The Cluster Implant *Source*

Interaction of Phosphorus and ClusterCarbon™ in the NMOS Si:C stress application

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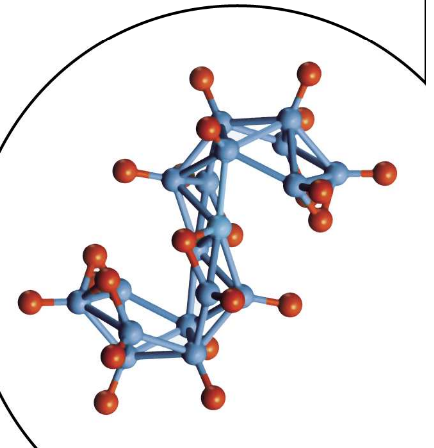
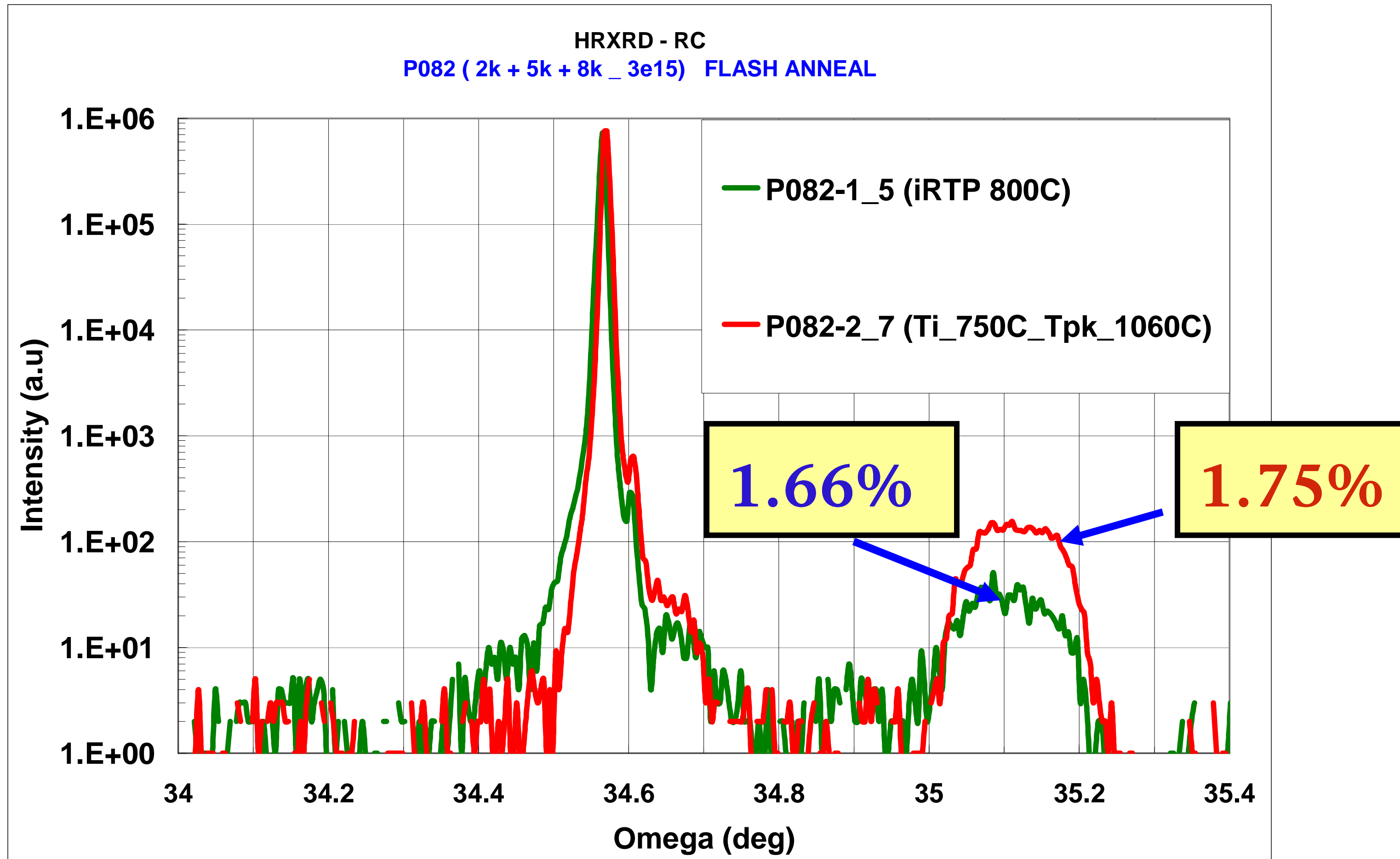


