Junction formation in Ge by co-implant. and pre-heating techniques

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Content

- Introduction
  Purpose and Motivation
- Experimental
- Acceptor impurity implanted Germanium
- Aluminum co-implantation with Phosphorus
- Pre-heating before implantation
- Summary

Introduction

Mobility, Bandgap

	Si	Ge	GaAs	InAs
Mobility, electron	1,600	3,900	9,200	40,000
Mobility, hole	430	1,900	400	500
Bandgap	1.12	0.66	1.42	0.36

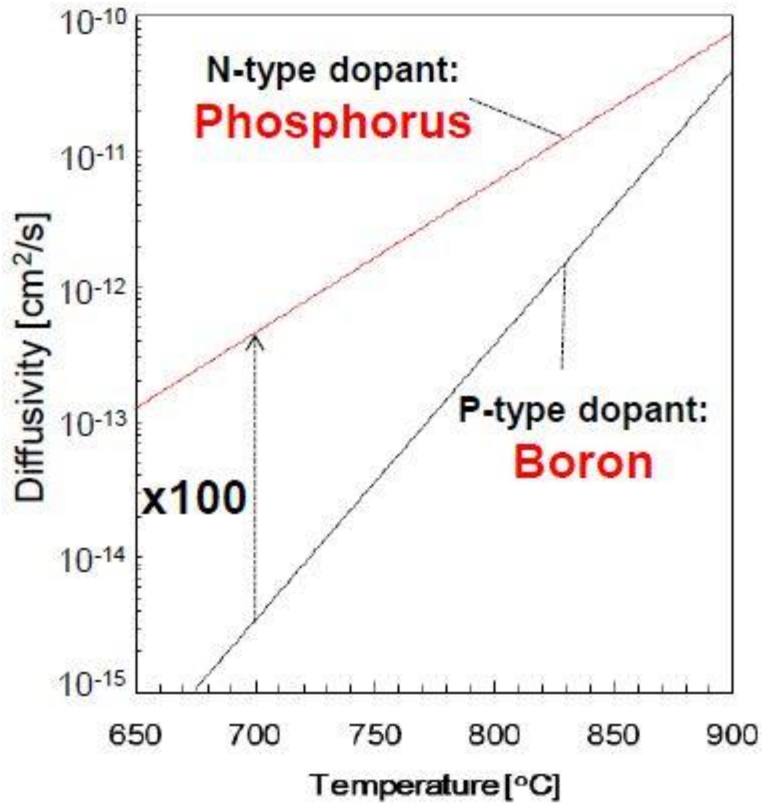
Integration Compatibility with Si

Substrate ⇔ Impurity

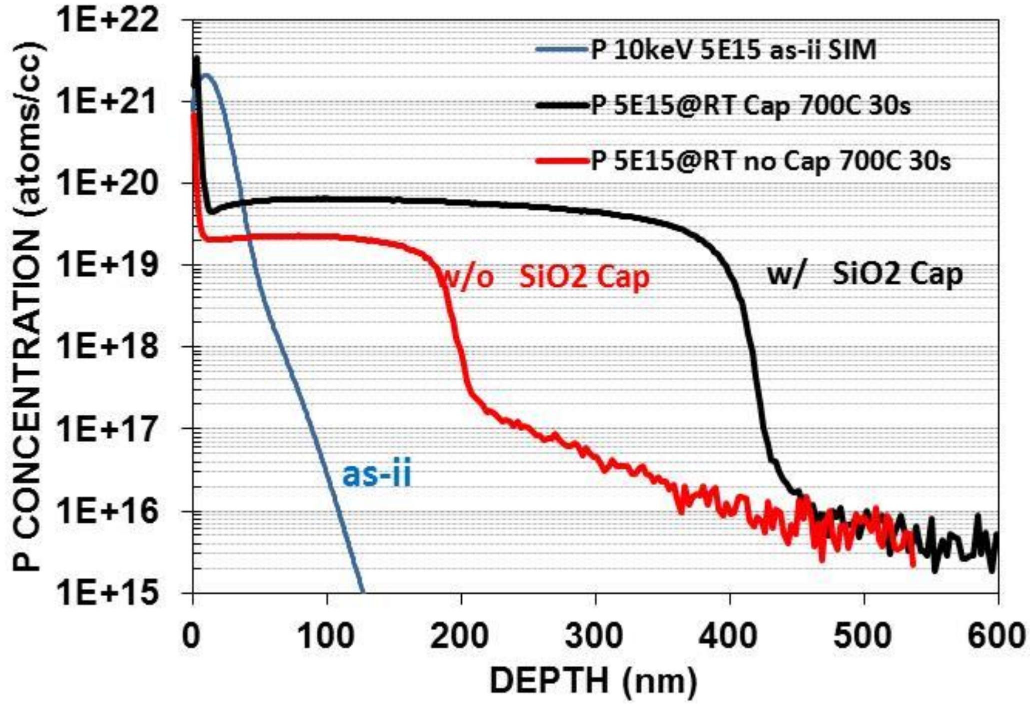
Ge is one of the promising channel materials for advanced CMOS devices.

Problematic in n-type dopants

- Large n-type dopant diffusivity



- Diffusivity change due to out-diffusion



- Large N^+/P Junction large leakage current

"Need precise control of dopant behaviors"

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Experimental

Sample preparation

- ✓ 4 inch CZ (100) Ge substrate
- ✓ Ion Implantation

  acceptor impurities: B, Al, Ga

  some samples co-implanted with

  PAI: Ge, C7
- ✓ SiO_2 cap depo: 10-30nm
- ✓ RTA 500-700^{o}C 30sec

Evaluation

Rs, SIMS, TEM, Hall effect measurement*

*the ALPro technology from Active Layer Parametrics, Inc. (CA) which uses a differential Hall measurement

