Implant Damage Engineering for sub-32 nm Device Fabrication

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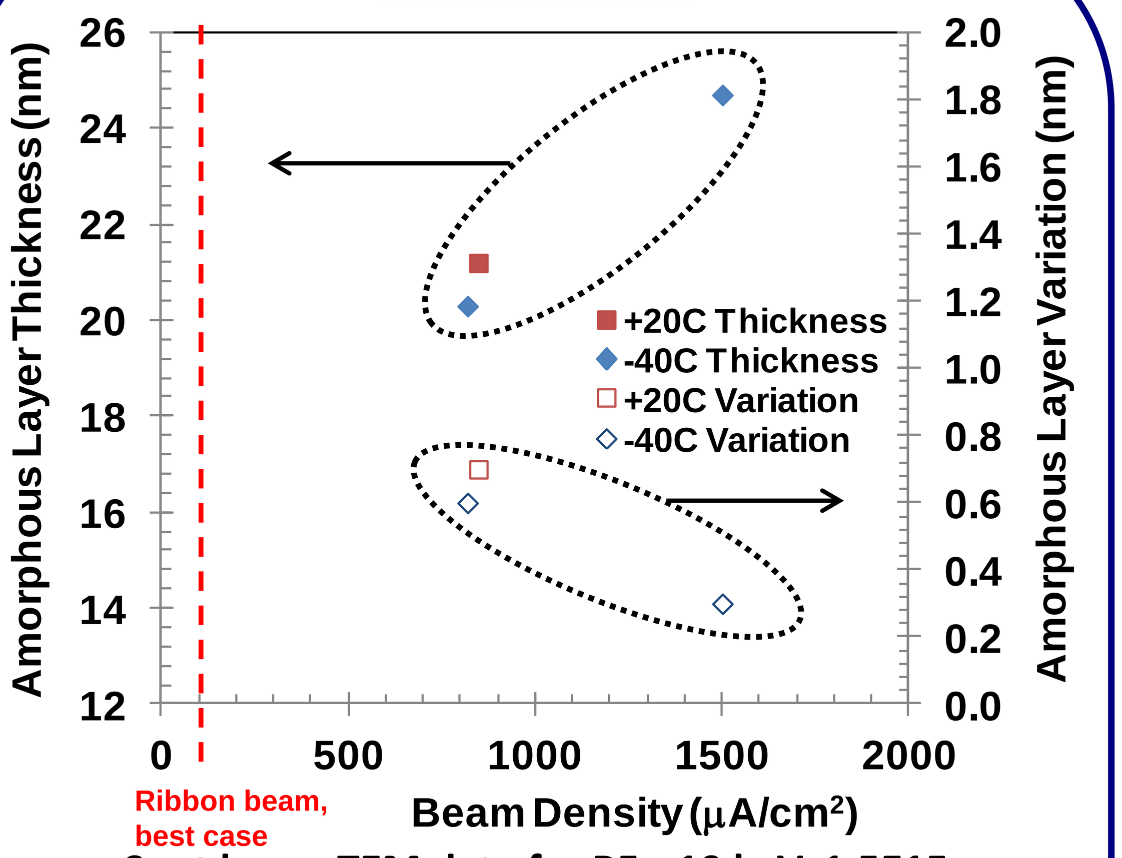
Introduction: There are 3 main methods to minimize implant damage:

1) High beam density (spot beam)
   - Largest effect on devices
2) Cold implant
   - High dose rate makes extreme cold not necessary
3) High-mass molecular implant

A combination of all 3 methods can be used to maximize the amorphous layer thickness