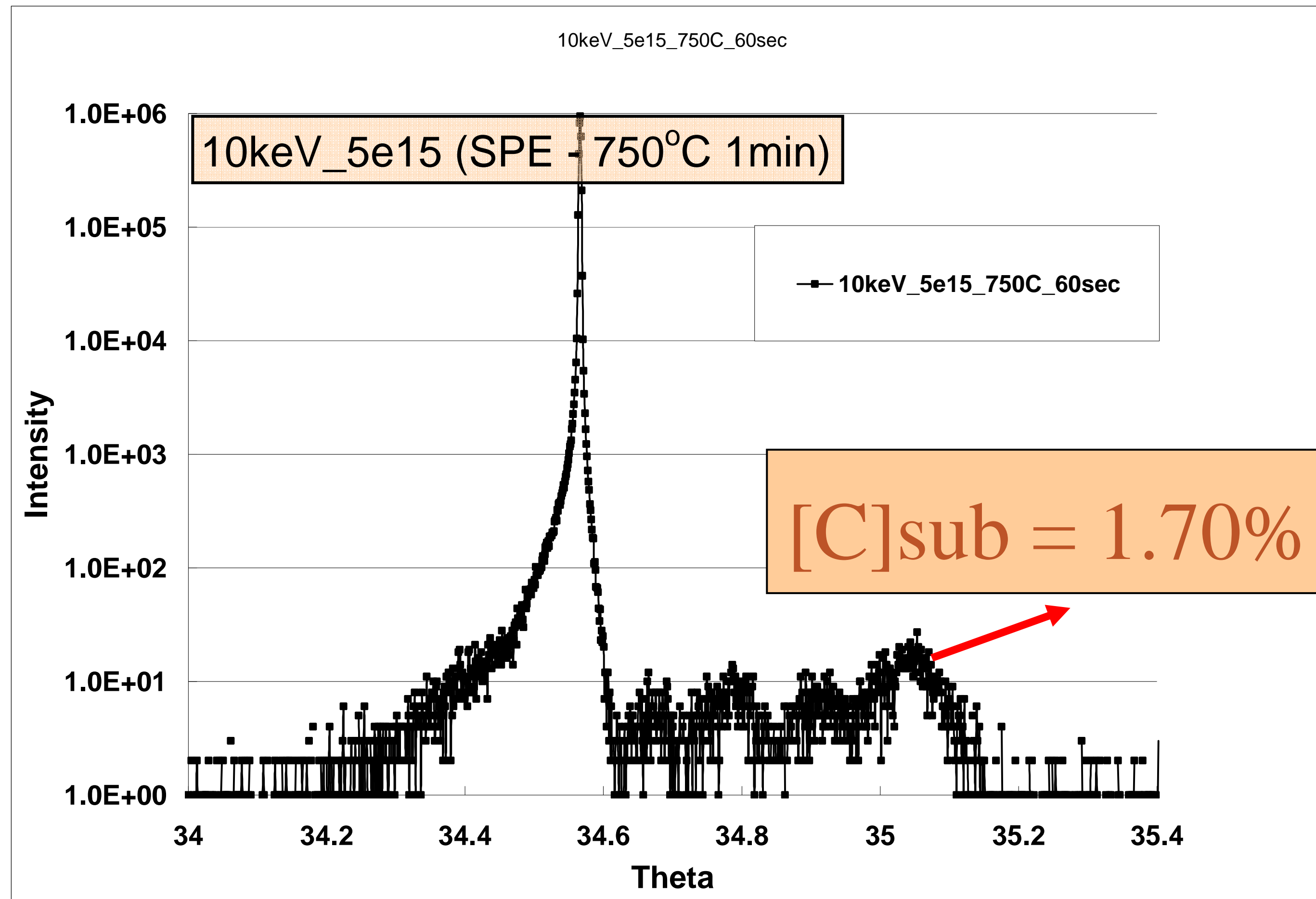
ClusterCarbon Implant for Si:C Stressor

- Silicon lattice only allows 2% carbon
  - Si:C materials science very different from SiGe
- Implant method fundamentally provides accurate control of carbon concentration
  - Multiple implant sequence allows design of carbon depth profile
- Highest substitutional carbon achieved by recrystallation of amorphous layer
  - MSA promotes high substitutionality
- Cluster implant
  - self-amorphization
  - low crystalline damage below a-Si layer

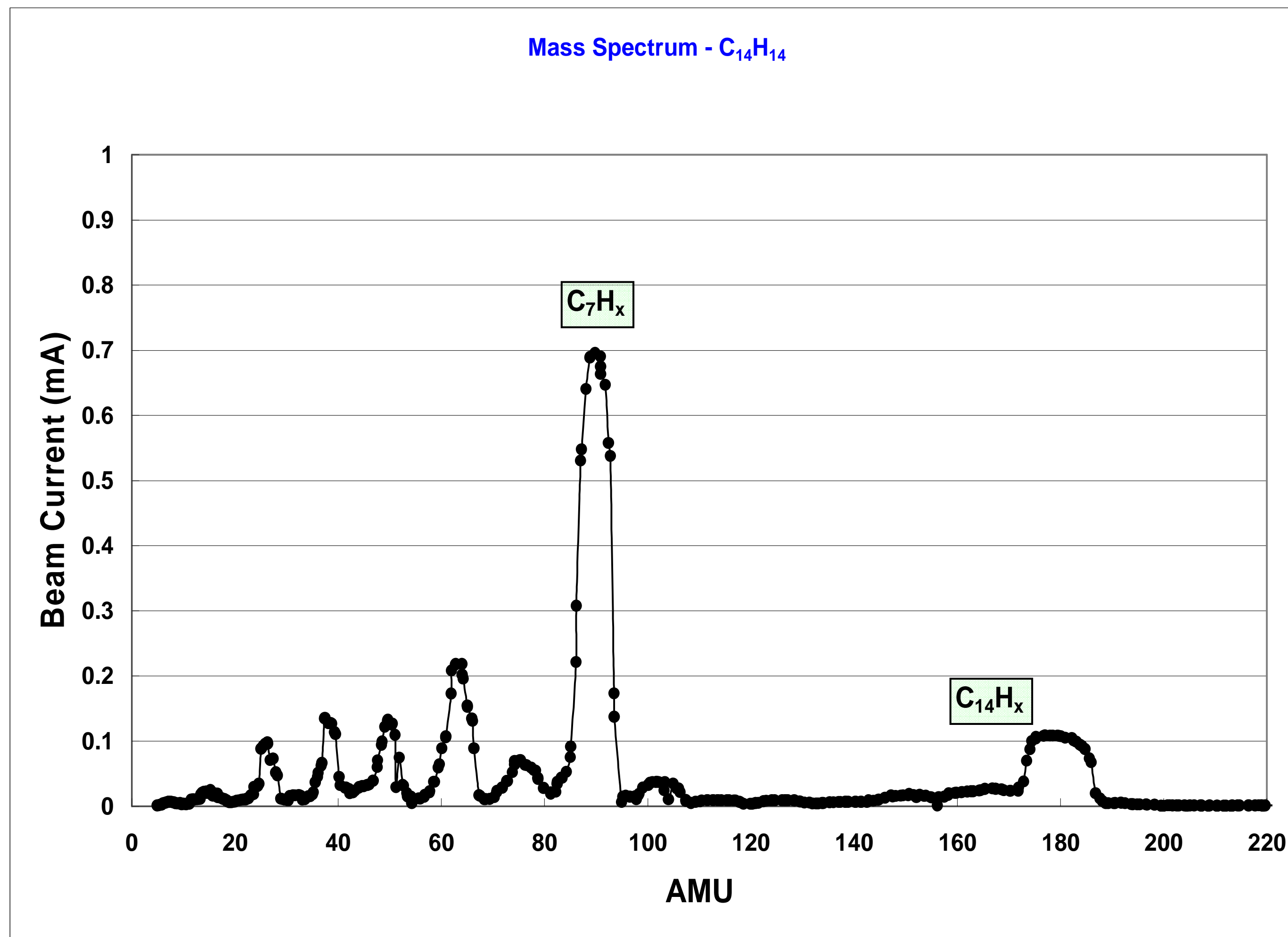
HRXRD -Multiple C7 implant –(2k+5k+8k)@3e15 Flash Anneal



