Effects of Cluster Carbon Implantation at Low Temperature on Damage Recovery after Annealing

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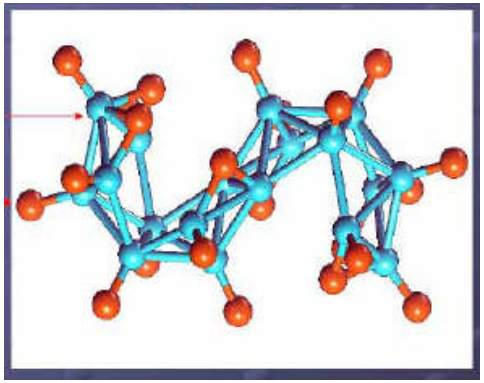
- Introduction
- Experimental
- Results and Discussions
  - Amorphous Si Formation by Cluster C implant
  - EORD Elimination with Cluster C co-implant
  - Boron Carrier Activation Improvement
- Summary

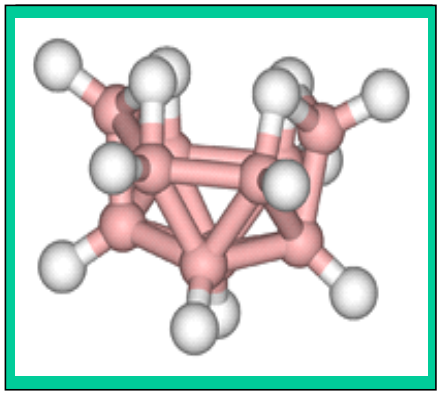
Introduction - Cluster Ion Implantation -

❑ Effective High Current and Low Equivalent Energy

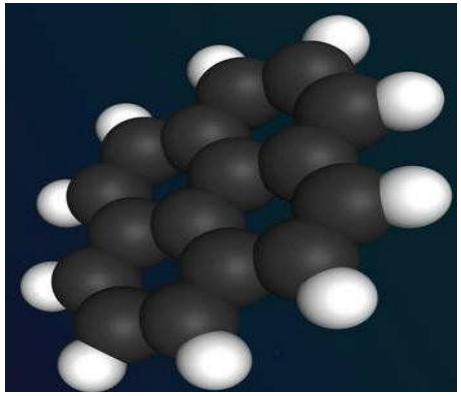
Octadecaborane $B_{18}H_{22}$



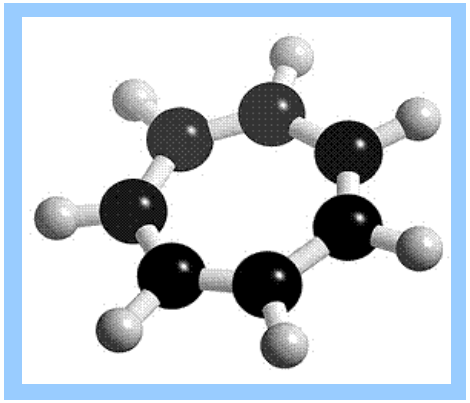
Decaborane $B_{10}H_{14}$



Pyrene $C_{16}H_{10}$



Dibenzyl➔ Benzyl C_7H_7



Cluster Characteristics	$B_{18}H_x$	$B_{10}H_x$	$C_{16}H_x$	C_7H_x
Mol. Weight	210	116	199	91
Typical Operation Temperature	90-100 ℃	30-40 ℃	90-100 ℃	40-50 ℃

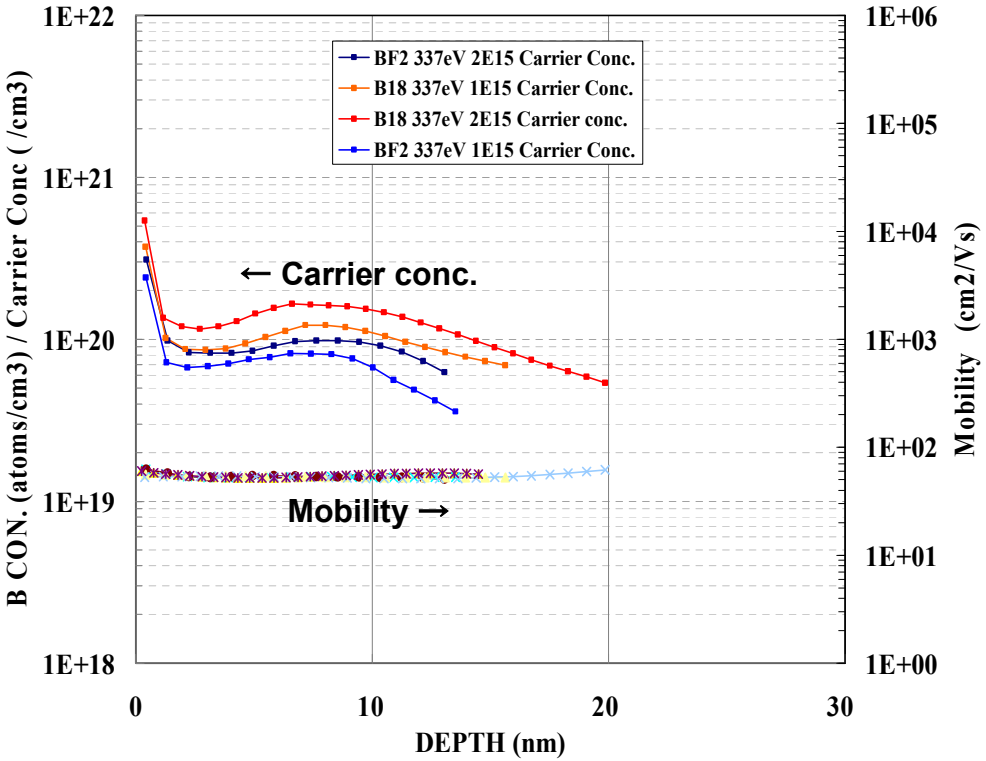
Major Applications of Cluster Ion Implantation

- **Ultra Shallow Junction Formation**
  Self amorphization & high activation

- **Diffusion control with cluster carbon co-implant**
- **NMOS strain engineering**

- **EORD (End of Range Defects) suppression**

High Carrier Activation



✓The B18 cluster implants generate twice the activated boron for the same dose than the BF2 beamline implant does.

✓Activation ratio is higher in B18 cluster samples.

✓Carrier mobilities are almost the same in all the samples.

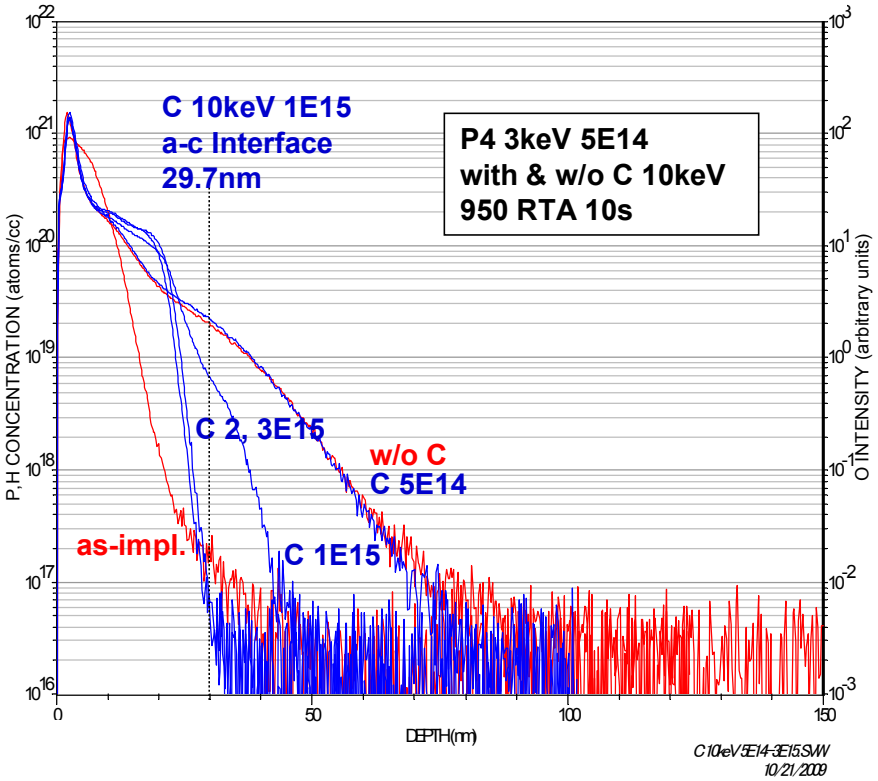
Hall measurement done by the CAOT at UCLA