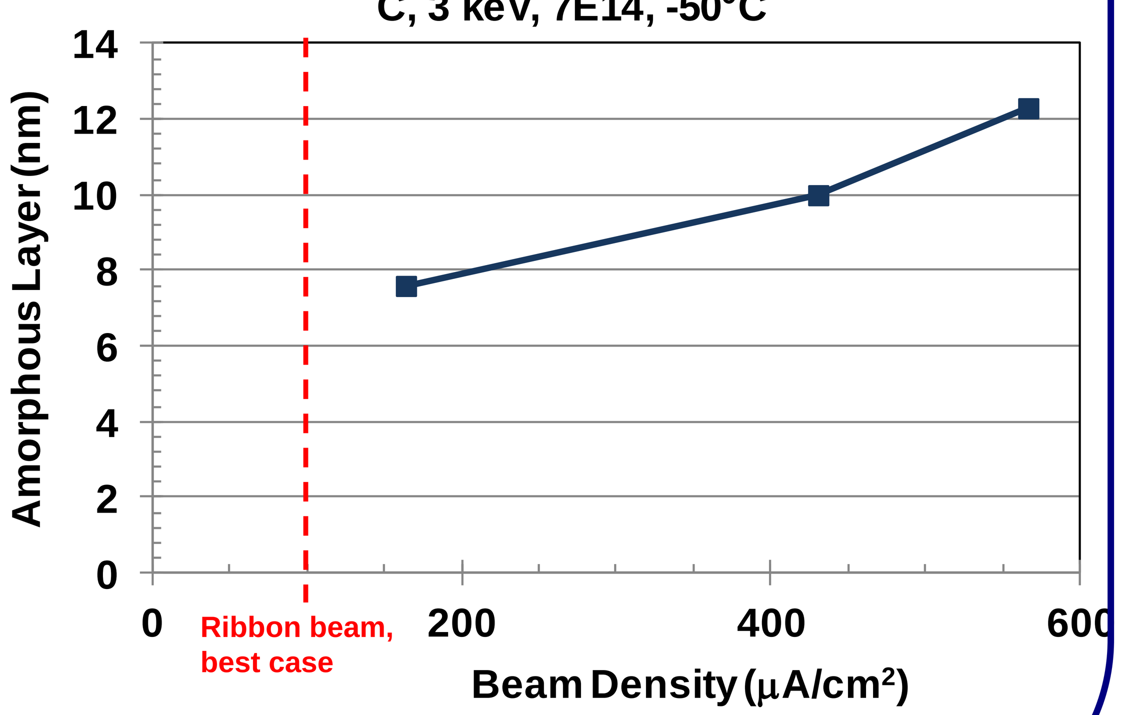
Beam Density



Spot beam TEM data for BF_2, 10 keV, 1.5E15

Higher beam density increases amorphous layer thickness and decreases interface roughness. The effect of wafer temperature is minimal.

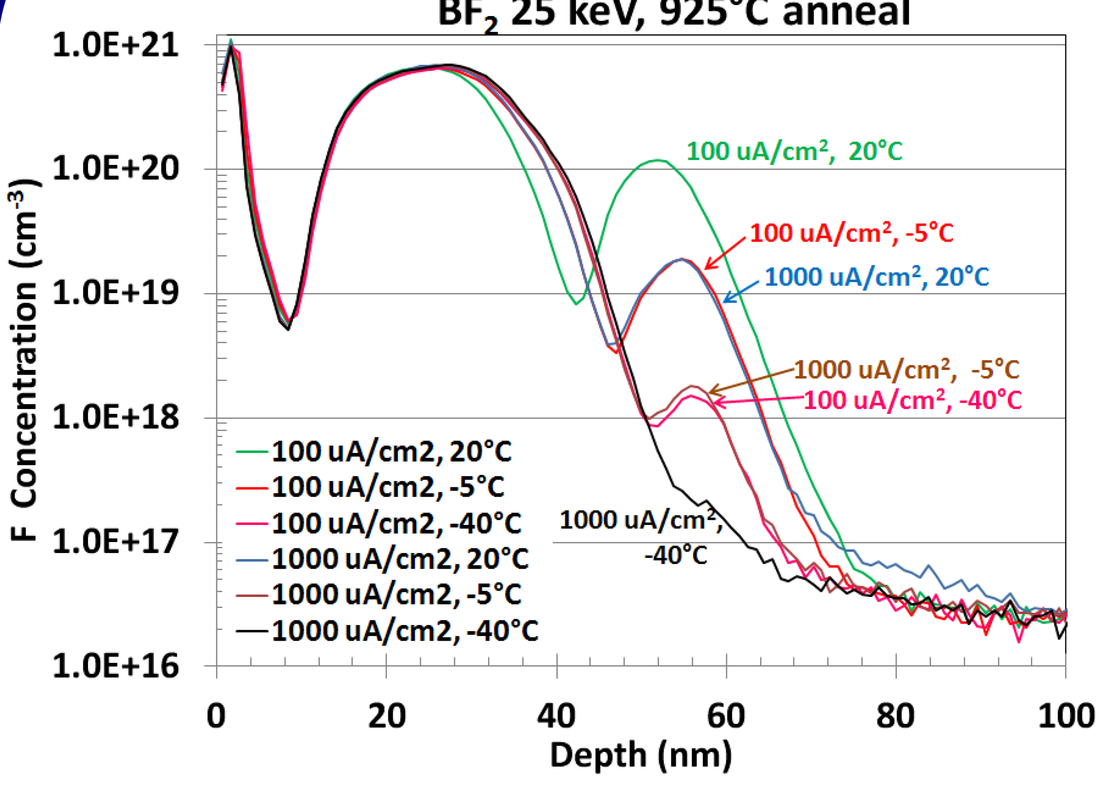
Spot Beam Amorphous Layer C, 3 keV, 7E14, -50°C