10keV_5e15 (SPE – 750°C, 60sec)

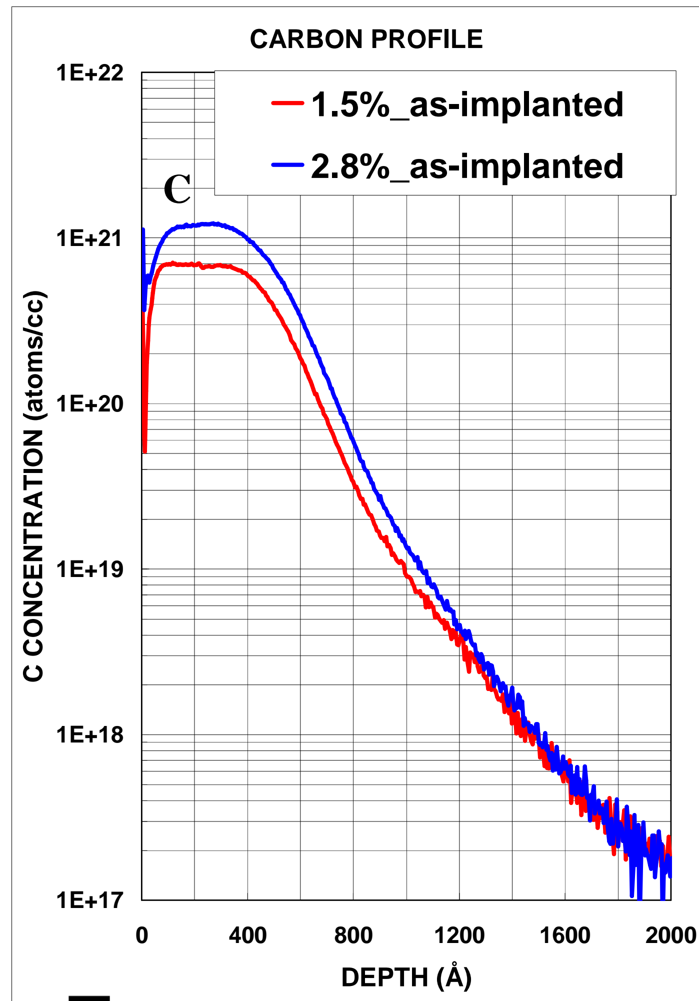


Mass Spectrum – 10keV, $C_7 H_7$



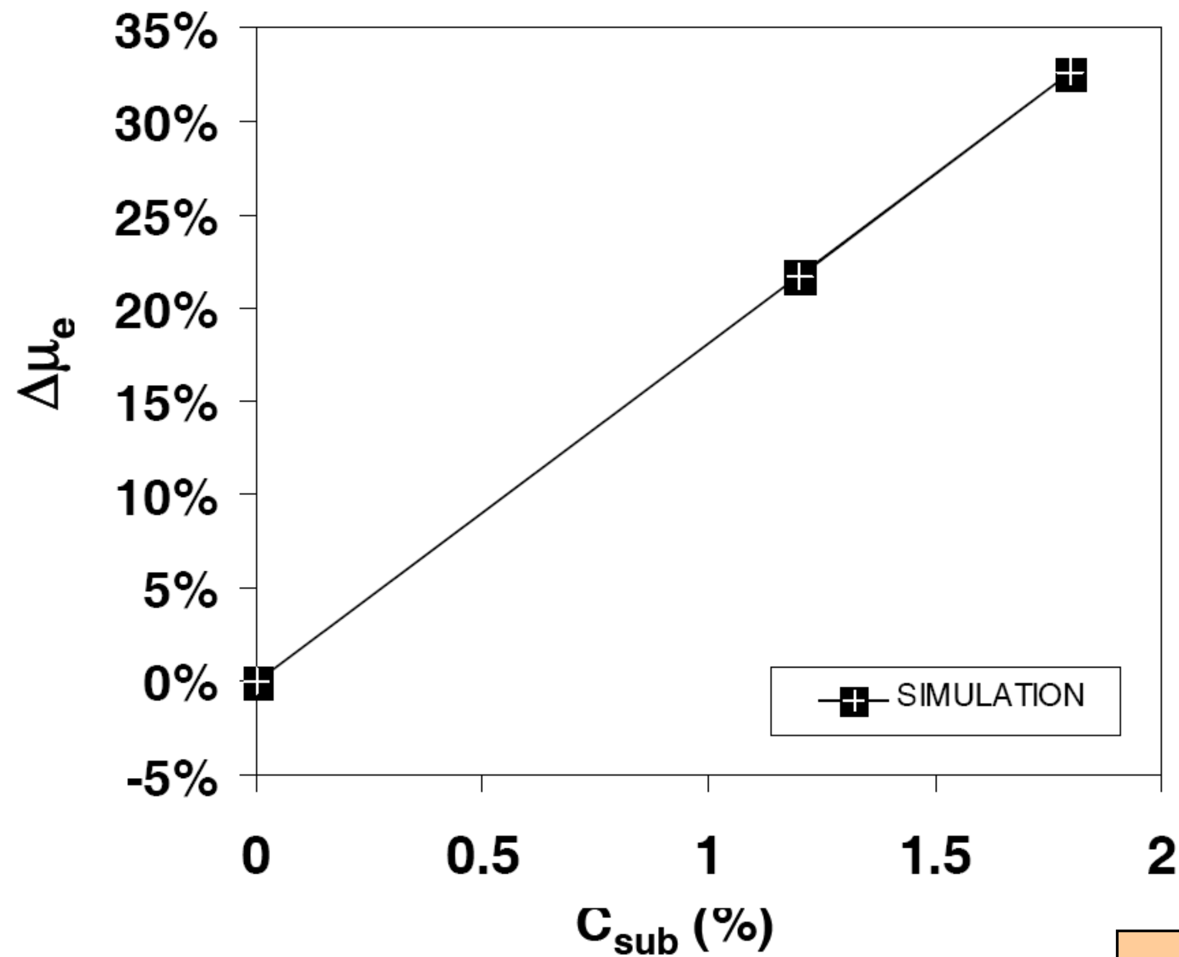
SIMS : 1.5% & 2.8%

C_7H_7 (1/3/10) & C_7H_7 (2/6/10)



Higher Peak concentration for high carbon atomic density

Mobility Enhancement vs % of $[C]_{subs}$



Y. Cho et al, EMRS, 2008

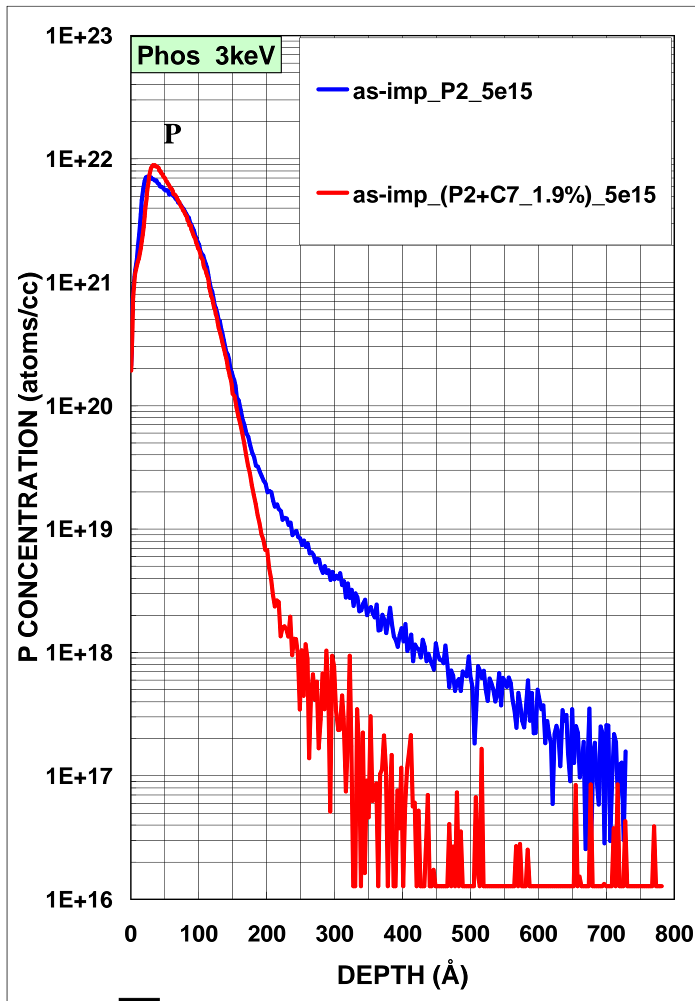
Multi-Process Optimization

- ClusterCarbon implant
- Phosphorus implants
- Annealing
  - MSA
  - Spike
- All processes interact and impose constraints
  - Must be optimized together

Process Interactions

- ClusterCarbon acts as PAI for Phos implant
- Carbon inhibits Phos diffusion
- Spike anneal degrades carbon substitutionality
- Carbon and Phos compete for substitutional sites
- Phos promotes regrowth, carbon inhibits regrowth