H.Onoda et.al IWJT 2010

Implant	Hall measurement			SIMS	Activation Ratio
	Sheet Resistance (Ω/sq)	Ave μ (cm^2/V-s)	Activated Dose (cm^{-2})	Retaied Dose (cm^{-2})	(%)
BF2 337eV 1E15	936.94	56.54	1.180E+14	6.70E+14	17.6%
BF2 337eV 2E15	662.66	54.60	1.727E+14	1.19E+15	14.5%
B18H11 337eV 1E15	492.63	52.55	2.414E+14	8.76E+14	27.6%
B18H11 337eV 2E15	359.74	50.79	3.421E+14	1.57E+15	21.8%

Phos. Diffusion Suppression

- ❑ Cluster Carbon co-implant is the promising candidate for USJ formation because of its self-amorphization and effective dopant diffusion suppression.
- ❑ Cluster Carbon co-implant can replace Ge PAI process and contributes to process simplification.



Nagayama et.al IWJT 2010

- ✓ Cluster carbon co-implant is effective for diffusion suppression.
- ✓ C 10keV 2E15 and more dose are very effective for forming abrupt junctions.
  This is caused by sufficient a-Si thick formation with higher dose.
- ✓ The location of a-c interface is important for TED suppression.

This Work

Cluster Carbon Implantation at low temperature down to -60°C has been studied.

- **Cluster carbon co-implantation**
- **Cold implant technology**

Both technologies have effect of damage accumulation into Si. The cluster carbon implant and cold implant must have synergy effects and bring improvements in junction performance.

- **In this work, basic data has been taken for cluster carbon implant and co-implant at low temperature.**

Experimental

- **Amorphous Si Formation Study**
  - Cluster Carbon Implant at 25°C, -30°C, -60°C
    C_7^+ Equi. Energy 10 keV Dose 2E14 to 3E15/cm^2
- **EORD Study and Carrier Activation Study**
  - B_{10}^+ Boron Equi. 4.5keV 3E15 /cm^2 @25℃ & -30 ℃
  - C_7^+ 10keV 1E15/cm^2 + B_{10}^+ 4.5keV 3E15 @25℃ & -30℃
  - monomer C 10keV 1E15/cm^2 + B_{10}^+ 4.5keV 3E15 @25℃ & -30℃
  - **Anneal : RTA 950° 10sec**

- **Evaluation :TEM, Ellipsometry, HR-RBS, SIMS, Rs, Hall measurement (DHE/CAOT)**

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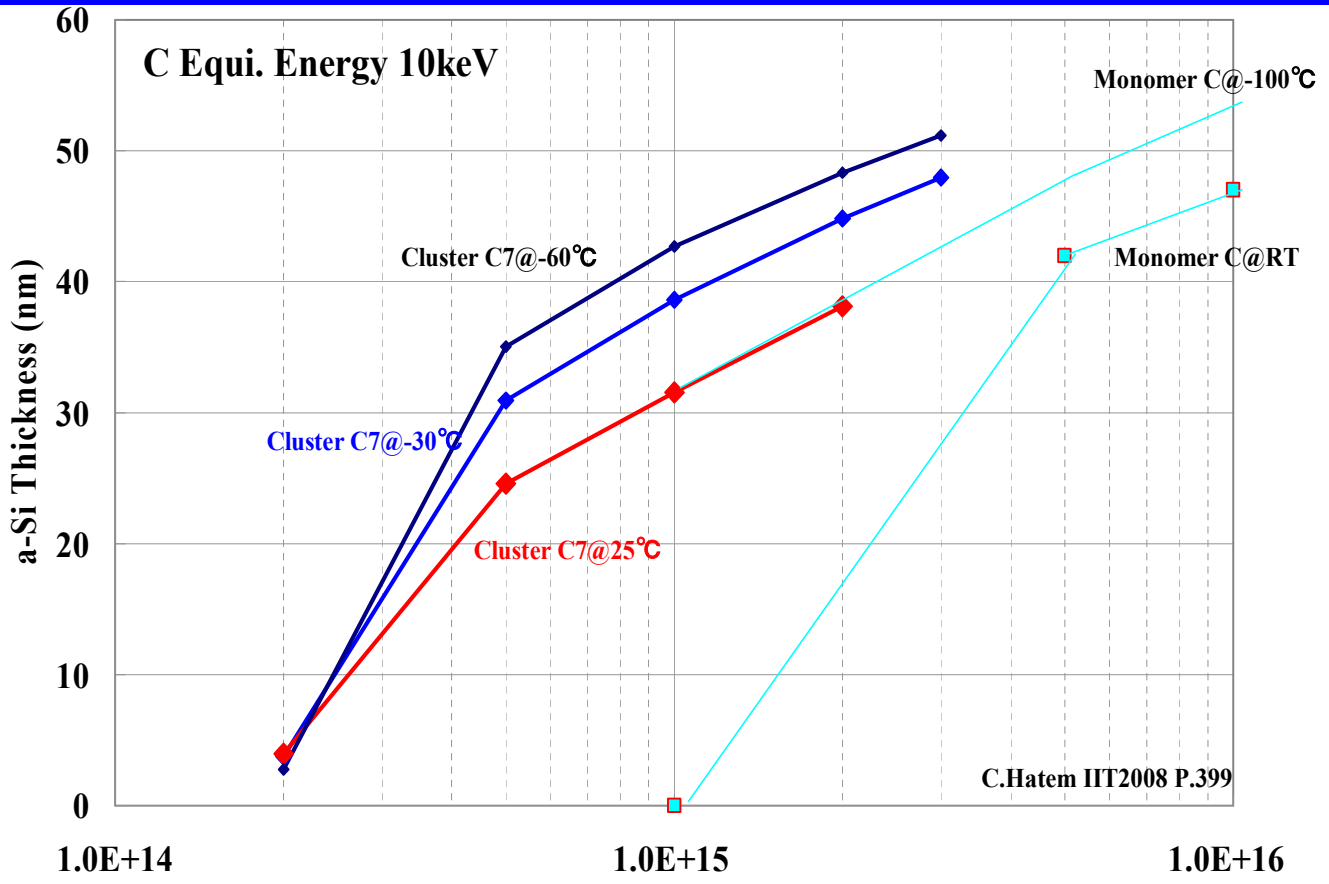
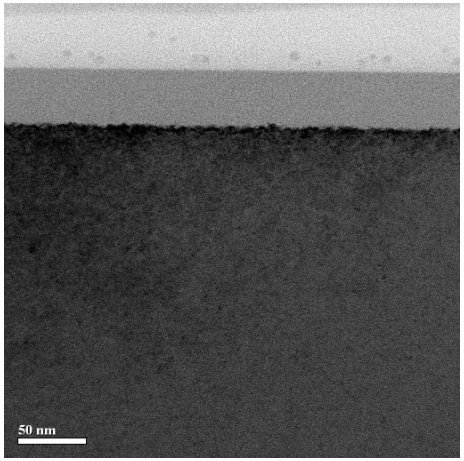
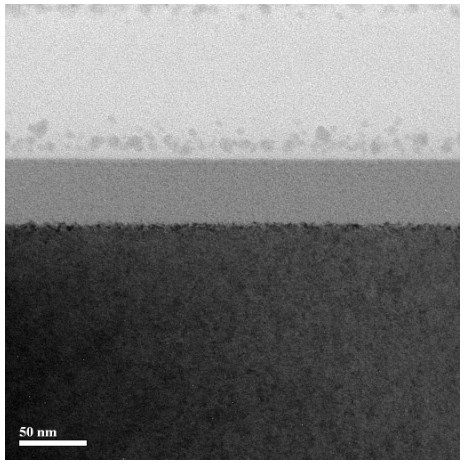
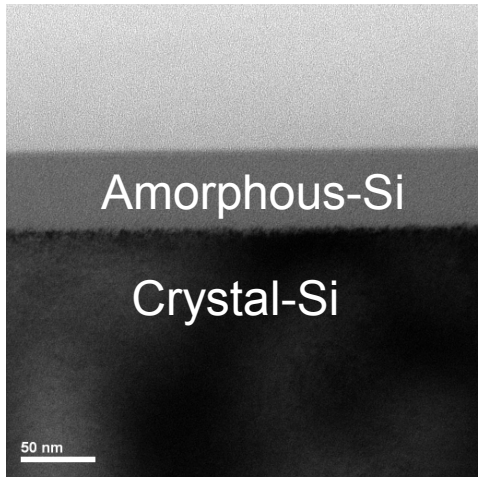
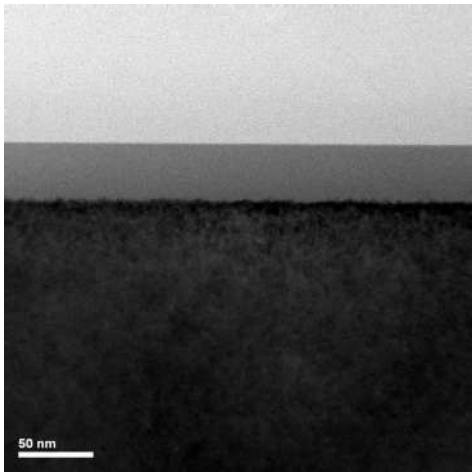
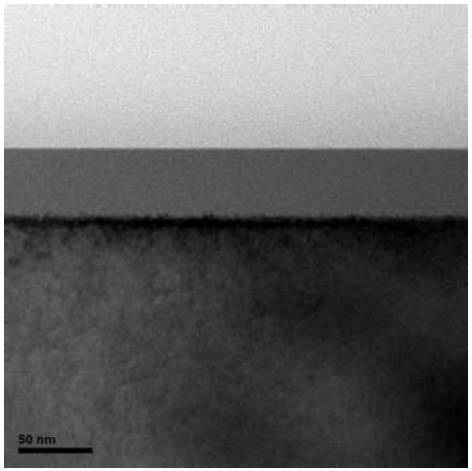
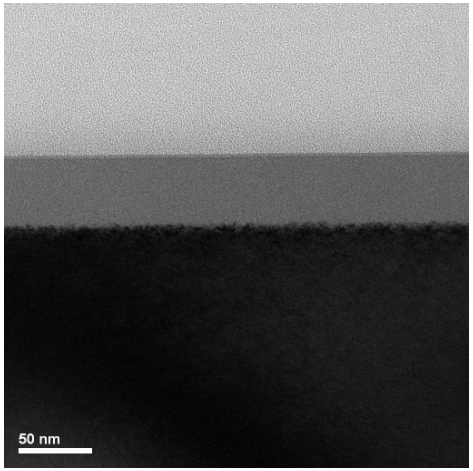
Amorphous Si Formation by Cluster Carbon at Low Temp.

