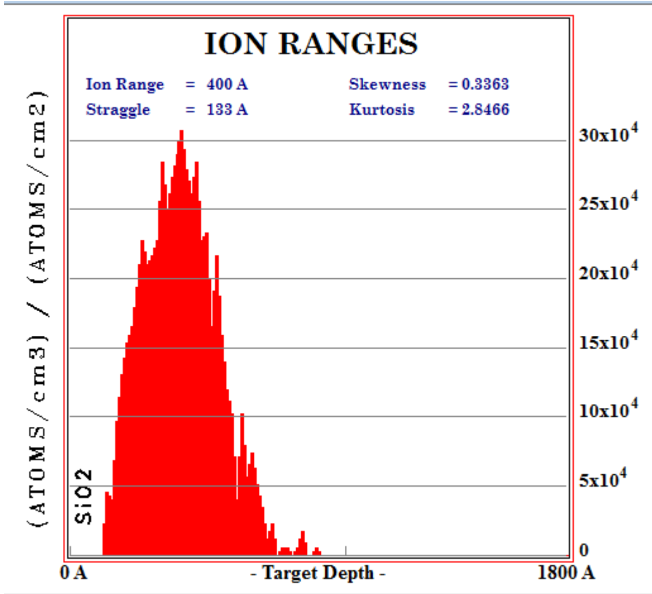
Ga into Si/SiO^2: Ion Distribution



ION RANGES

Ion Range = 481 A
Straggle = 170 A
Skewness = 346.6223
Kurtosis = -554.7139

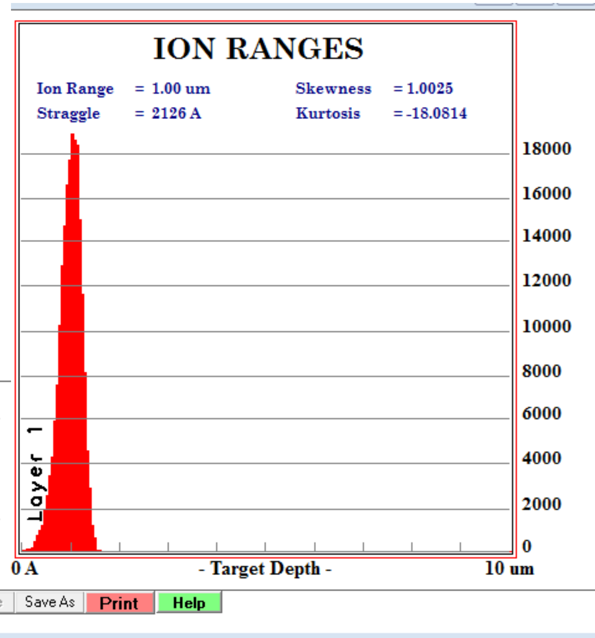
60keV Ga into Si
Mean ≈ 0.05µm
Max ≈ 0.1µm