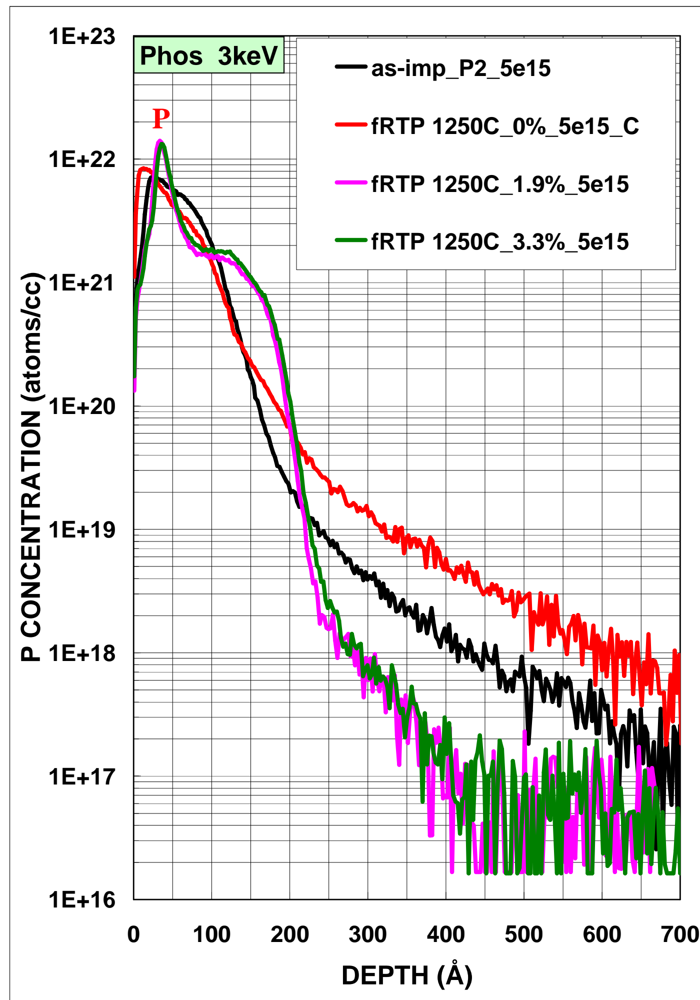
SIMS Profile : Phos 3keV , 5e15 atoms/cm^2 with and without C_7



- With C_7 implant, Xj is reduced by about 75Å and an abrupt junction is obtained.

SIMS Profile : Phos 3keV , 5e15 atoms/cm^2

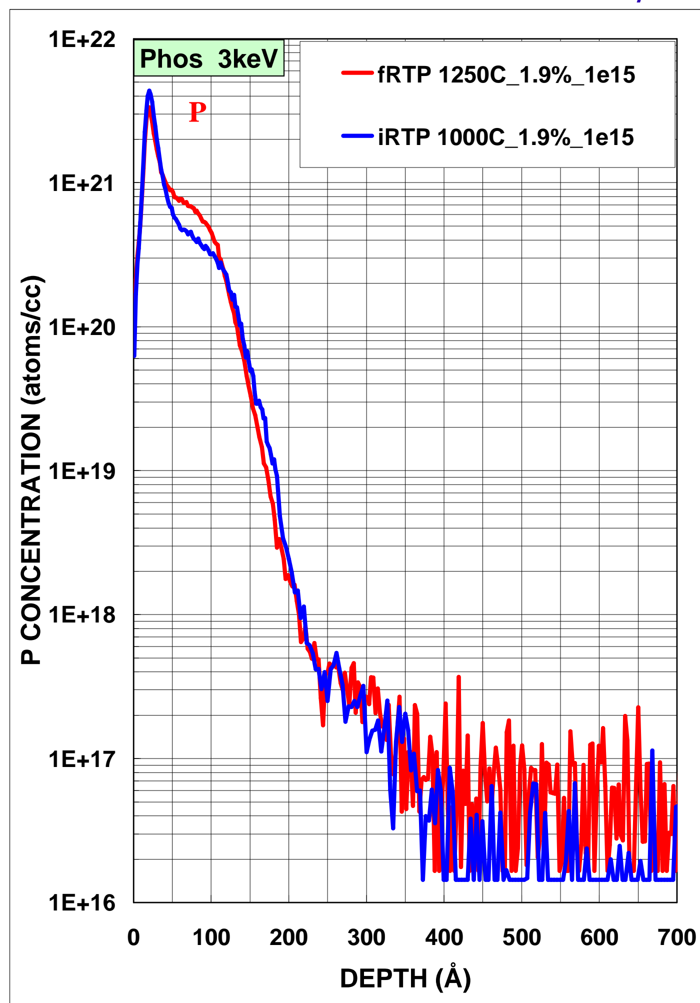
Dependence on C_7 atomic percentage



- Even at 1.6% atomic carbon, the dopant profile is box-like with an abrupt junction with flash anneal. Increase in concentration beyond 1.6% does not provide any better Xj and abruptness.