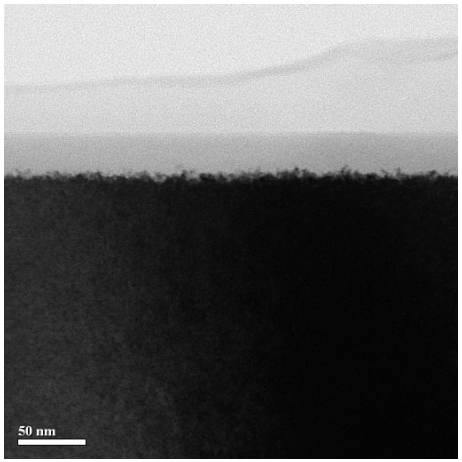
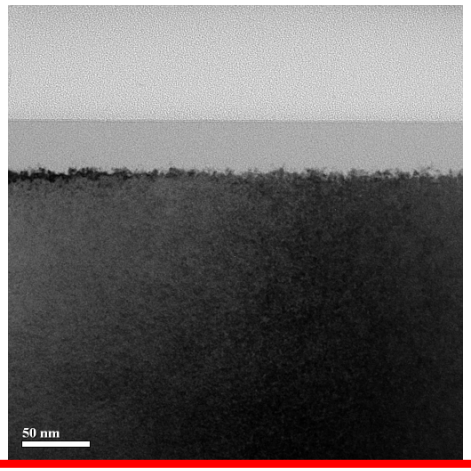
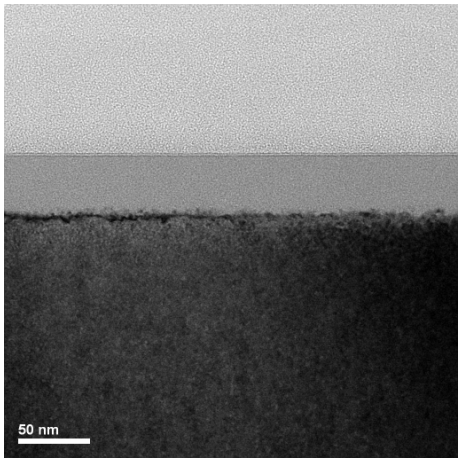
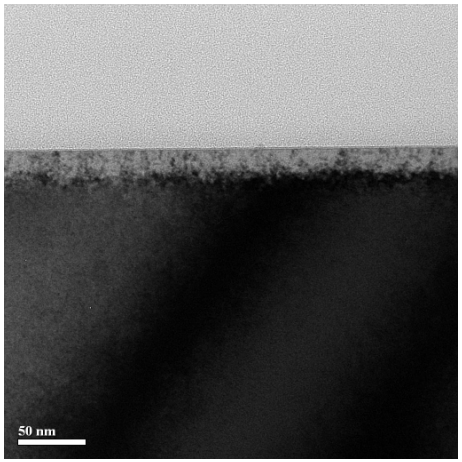
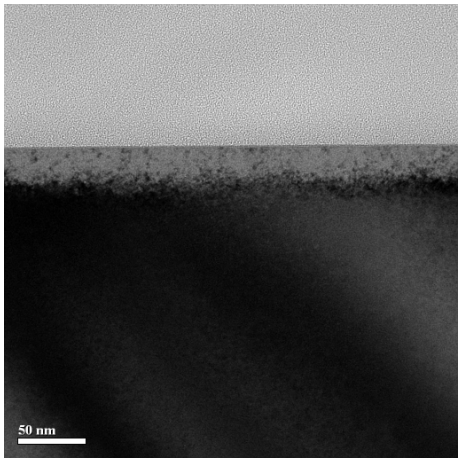
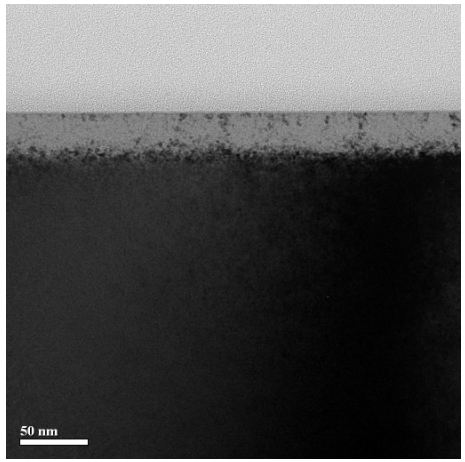
- Amorphous Si thick formed by Cluster C7 implant at 25℃ is almost the same as that of monomer C implant at "–100℃".
- With lowering the substrate temperature, a-Si thickness increases well beyond the a-Si thickness by monomer carbon implant.