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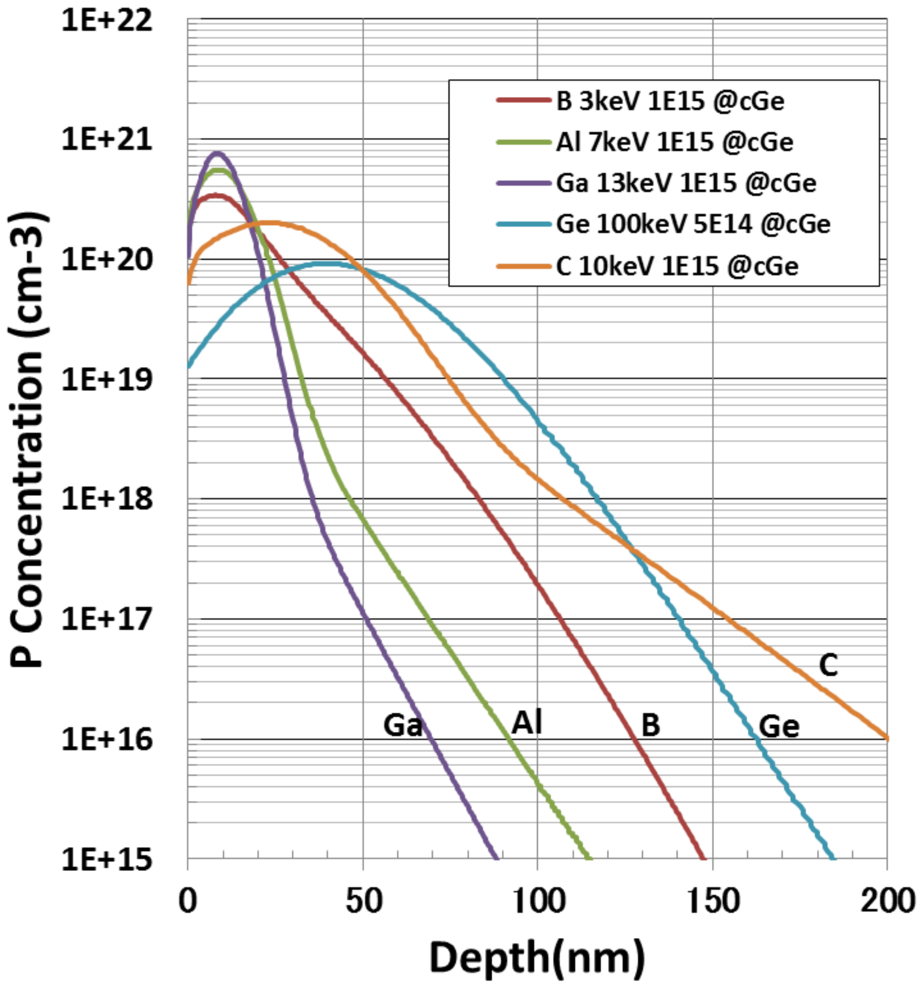
Profile Simulation



- Energies are chosen as Rp's are almost the same.
- C and Ge PAI:

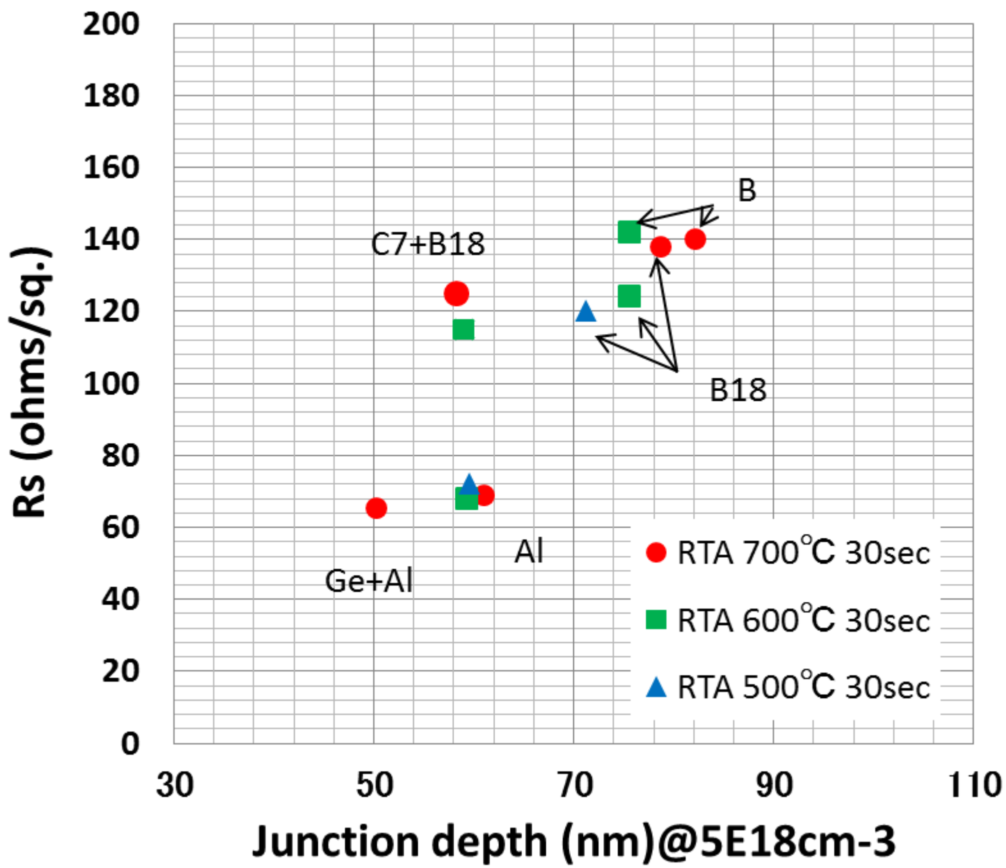
  A little deeper profile

  Amorphous Ge thick

  Ge 100nm

  C 21nm

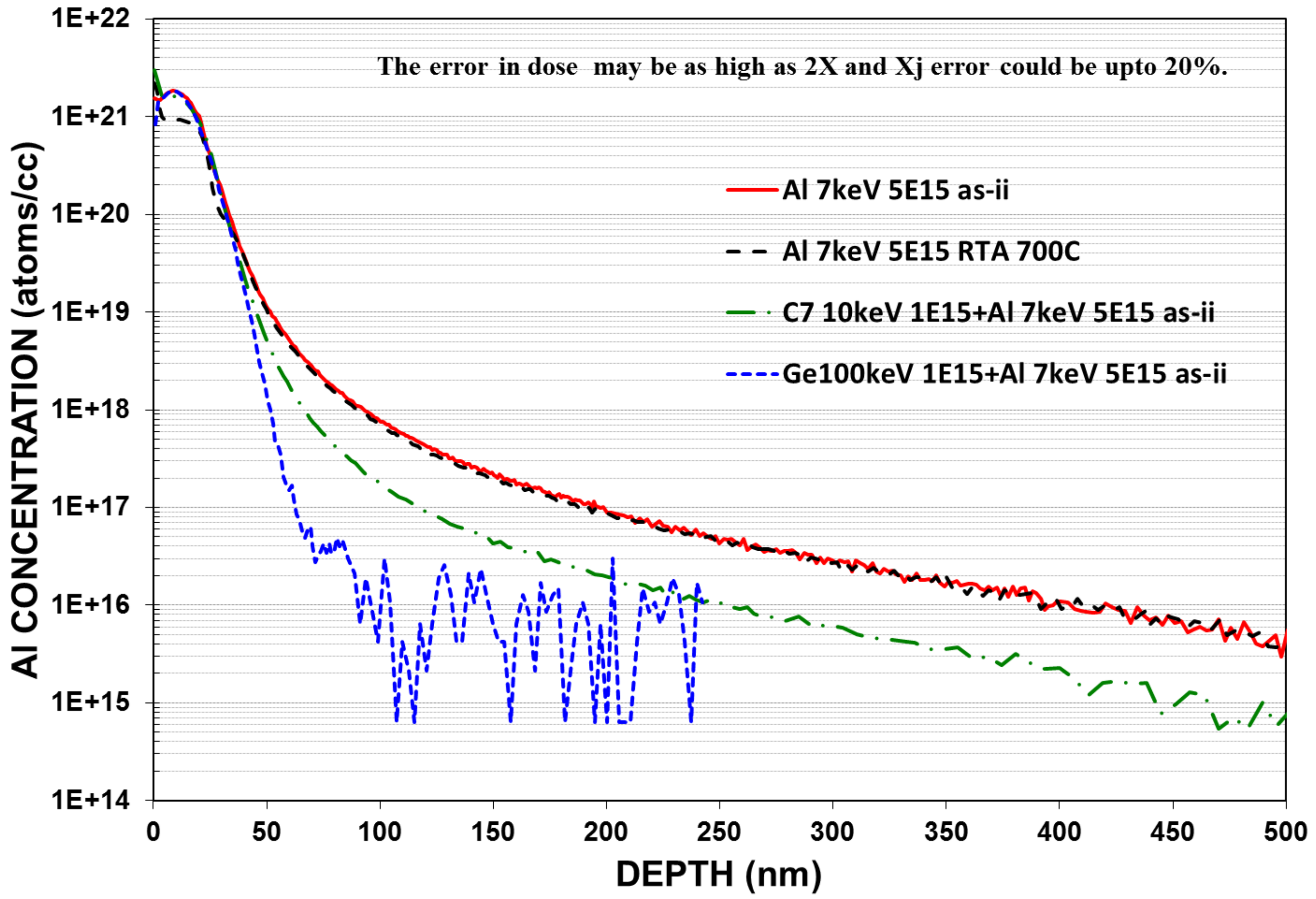
– Rs vs Xj – Acceptor impurities



- For Al, lowest Rs can be obtained including Ga not in the figure.
- Ge or C7 co-implant induces shallower and lower resistance.

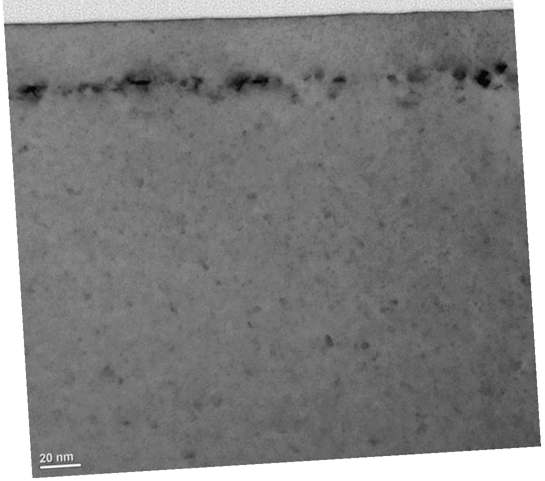
Al depth profiles

- **Al has a large tail. The tail is suppressed with PAI.**
- **Al diffusion never occurs during annealing up to 700^{o}C 30sec.**



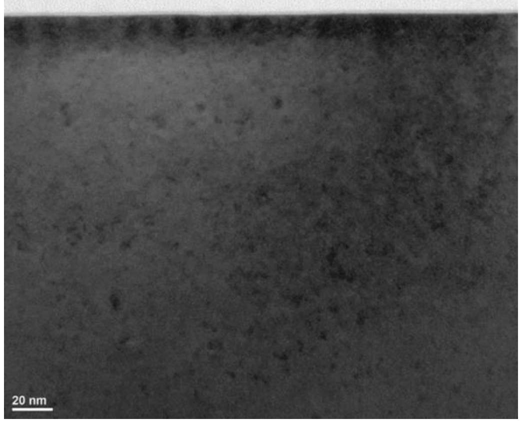
TEM observation

Al 7keV 5E15 600°C 30s

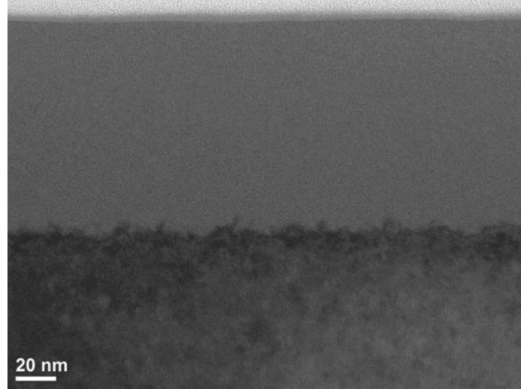


- EORD’s remains in Al implant sample after 600°C anneal. EORD’s disappears after 700°C anneal, but defects remains at near surface.
- Ge PAI produces ~100nm a-Ge.
- No defects can be seen in Ge PAI sample after 700oC anneal. This explains the low Rs.

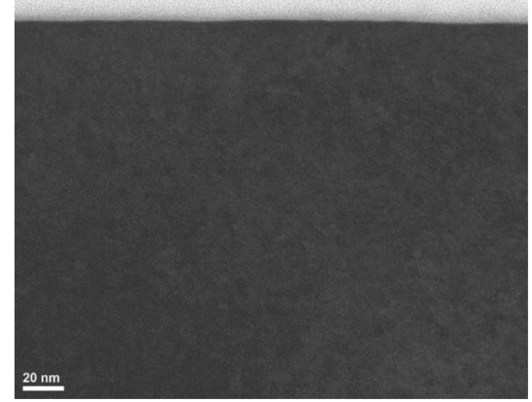
Al 7keV 5E15 700°C 30s



Ge 100keV 1E15
+Al 7keV 5E15 as-ii



Ge 100keV 1E15
+Al 7keV 5E15 700°C 30s



Sub-summary

Annealing behavior of Aluminum implanted Ge has been studied.