SIMS Profile : Phos 3keV , 1e15 atoms/cm^2

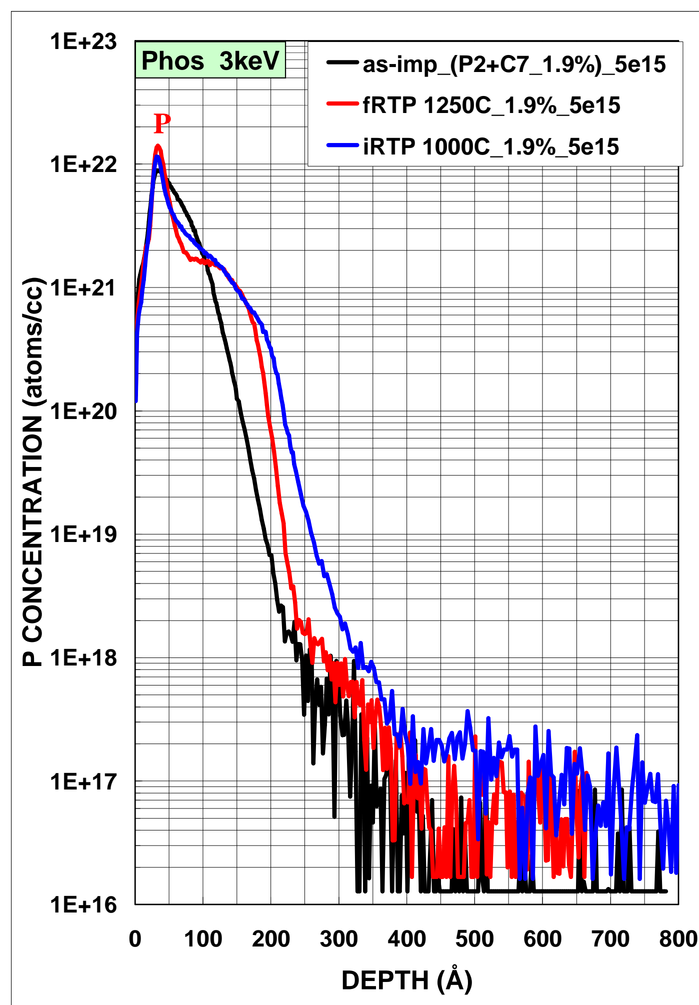
Anneal comparison - C_7 1.9%



- At 1e15 dose, there is enhanced dopant activation (shoulder) between 50-100Å with flash anneal.

SIMS Profile : Phos 3keV , 5e15 atoms/cm^2

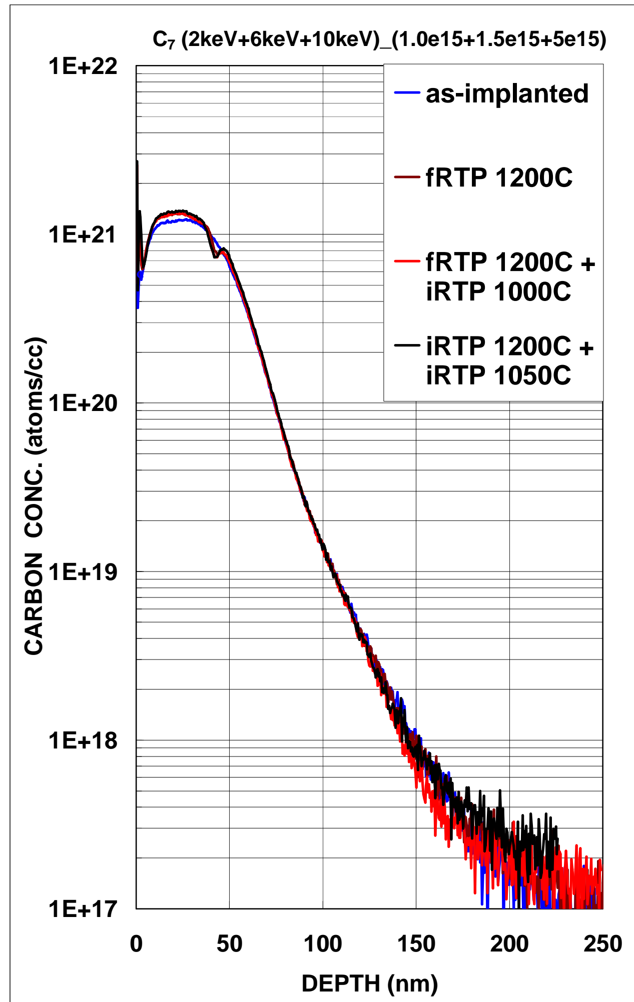
Anneal comparison - C_7 1.9%



- At 5e15 dose, the dopant profile is box-like with an **abrupt junction with flash anneal** when compared to impulse spike anneal.