a- Si formation at 25, -30, -60 ℃ 10keV 2E15, 3E15

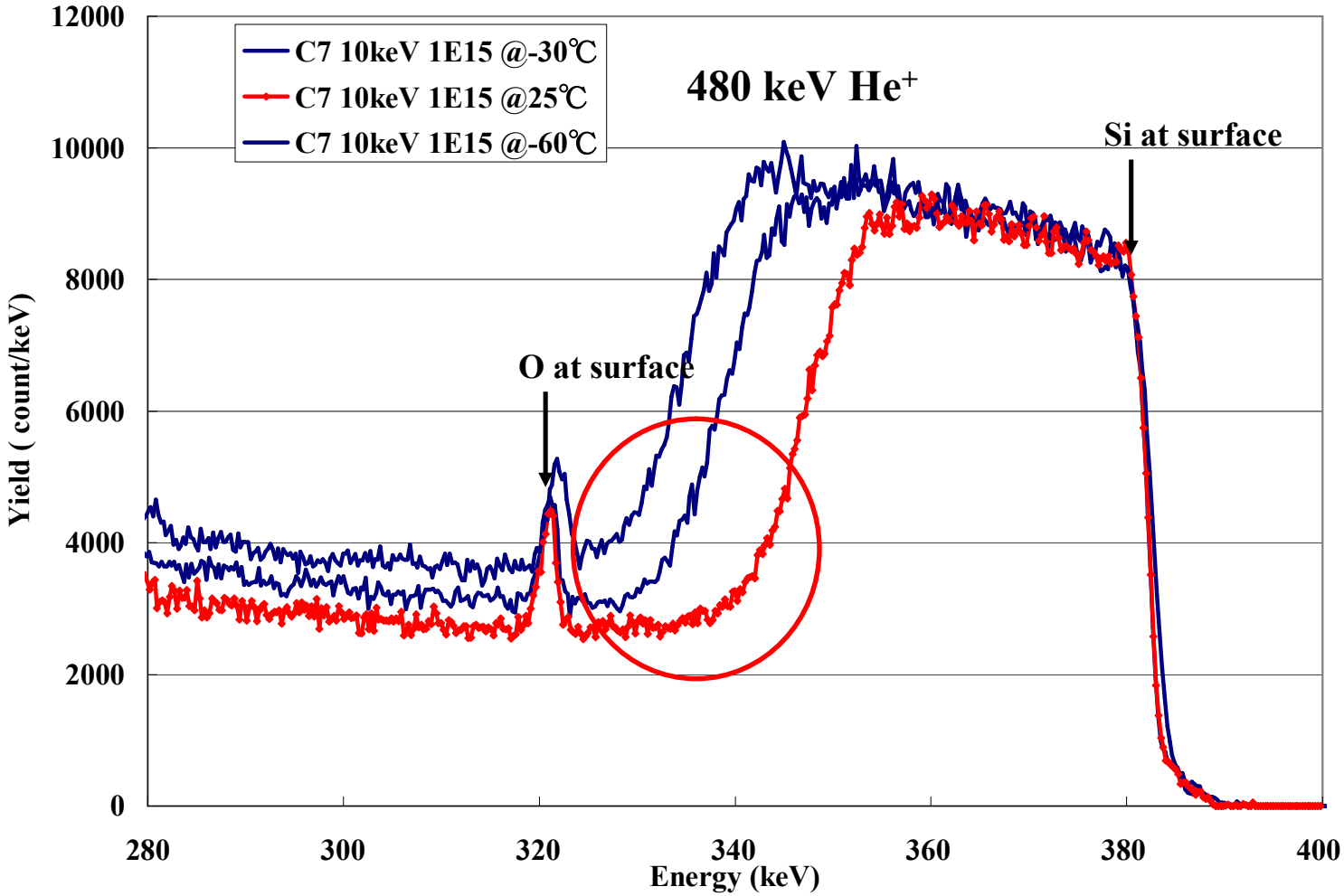
	@25°C	@-30°C	@-60°C
C7 10keV 3E15/cm²			
C7 10keV 2E15/cm²			

a- Si formation at 25, -30, -60 ℃ 10keV 5E14/1E15

	@25°C	@-30°C	@-60°C
C7 10keV 1E15/cm2			
C7 10keV 5E14/cm2			

High Resolution Rutherford Back Scattering Spectra

- HR-RBS spectra clearly show the difference of a-Si thickness.
- Focusing on crystal side of the a-c interface.

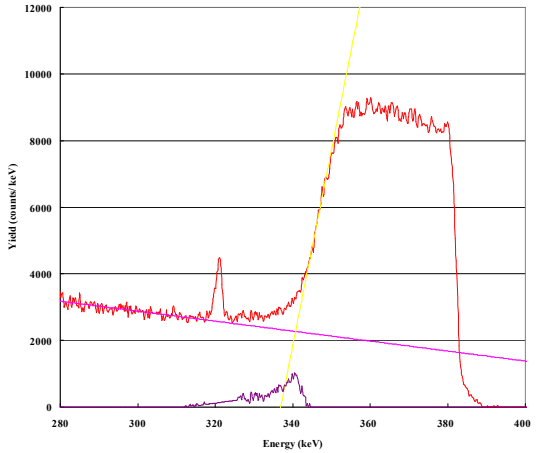


Damage Integration

- Implant damage were integrated in crystal side of a-c interface with subtracting background and a-c interface line.
- Lower implant temperatures have less residual damage in crystal side of interface.