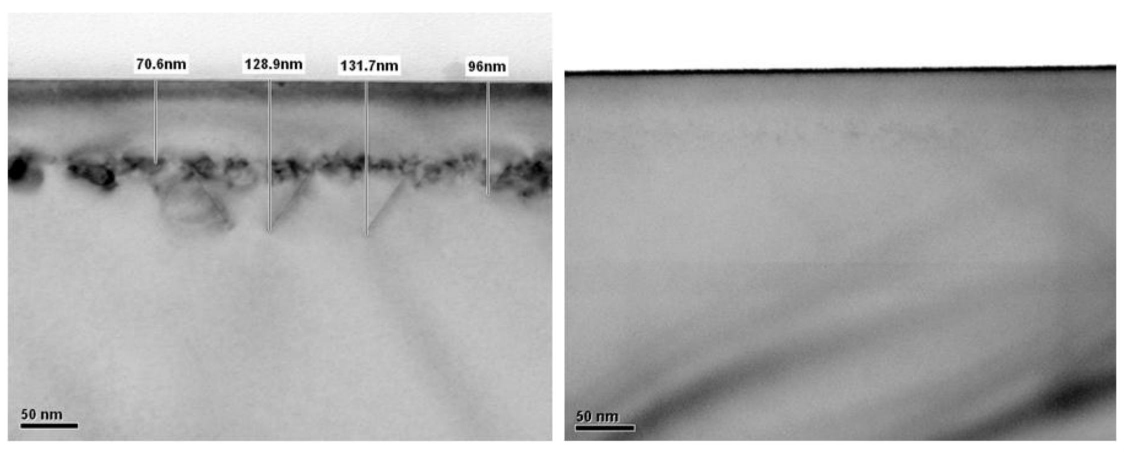
Higher beam density increases amorphous layer thickness for carbon, similar to BF_2

Damage Elimination

BF_2 25 keV, 925°C anneal



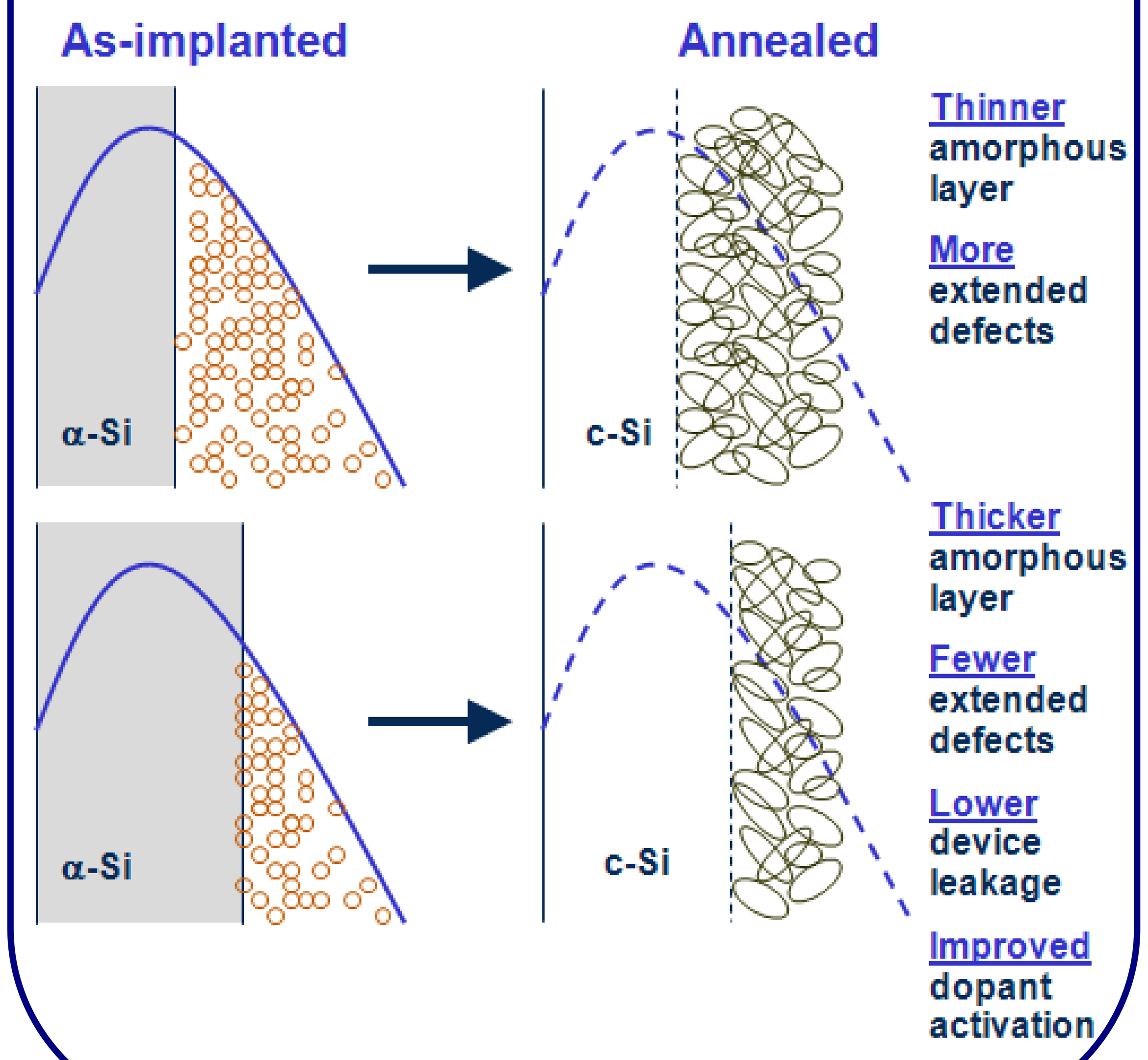
Fluorine decoration of damage showing the effect of beam density and wafer temperature on the residual damage at the EOR region