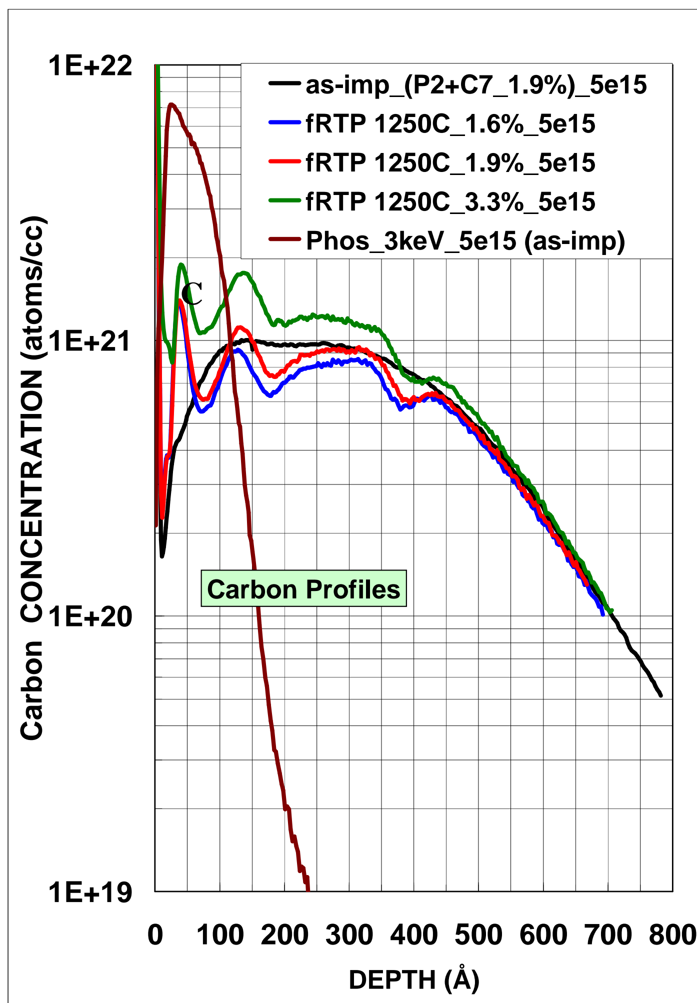
CARBON SIMS PROFILES

C_7H_7: 2/6/10



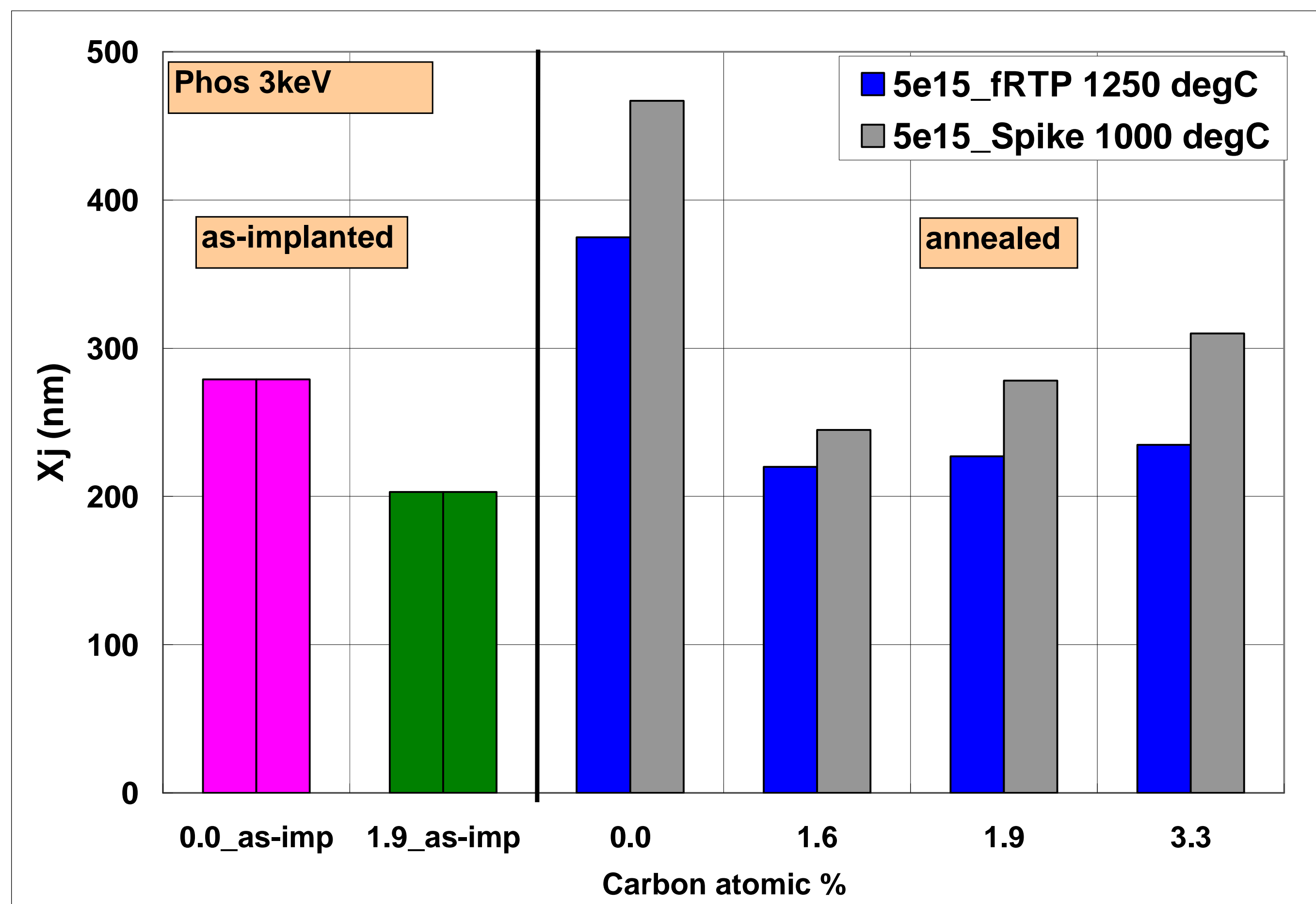
No change in carbon profiles.

Carbon Profiles