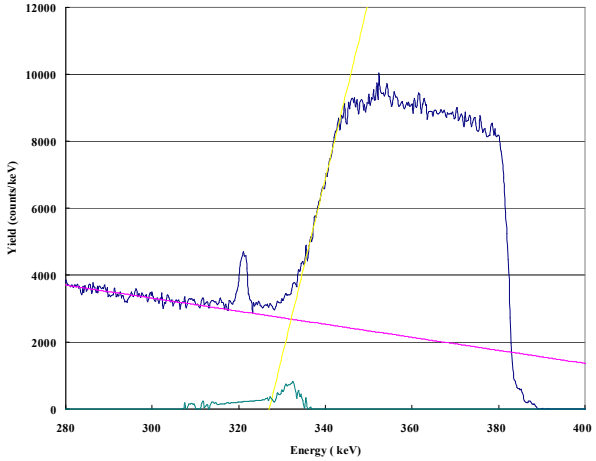
C7 10keV 1E15 /cm2

Sub. Temp 25℃



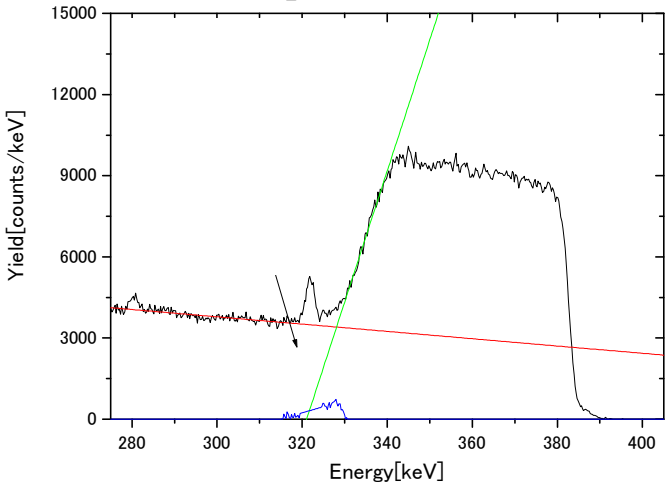
Area:9954

Sub. Temp -30℃



Area:7550

Sub. Temp -60℃



Area:4838

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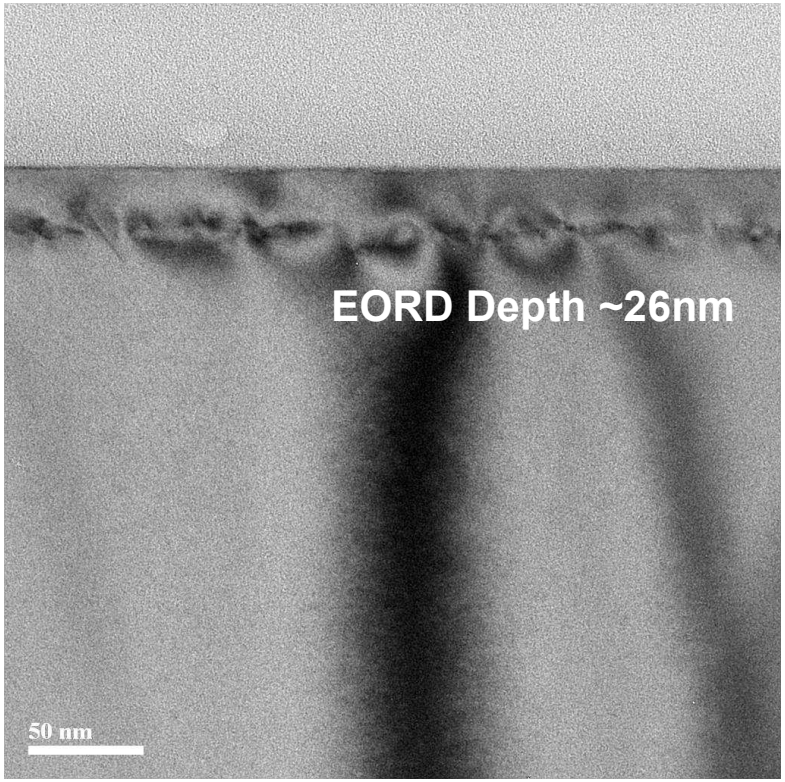
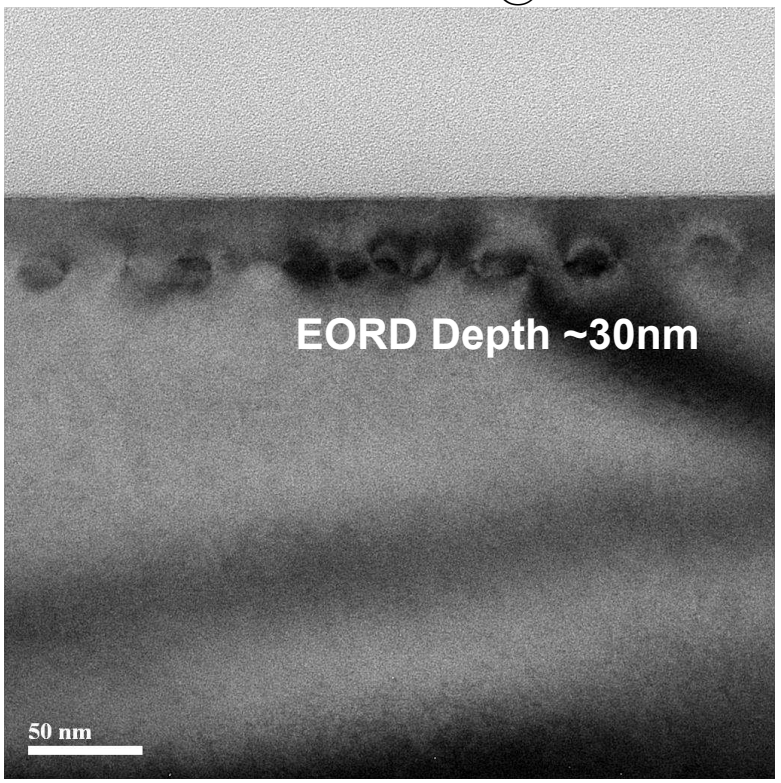
Cluster B10 implant @25℃&-30℃

- A high density of end of range defects (dislocation loops) remain after RTA for only B10 implanted both at 25 and -30℃
- -30 degree C implant reduces the number of defects a little bit, but many EORD still remain.

B10 4.5keV 3E15/cm2 @25°C



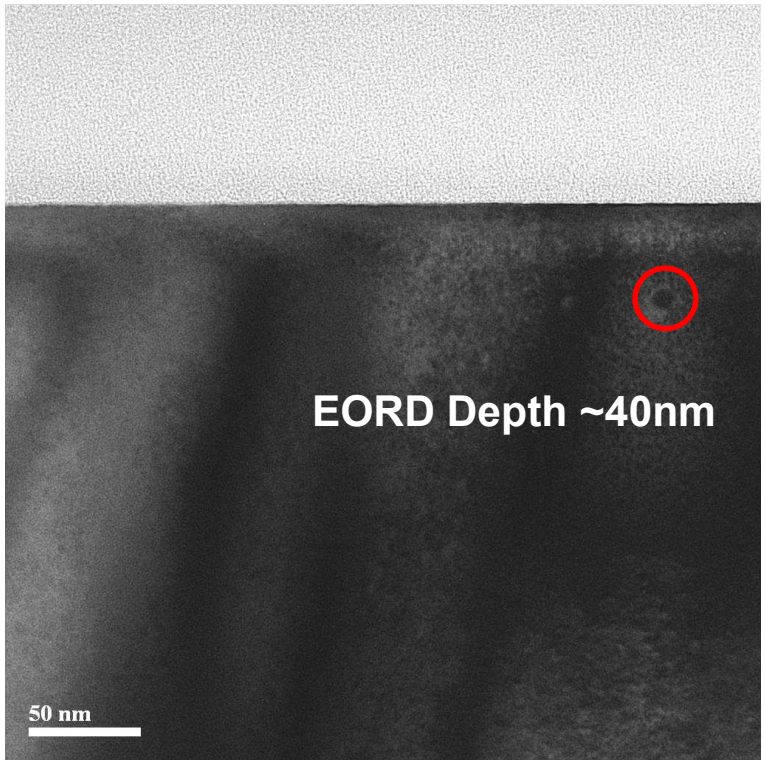
B10 4.5keV 3E15/cm2 @-30°C



Cluster C7 co-implant with B10 @25℃ &-30℃

- ❑ Cluster Carbon co-implant with B10 drastically reduces EORD in both temperature.
- ❑ With lower temperature implant down to -30℃, EORD free can be realized.

C7 10keV 1E15/cm2 @25℃
B10 4.5keV 3E15/cm2 @25℃

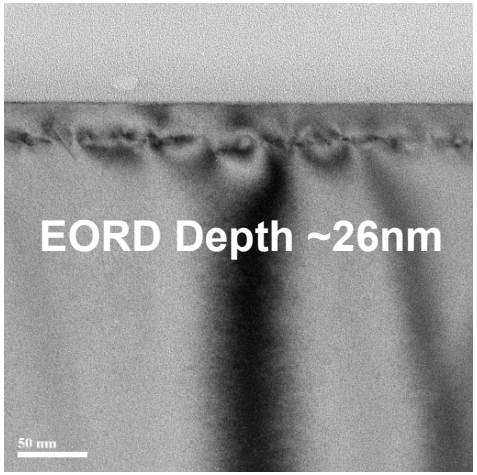


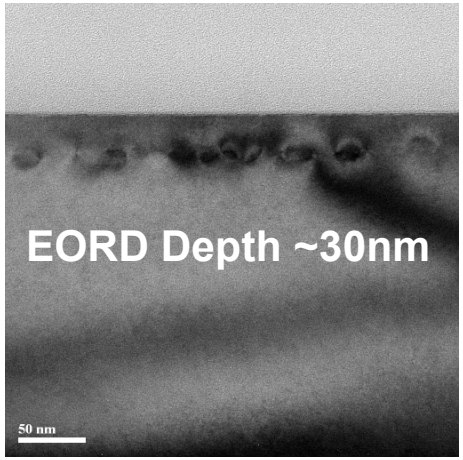
C7 10keV 1E15/cm2 @-30℃
B10 4.5keV 3E15/cm2 @-30℃