+20°C Implant -50°C Implant

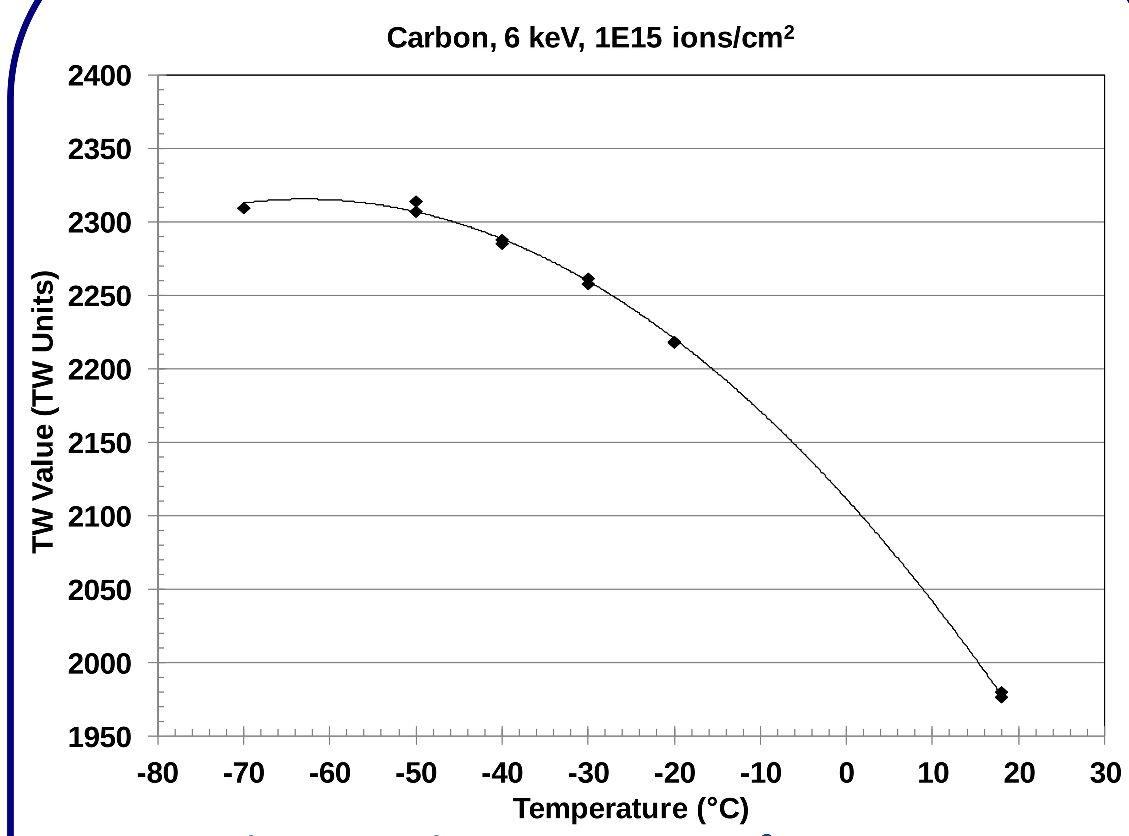
TEM images after annealing for B, 15 keV, 3E15