(1) High solid solubility

(2) Al profiles with severe tailing, but suppressed by PAI

(3) No visible diffusion at less than RTA 700^{o}C,
(No radiation enhanced diffusion)

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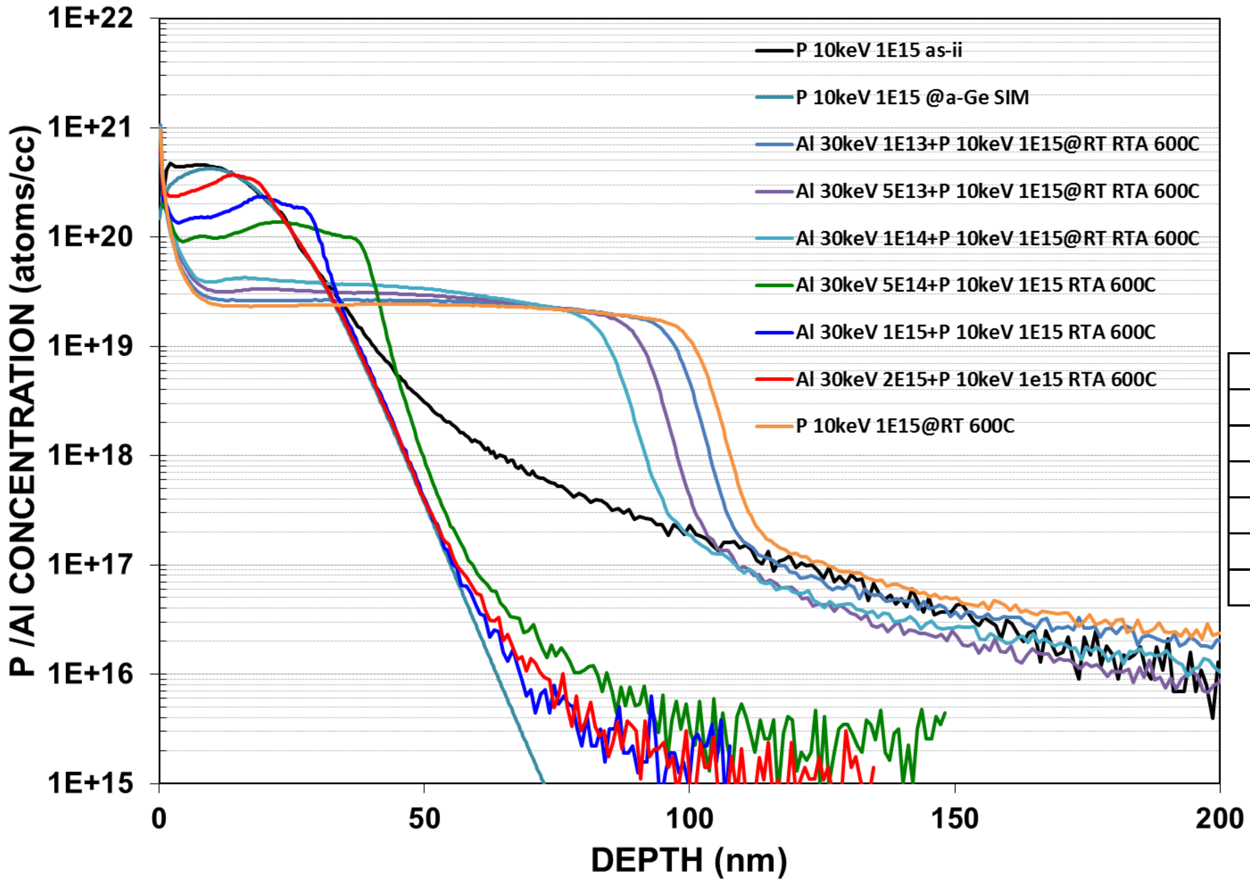
Al + P co-implant

- P diffusion retardation
- Diffusion retardation differs in between Al dose of 1E14 and 5E14



	Energy	Dose	a-Ge Thick (nm)
Al	30keV	2.00E+15	63
Al	30keV	1.00E+15	55
Al	30keV	5.00E+14	47
Al	30keV	1.00E+14	0
Al	30keV	5.00E+13	0
Al	30keV	1.00E+13	0