EORD Summary

B10 4.5keV 3E15/cm2

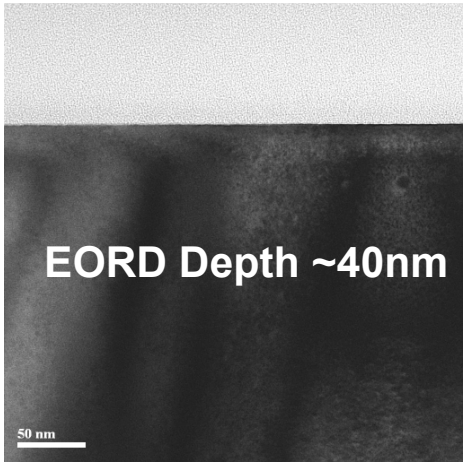
25℃ **−30℃**





C7 10keV 1E15/cm2 + B10 4.5keV 3E15/cm2

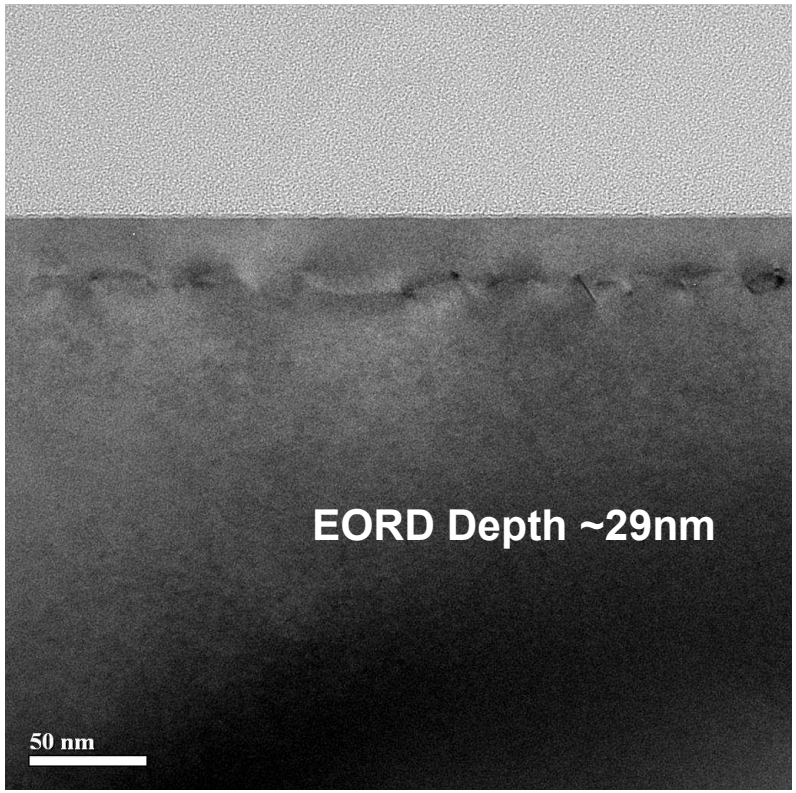
25℃ **−30℃**



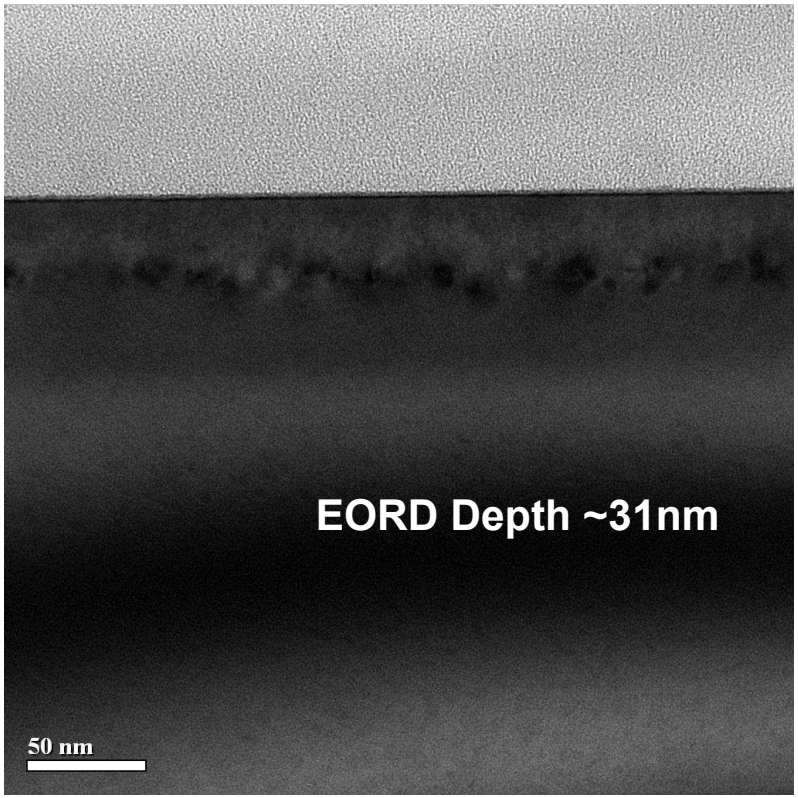
Monomer C co-implant with B10 @25℃ &-30℃

❑ Monomer C co-implant with B10 is not effective for EORD elimination. Thick density of EORD remains in both 25℃ and -30℃ implant.