Creating a thicker amorphous layer for a given Energy & Dose leads to less residual damage and lower leakage



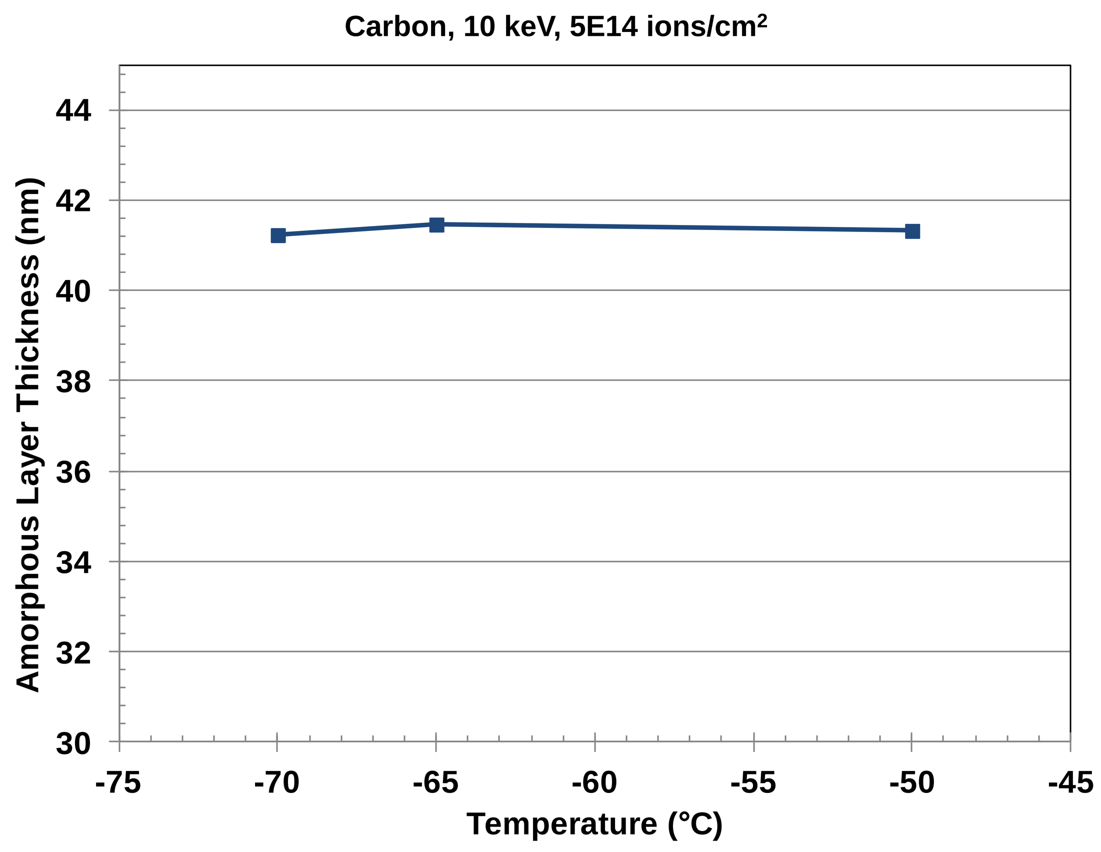
Cold Implant

Carbon, 6 keV, 1E15 ions/cm²



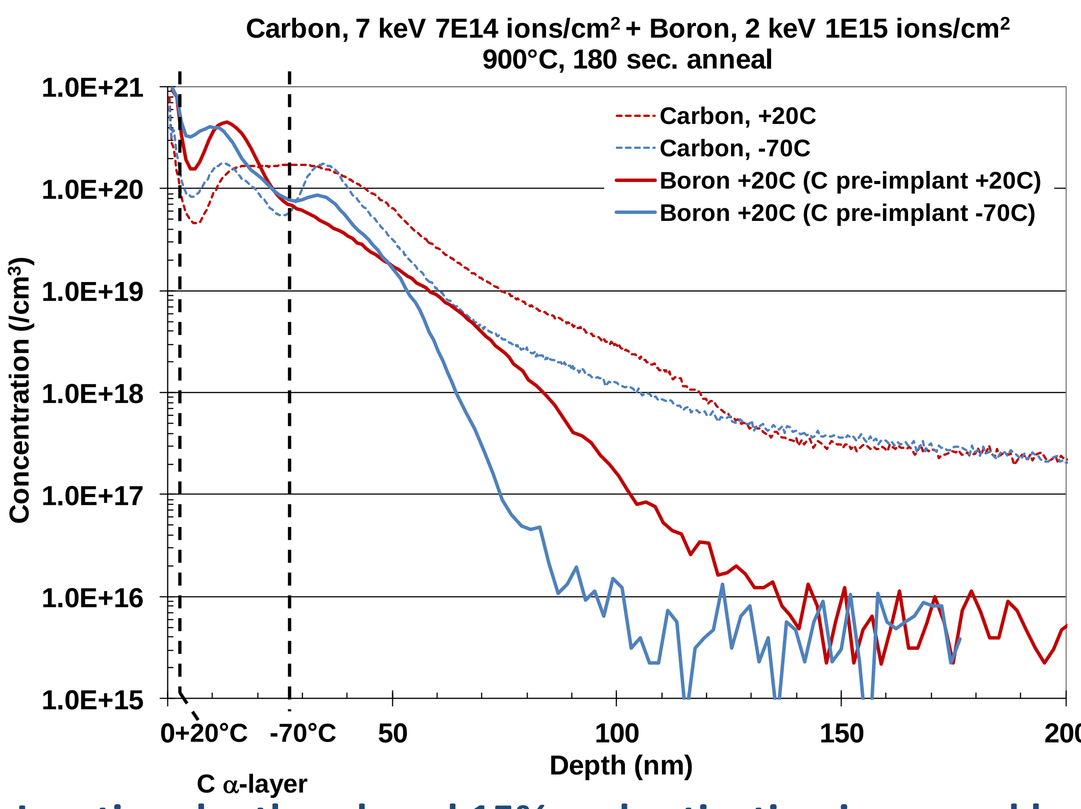
Damage (TW value) saturates by -70°C due to the high density