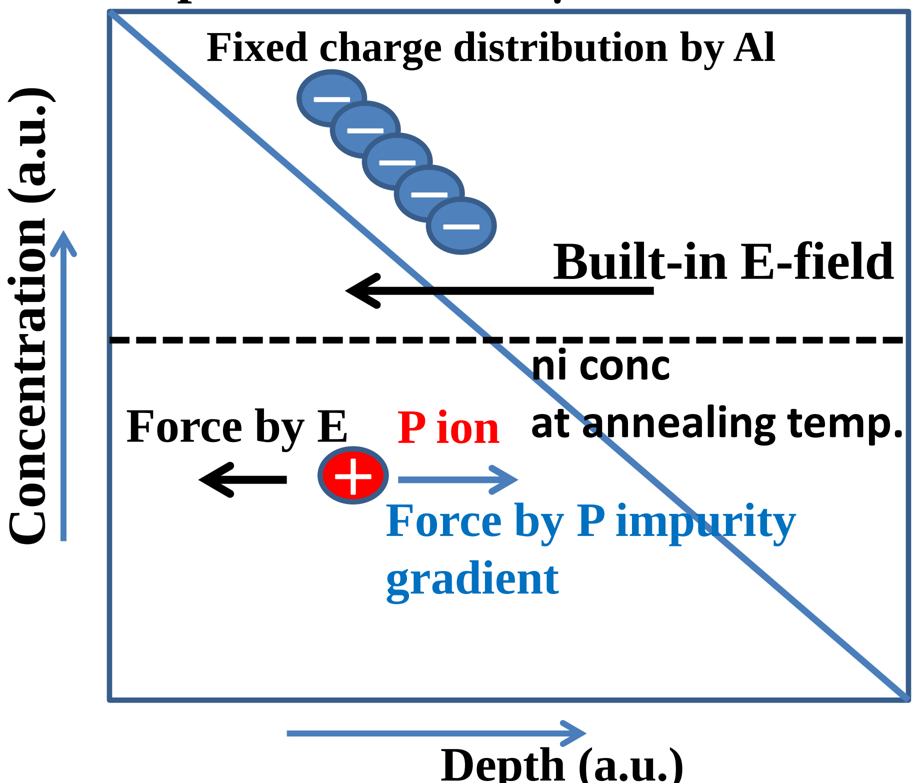
Reason for Phos. Diffusion Retardation

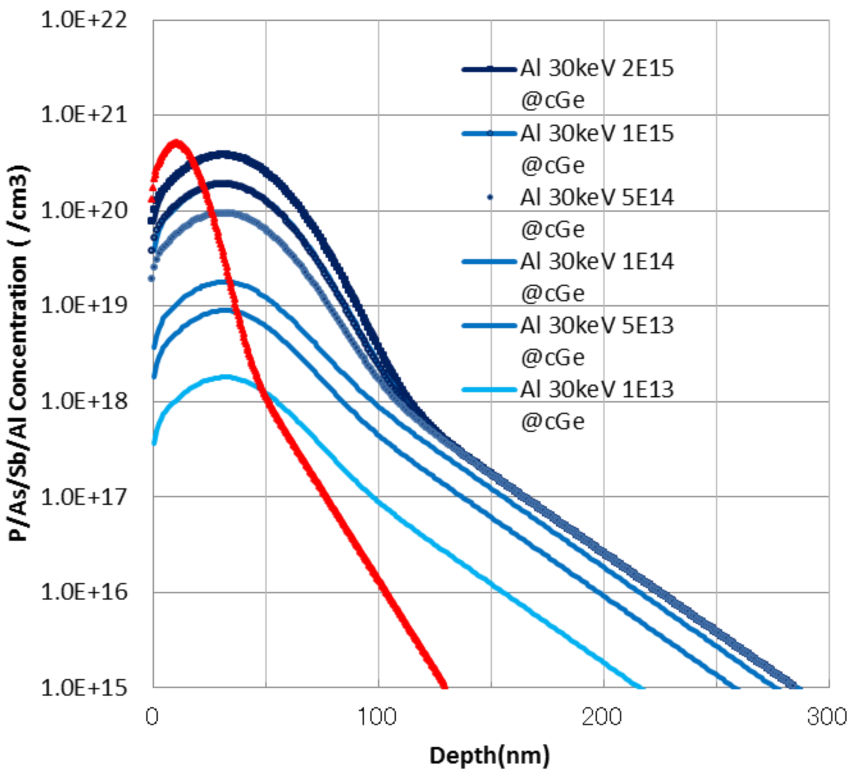
- Amorphous Ge formation & vacancy mediated diffusion
- Electric field by Acceptor impurity

Field Retarded Phosphorus Diffusion in Al-implanted Germanium

When carrier produced by Al exceeds the intrinsic carrier conc. ni at annealing temperature, remarkable diffusion retardation seems to occur by electric field induce by fixed charge distribution of Al.

$$Jp = -D \cdot dc/dx - \mu \cdot Nd \cdot E$$





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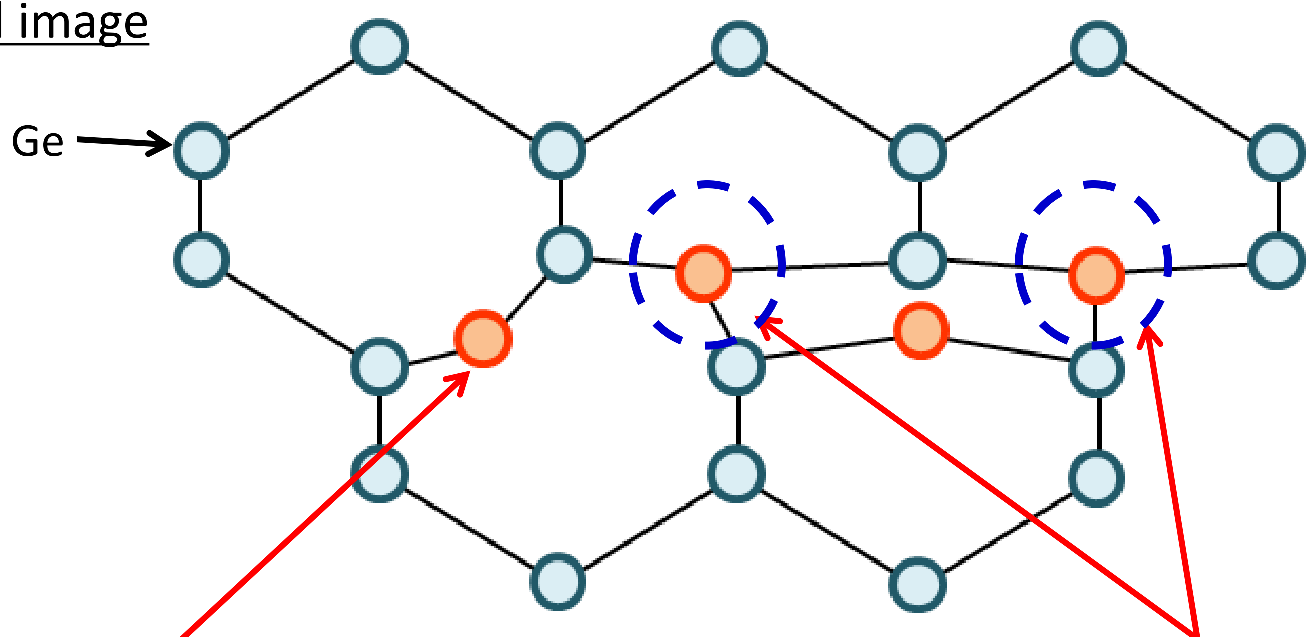
Effect of oxygen in Ge substrate

Root cause of low activation is oxygen atom at the surface of the Ge substrate.