Carbon atomic percent dependence



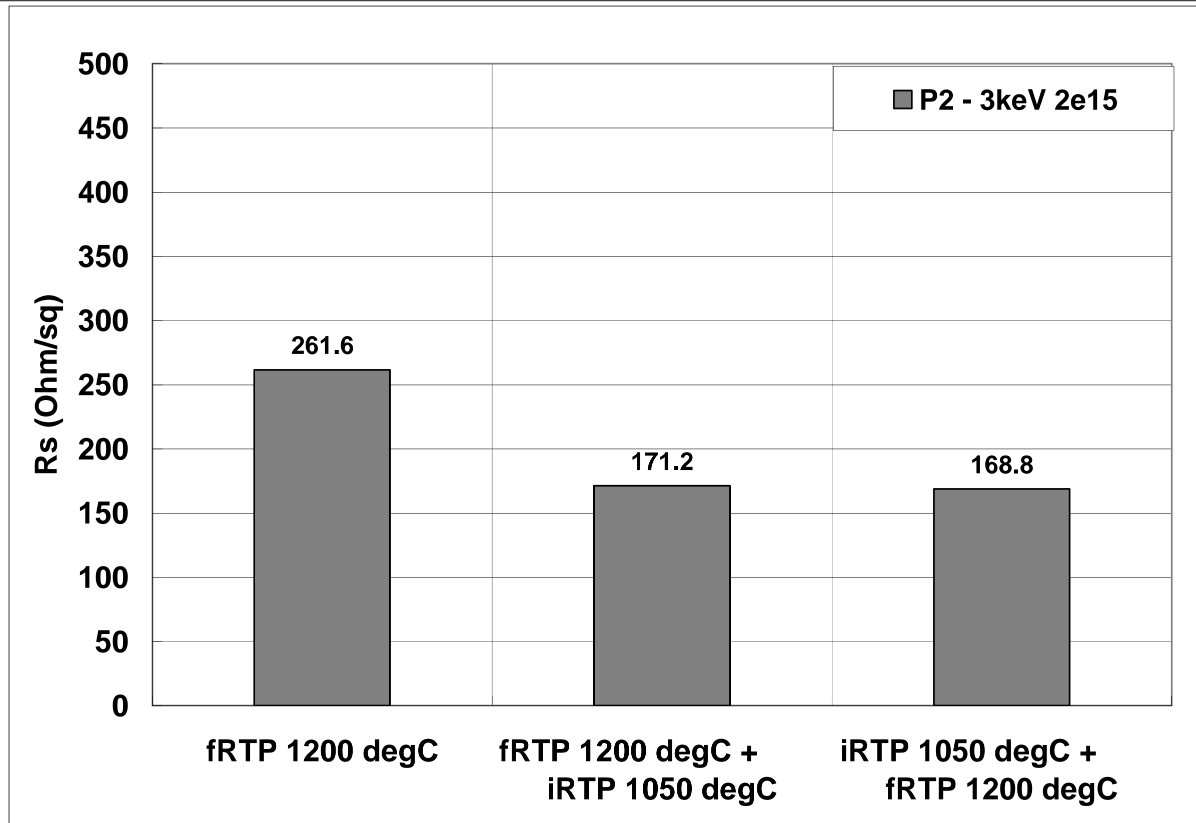
- For high dose Phos (5e15) case, the carbon profiles show similar trend irrespective of the carbon atomic percentage.