of a spot beam, even for light ions such as C

Carbon, 10 keV, 5E14 ions/cm²



TEM confirms unchanged amorphous layer thickness from -50°C to -70°C due to spot beam saturation

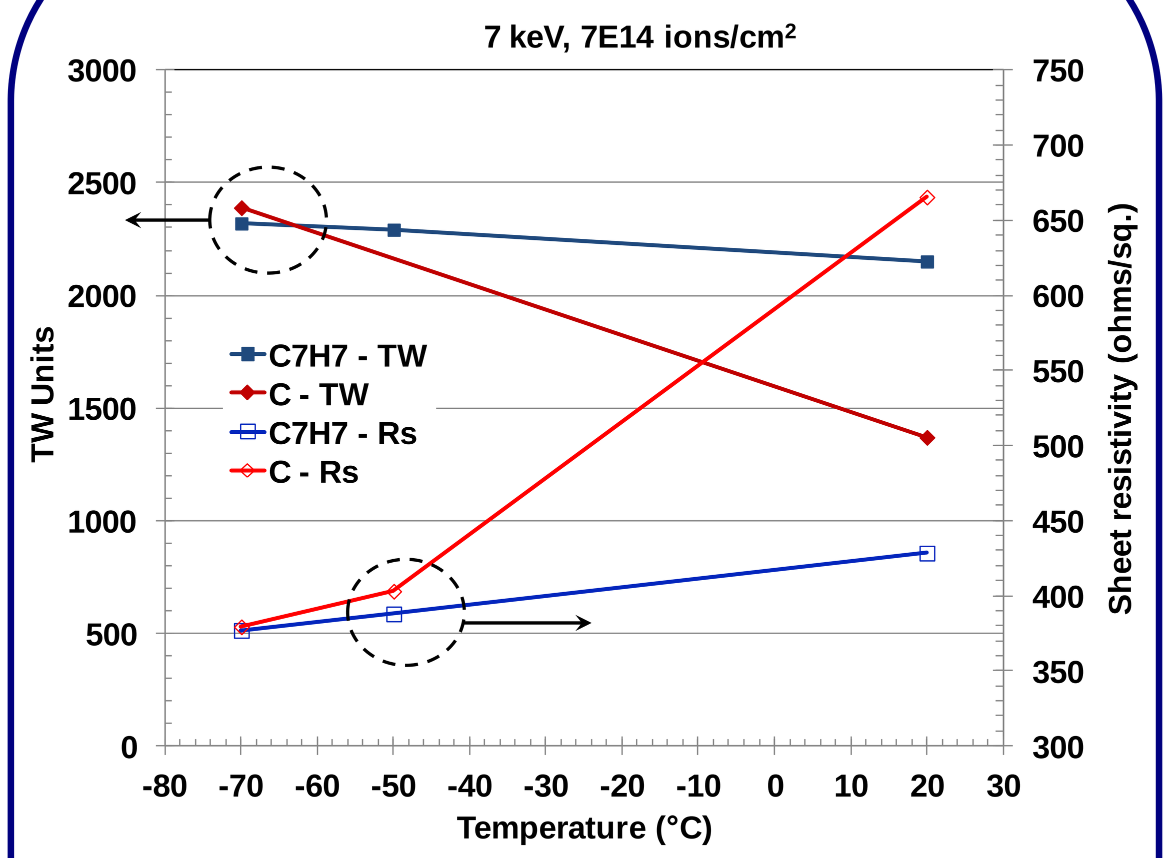
Carbon, 7 keV 7E14 ions/cm² + Boron, 2 keV 1E15 ions/cm² 900°C, 180 sec. anneal