Ge crystal image



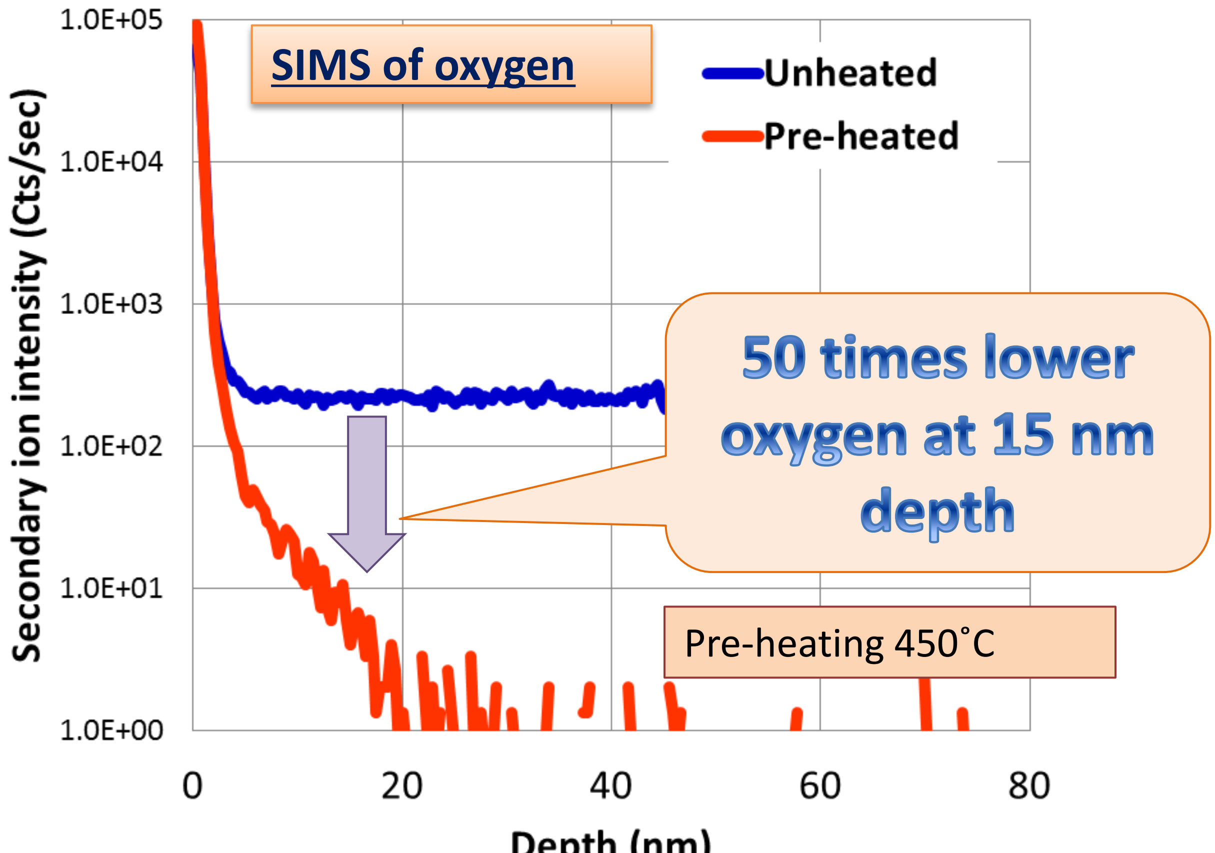
Solved oxygen

Act as donor (Thermal Double Donor)

2. Oxygen desorption by heating Ge substrate

Pre-heating before ion implantation

- Solid-solved oxygen is out-diffused by heating the substrate >400 ˚C.



High temperature implanter "IMPHEAT"

Up to 500°C

High temperature platen

- IMPHEAT is high-temperature implanter for SiC power device.
- Substrate on the platen can be heated up to 500 degC.
- In this study, Ge substrates were heated up to 450 degC and implanted after cooling in the vacuum chamber.

Experimental sequence

In vacuum

Pre-heating in vacuum
- Ge substrate was heated up to 450 degC.

Cooling down
- Keep the wafer in the vacuum chamber before implantation.