ION RANGES

Ion Range = 400 A
Straggle = 133 A
Skewness = 0.3363
Kurtosis = 2.8466

60keV Ga into SiO2
Mean ≈ 0.04µm
Max ≈ 0.08µm

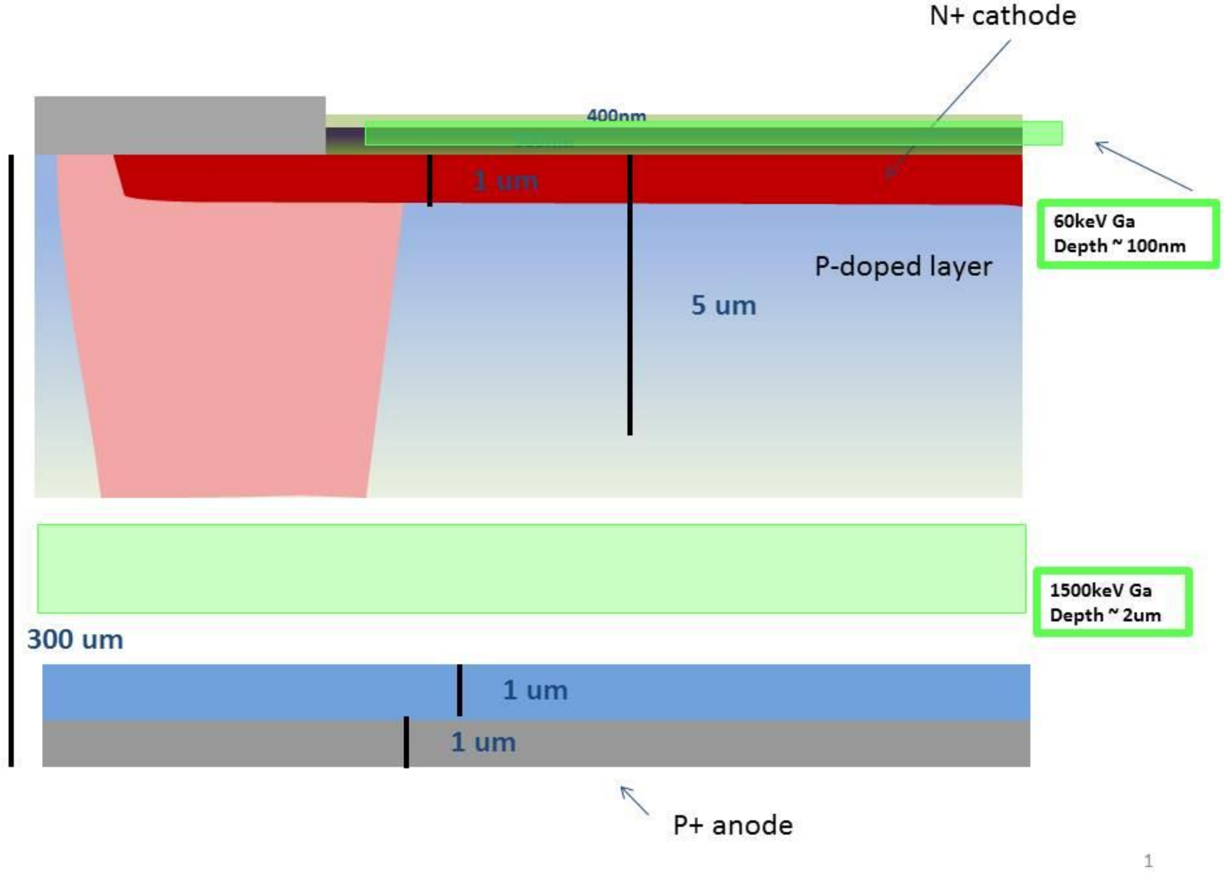


ION RANGES

Ion Range = 1.00 um
Straggle = 2126 A
Skewness = 1.0025
Kurtosis = -18.0814

1500keV Ga into Si
Mean ≈ 1µm
Max ≈ 1.4µm

Ga into LGAD: Ion Distribution

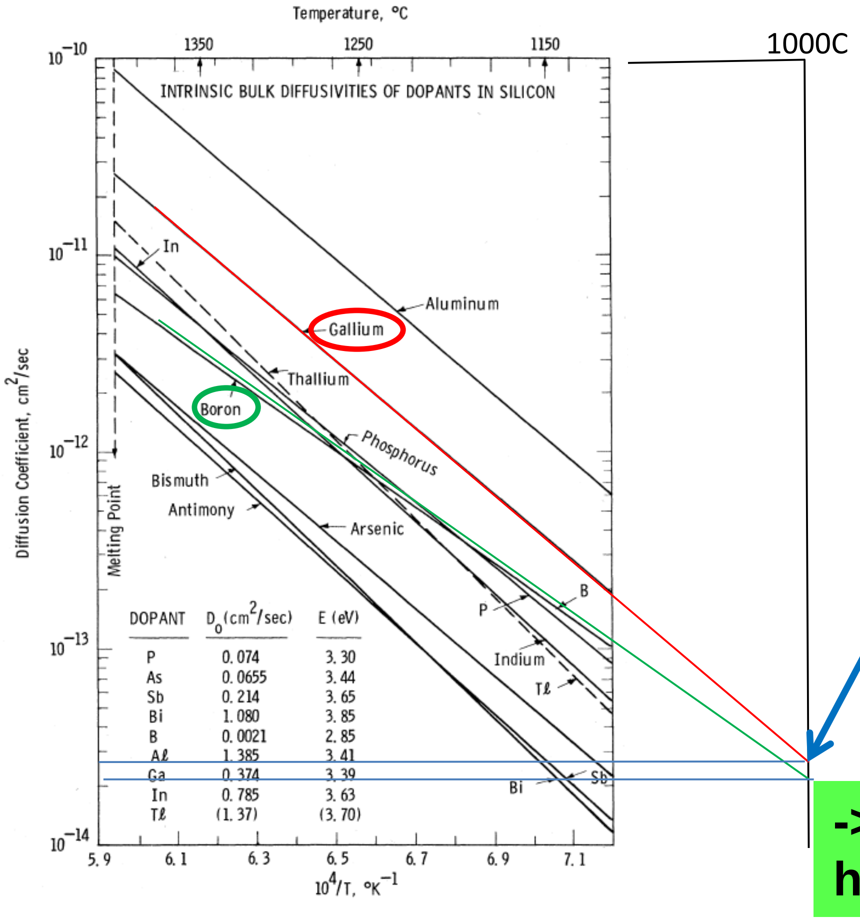


Ion Penetration:
60keV Ga into SiO_2
Max Depth ≈ 0.1µm
i.e. all end up within SiO_2