Cmono 10keV 1E15/cm2 @25℃
B10 4.5keV 3E15/cm2 @25℃

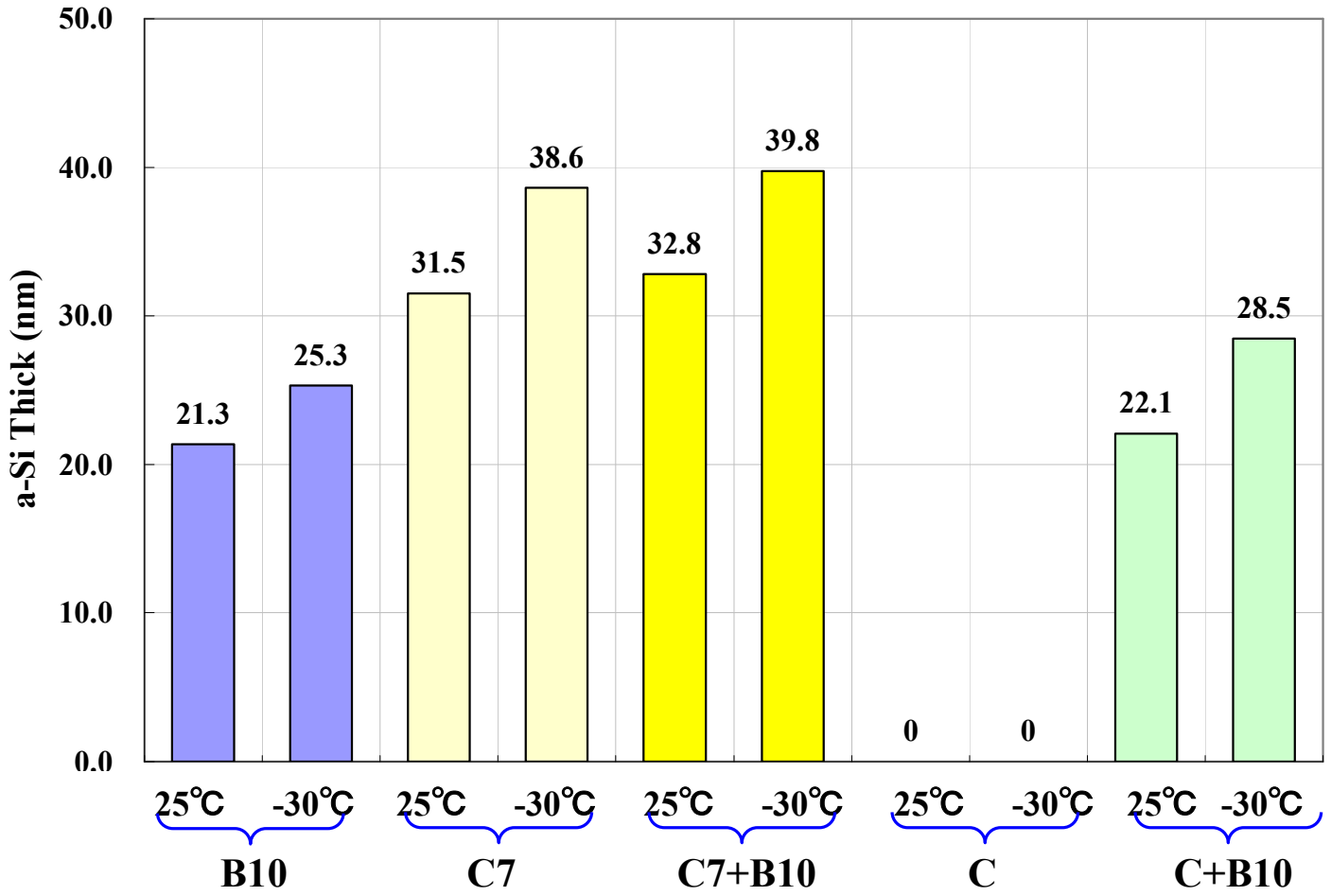


Cmono 10keV 1E15/cm2 @-30℃
B10 4.5keV 3E15/cm2 @-30℃



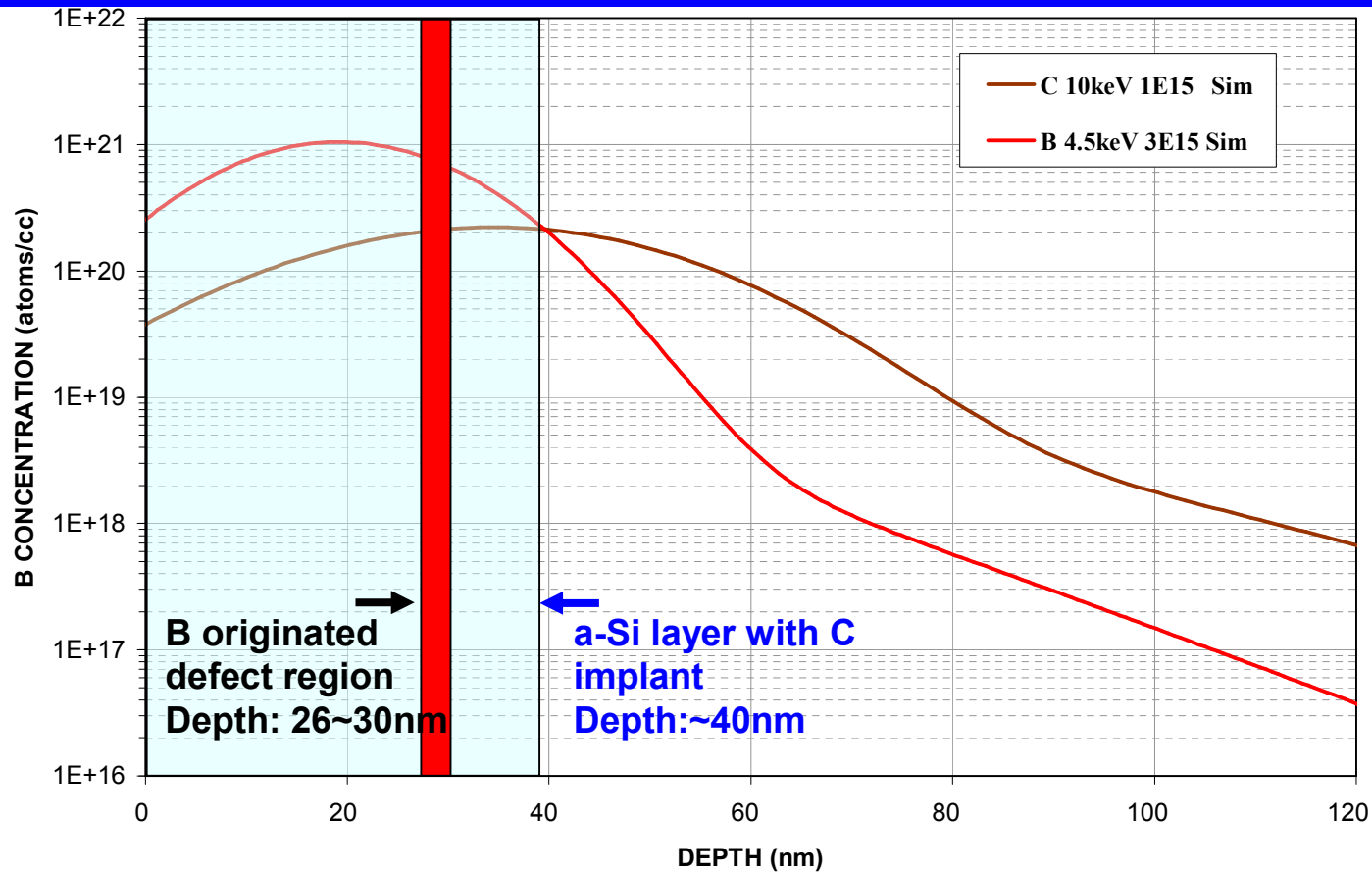
a-Si Thickness

- Amorphous Si thick with C7 implant covers the a-Si thick with B10 implant.
- Monomer carbon never creates a-Si layer both at 25 & -30℃ implants.



EORD Elimination Mechanism

- Thickness of a-Si formed with Cluster C implant covers EORD originated by B implant.
- Cold implant at -30℃ assists the EORD free realization.
- Monomer C implant never creates a-S layer, and EORD free can not be realized.



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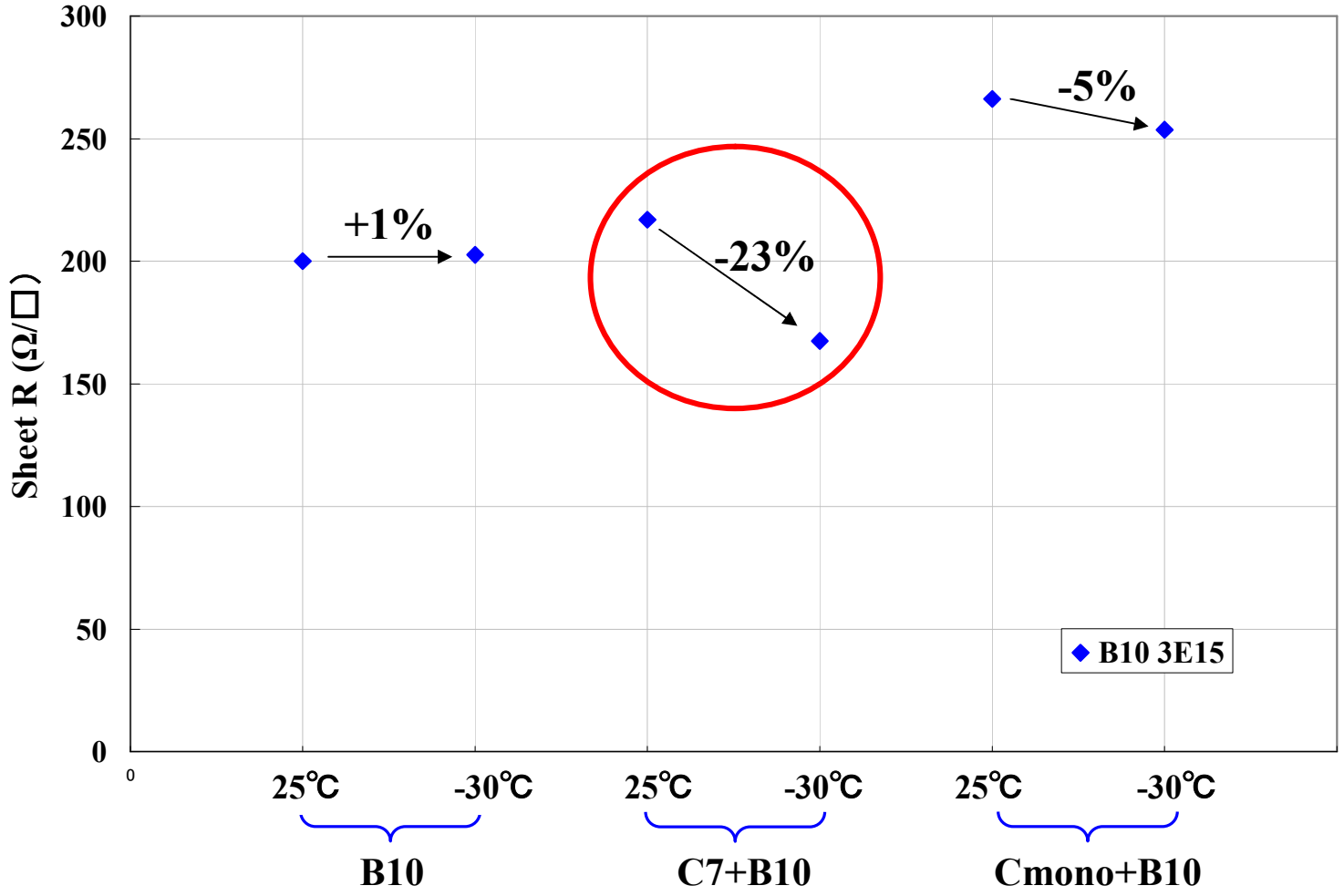
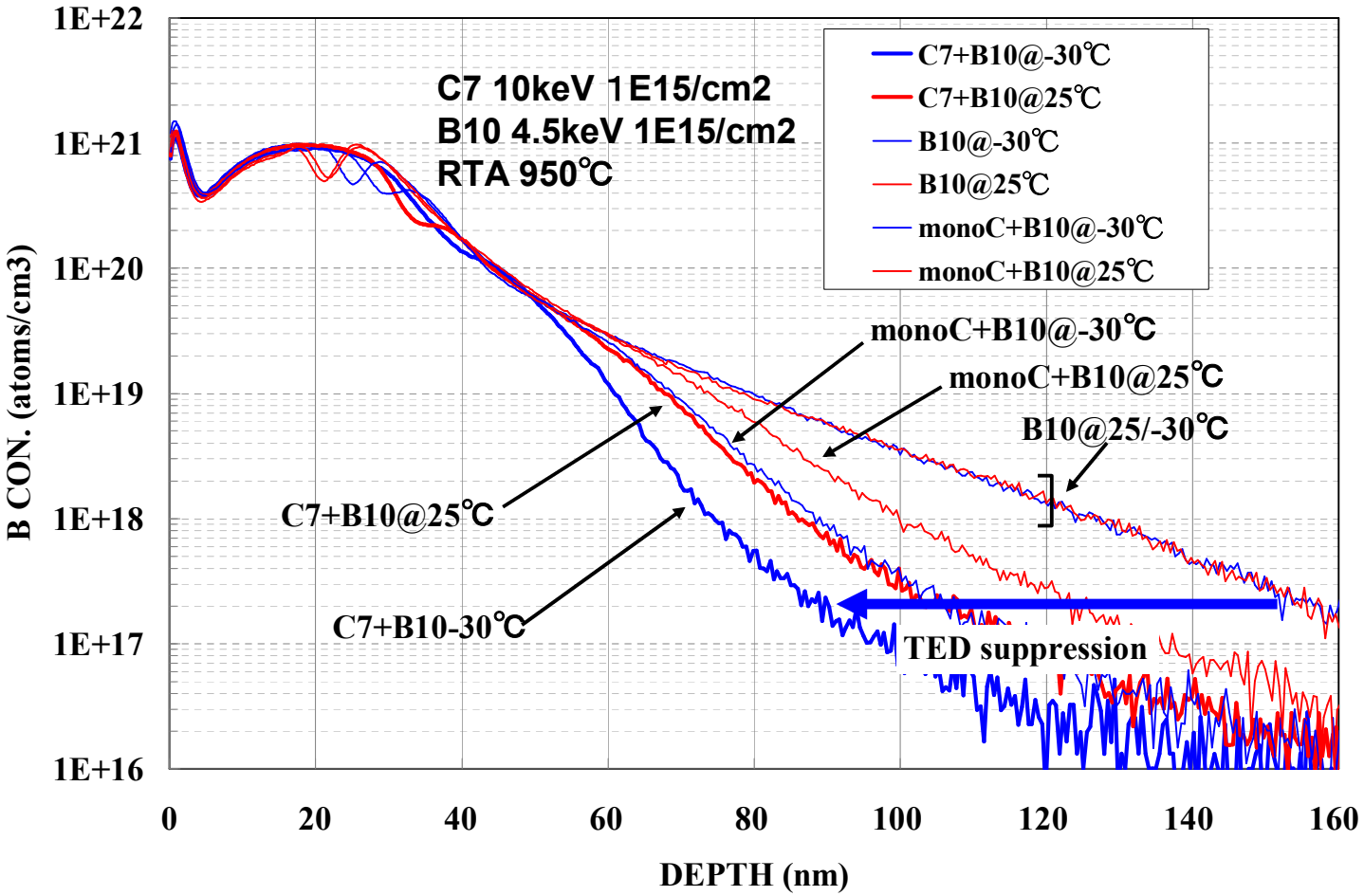
Sheet R