Pre-amorphization implant (PAI)
- Ge^+, 10keV, 1E15

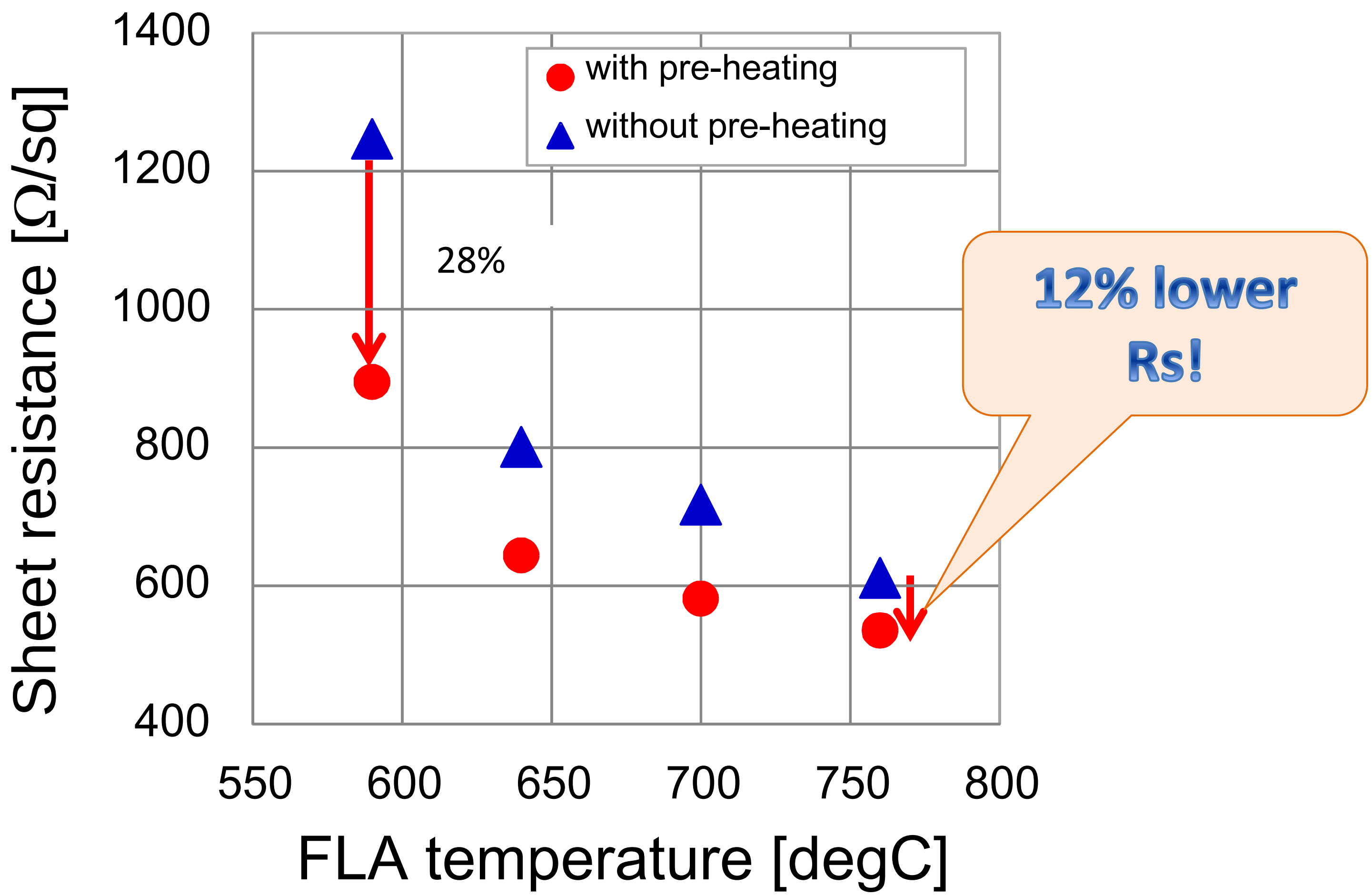
Ion implantation
- BF_2^+, 4keV, 1E15

Flash lamp annealing
- "LA-3000-F" of SCREEN Semiconductor Solutions
- 590 to 760 ˚C

Evaluation
- Sheet resistance
- SIMS
- Carrier concentration, Carrier mobility by hall effect measurement