Junction depth reduced 15% and activation increased by changing C implant from +20°C to -70°C

Molecular Implant

7 keV, 7E14 ions/cm²

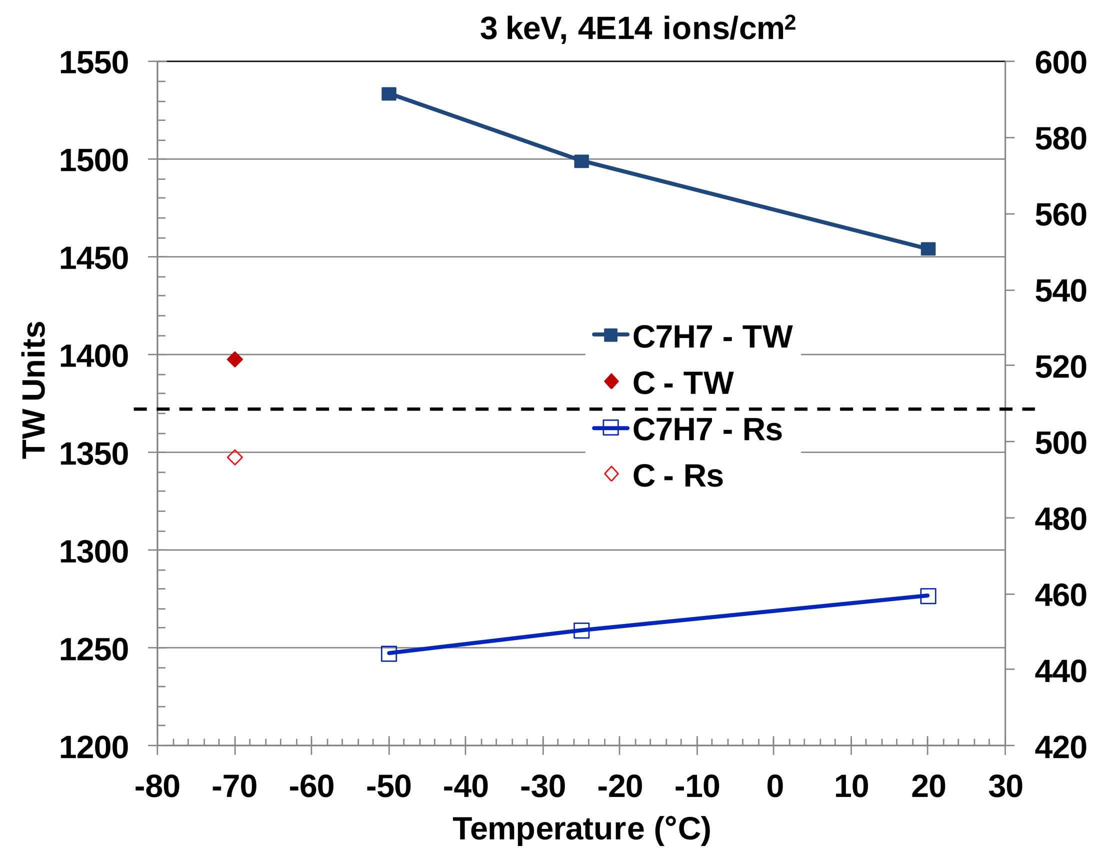


For 7 keV, C_7H_7 is nearly saturated at +20°C

Weak temp. dependence of TW and R_S relative to C

C_7H_7 has higher TW and lower R_S than C at +20°C

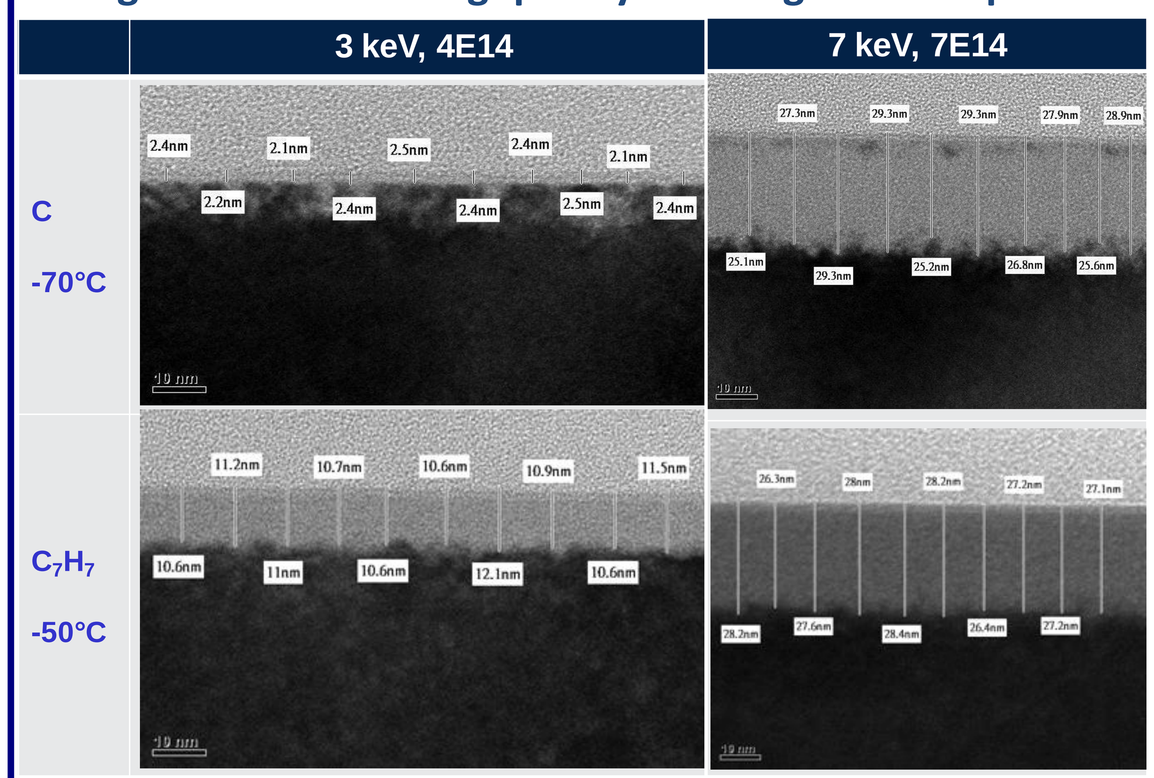
3 keV, 4E14 ions/cm²



For 3 keV, C_7H_7 at +20°C has higher TW and lower R_S than C at -70°C

Advantage of C_7H_7 over C increases at low energies

Big increase in throughput by avoiding a cold implant



TEM data for C_7H_7 at -50°C is better than C at -70°C

C_7H_7 amorphizes completely at -50°C

C does not completely amorphize even at -70°C

C_7H_7 gives a smoother α/c interface than C

Conclusions

(1) High dose rate

(2) Cold implant

(3) Molecular implant

Can be substituted for each other, giving maximum process flexibility

- High instantaneous dose rate leads to thicker amorphous layer for a given dose/energy
- No need for cryogenic implants below -70°C, even for light ions such as C
- Further damage engineering gains possible by substituting C_7H_7 for C
- C_7H_7 at +20°C may outperform C at -70°C in some cases