- Sheet R largely decreases by 23% with cluster C7 co-implant at -30℃.
- Only B10 implant does not change sheet R with substrate temperature.
- Monomer C co-implant increases sheet R more than 25%.



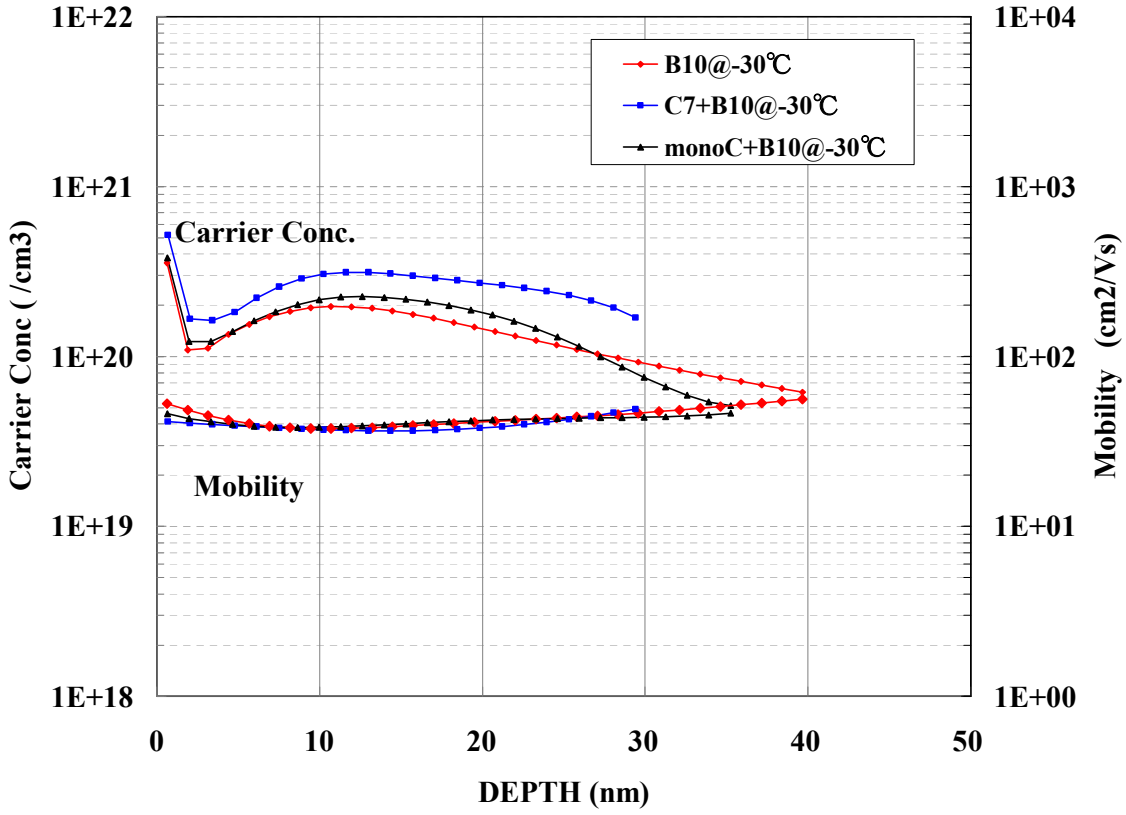
Boron SIMS Depth Profile

- Cluster C7 co-implant with substrate temperature of -30℃ is very effective for Boron TED suppression.



Carrier & Mobility Comparison

- ✓ C7 co-implant at substrate temperature of -30℃ sample show highest carrier concentration.
- ✓ Mobilities of all the samples are almost the same.



Hall measurement done by the CAOT at UCLA

Implant Condition	Sheet Carrier Dose (/cm2)	Activation Ratio
B10@25°C	6.1E+14	20.4%
B10@-30°C	5.5E+14	18.2%
C7+B10@25°C	5.9E+14	19.7%
C7+B10@-30°C	8.2E+14	27.5%
monomer C+B10@25°C	5.1E+14	16.8%
monomer C+B10@-30°C	5.3E+14	17.6%

Summary

Amorphous Si formation and EORD elimination by using cluster carbon implant at low temperature have been studied.

- **Amorphous Si layers are formed efficiently by Cluster C7 implant. With lowering the substrate temperature, a-Si thick increases well beyond the monomer C implant.**

- **B implant originated EORD are eliminated by cluster carbon co-implant. The low temperature of -30°C assists the EORD elimination.**

- **Cluster C co-implant at -30°C largely decreases sheet R in spite of shallower diffusion profile. Highly activated B profile can be obtained.**

Thank you for your attention