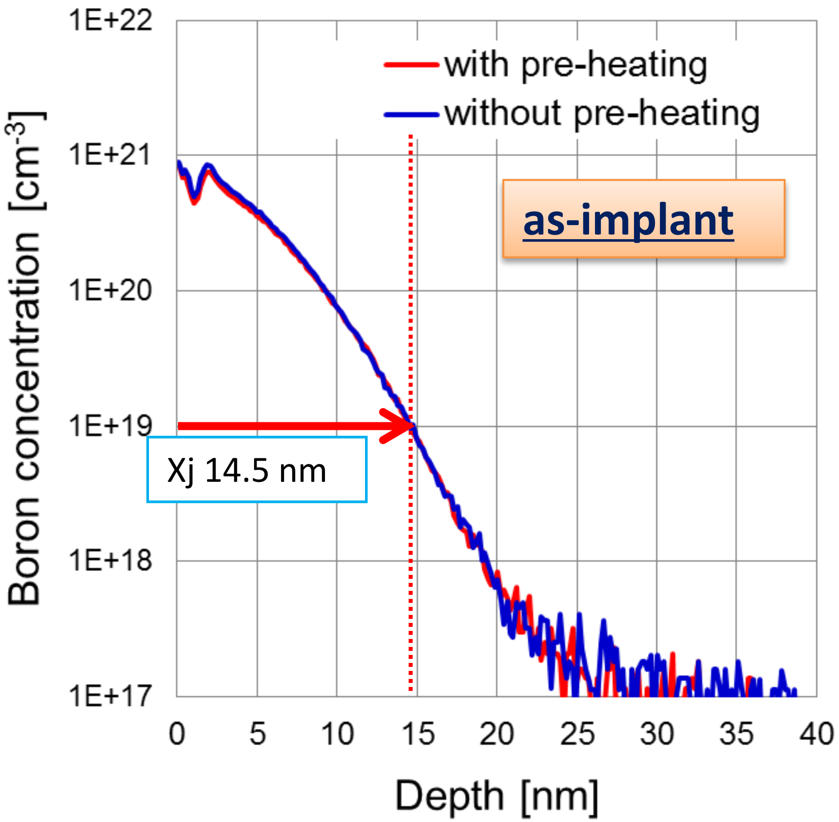
IMPHEAT
Chain implant recipe

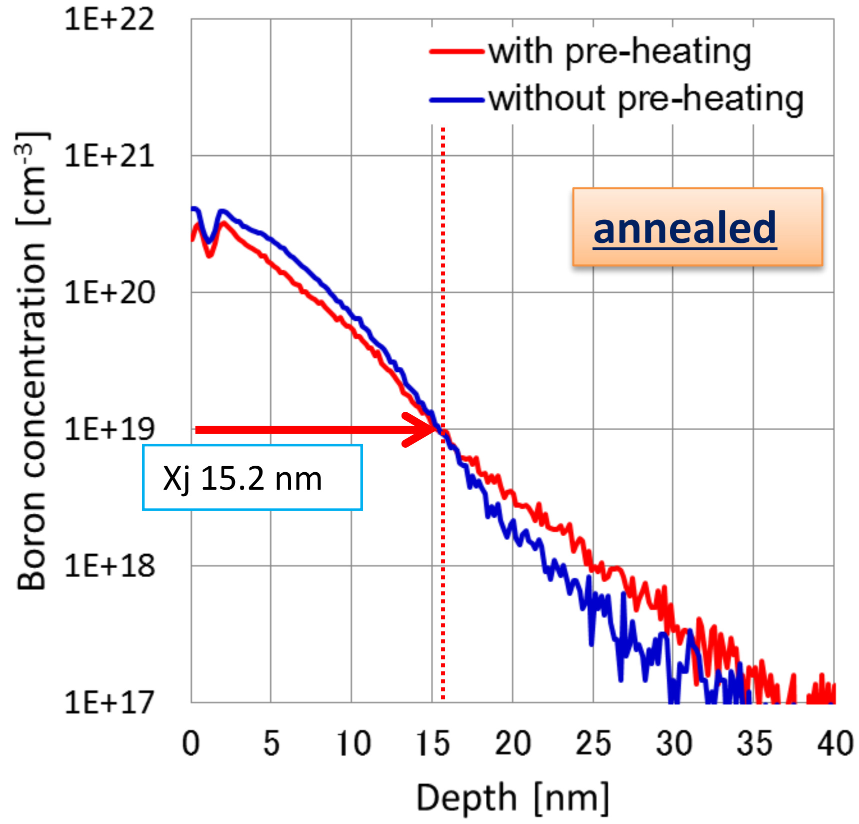
3. Result of p+ dopant activation



- Rs can be reduced by oxygen desorption by pre-heating

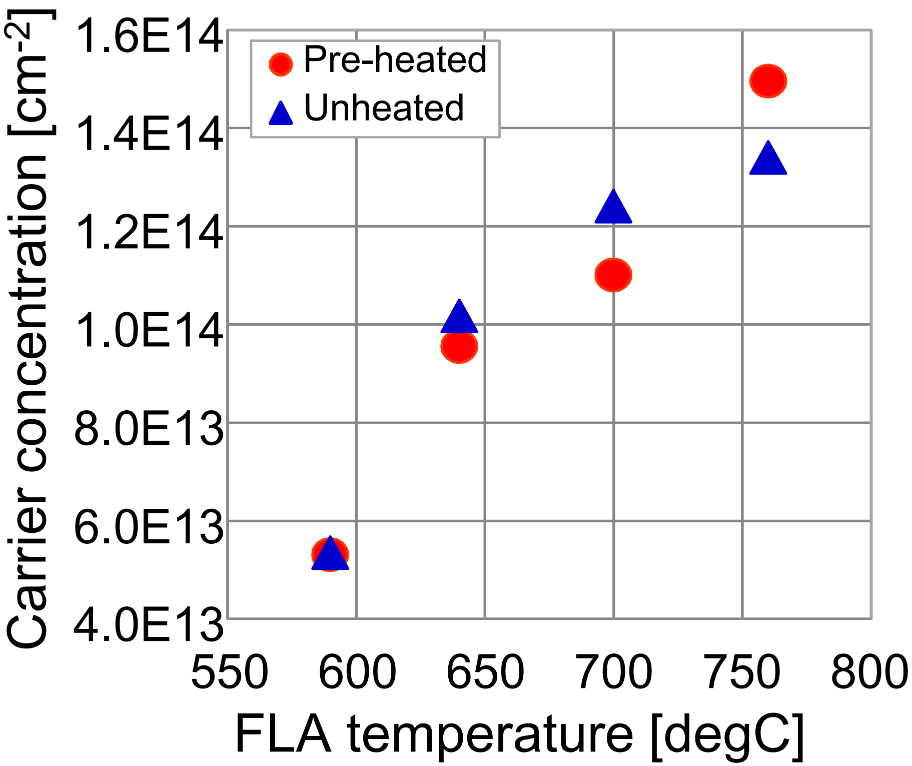
SIMS profile of boron



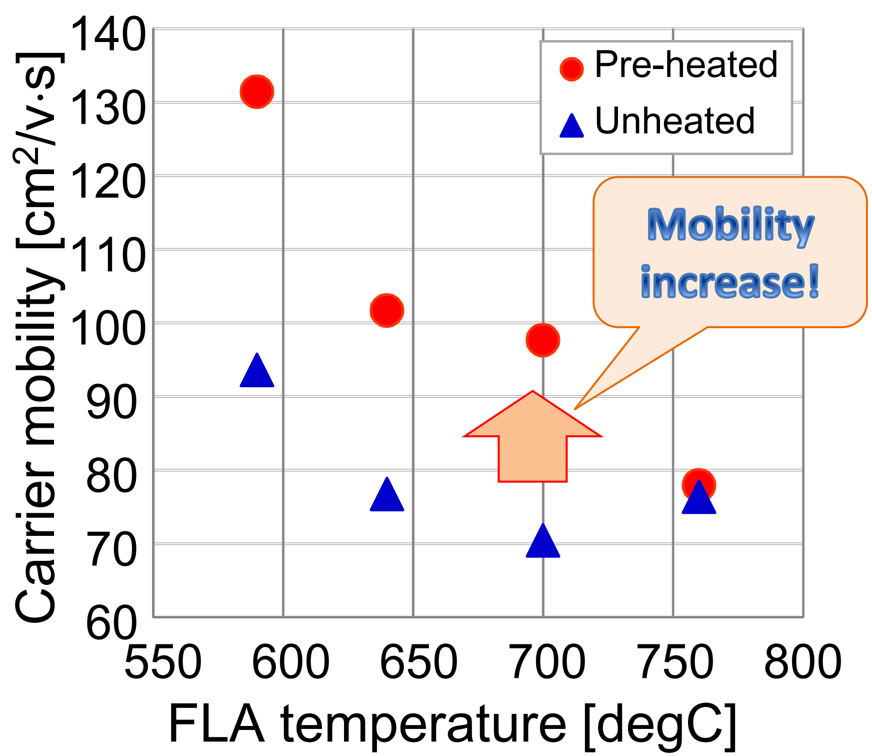


Dopant profile is not the cause of the difference of Rs.

Carrier concentration, Carrier mobility



Carrier concentration



Carrier mobility

Lower Rs of pre-heated wafer is due to the higher carrier mobility.

Sub-summary

- Oxygen at the surface region of Ge substrate affects activation of accepter ion.
- Oxygen at the surface is possible to desorb by heating in vacuum.
- Sheet resistance of Ge substrate can be decreased by the pre-heating.
- The increase in carrier mobility is reason for this phenomenon.

Reduction of oxygen in Ge substrate by pre-heating is effective for forming p^+ diffusion layer with low resistance.

Summary

Donor and acceptor impurities mainly focused on Al, B and P implanted Ge has been characterized in terms of diffusion behaviors, carrier activations and others.

- **Among Group III elements, Al shows shallower junction and lower Rs performance. No diffusion occurs under annealing conditions performed in the experiment (up to 700^{o}C 30sec).**
- **The co-existence of acceptor and donor impurities influences the diffusion and activation behaviors of donor impurity.**
  Al co-implanted with P retards the P diffusion.
  Two possible mechanisms: One is crystal state difference before annealing due to Al dose, and the other is inverse electric field induced by activated Al distribution. Further studies are necessary to clarify.
- **Reduction of oxygen in Ge substrate by pre-heating is effective for forming p^+ diffusion layer with low resistance.**

This work is based on the presentation of IIT2016 and ITJT2017.

IIT2016

“Annealing Behavior of Aluminum Implanted Germanium”

by H. Onoda, Y. Nakashima, T. Nagayama, S. Sakai (Nissin Ion Equipment)

A. Joshi (Active Layer Parametrics) and S. Zaima (Nagoya University)

IWJT2017

“A Novel Approach for Highly Activated p^+ Diffusion Layer Formation in Germanium by Pre-heating Oxygen Desorption before Ion Implantation”

by T. Igo, T. Higuchi, T. Nagayama, T. Kuroi, N. Hamamoto (Nissin Ion Equipment)

H. Tanimura, H. Kawarazaki, T. Aoyama, S. Kato and I. Kobayashi (SCREEN Semiconductor Solutions)