Ion Penetration:
1500keV Ga into SiO_2/Si
Max Depth ≈ 2 µm
i.e. Large fraction ends up within Si

Annealing of B/Ga in Si/SiO_2

Diffusion Constant D for Si/SiO_2



DOPANT	D_o (cm^2/sec)	E (eV)
P	0.074	3.30
As	0.0655	3.44
Sb	0.214	3.65
Bi	1.080	3.85
B	0.0021	2.85
Aℓ	1.385	3.41
Ga	0.374	3.39
In	0.785	3.63
Tℓ	(1.37)	(3.70)

SiO2 data from
H. G. Francois-Saint-Cyr et al.
JOURNAL OF APPLIED PHYSICS, VOLUME 94, No 12
15 DEC. 2003

D(1000°C) [cm^2/sec]

	SiO_2	**Si**
B:	< 6e-18	2e-14
Ga:	< 6e-18	3e-14

In Si, 1000°C:

D(B,Si)) ≈ D(Ga,Si)

Si vs.SiO_2:

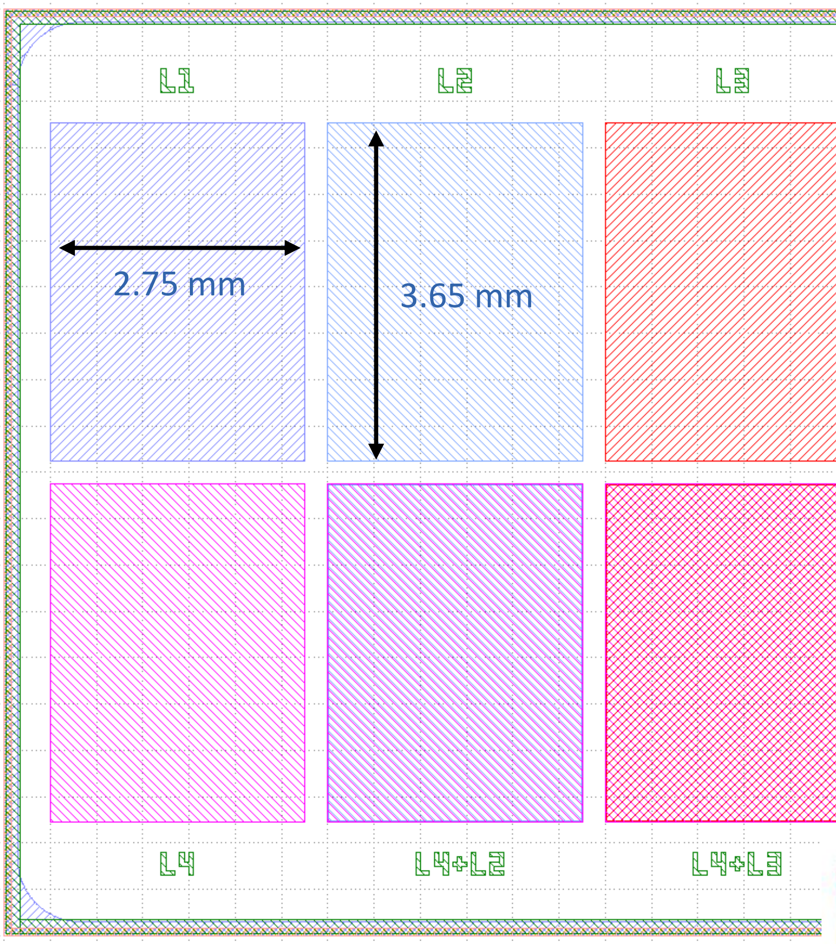
$D(B,SiO_2) < 3*10^{-4}\ D(B,Si)$
$D(Ga,SiO_2) < 2*10^{-4}\ D(Ga,Si)$

Ions implanted in SiO_2 can’t anneal out!

-> Ga implantation needs to be made at higher Energy (~1500 keV)

-> Doping Concentration Test structures need to include the entire stack (SiO_2 & Si)

Specific Test Structure. SRP, SIMS, XPS



- L1 P-Stop, C-Stop Well
- L2 P-Well (P Multiplication)
- L3 JTE
- L4 N-Well
- L4 + L2 N-Well over P-Well
- L4 + L3 N-Well over JTE

+ Oxide + Alumina

The bevel angle α determins the depth d of probing:

α =1 deg d= 3mm*0.017 = 50 μm

α =4 deg d= 200 μm