Phos 3keV , 5e15 atoms/cm^2 with and without C_7: Junction Depth (Xj): Annealed



With C_7 (1.9%), Xj ~ 200Å for as-imp case.

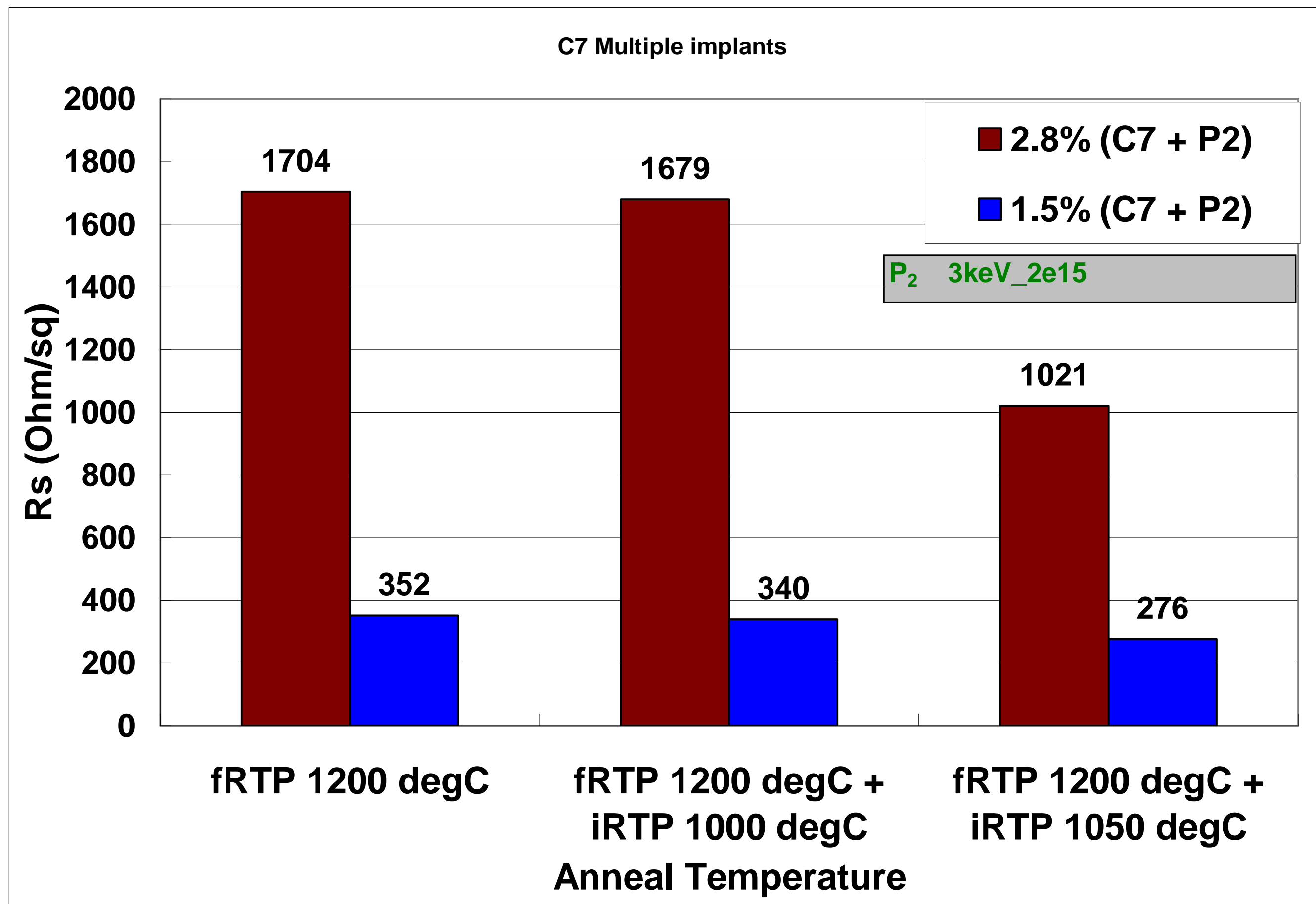
P_2 - 3keV, 2e15 atoms/cm^2
Rs results



No difference in activation whether flash anneal is done first or last. Probably it might have an effect on subs. carbon percentage.

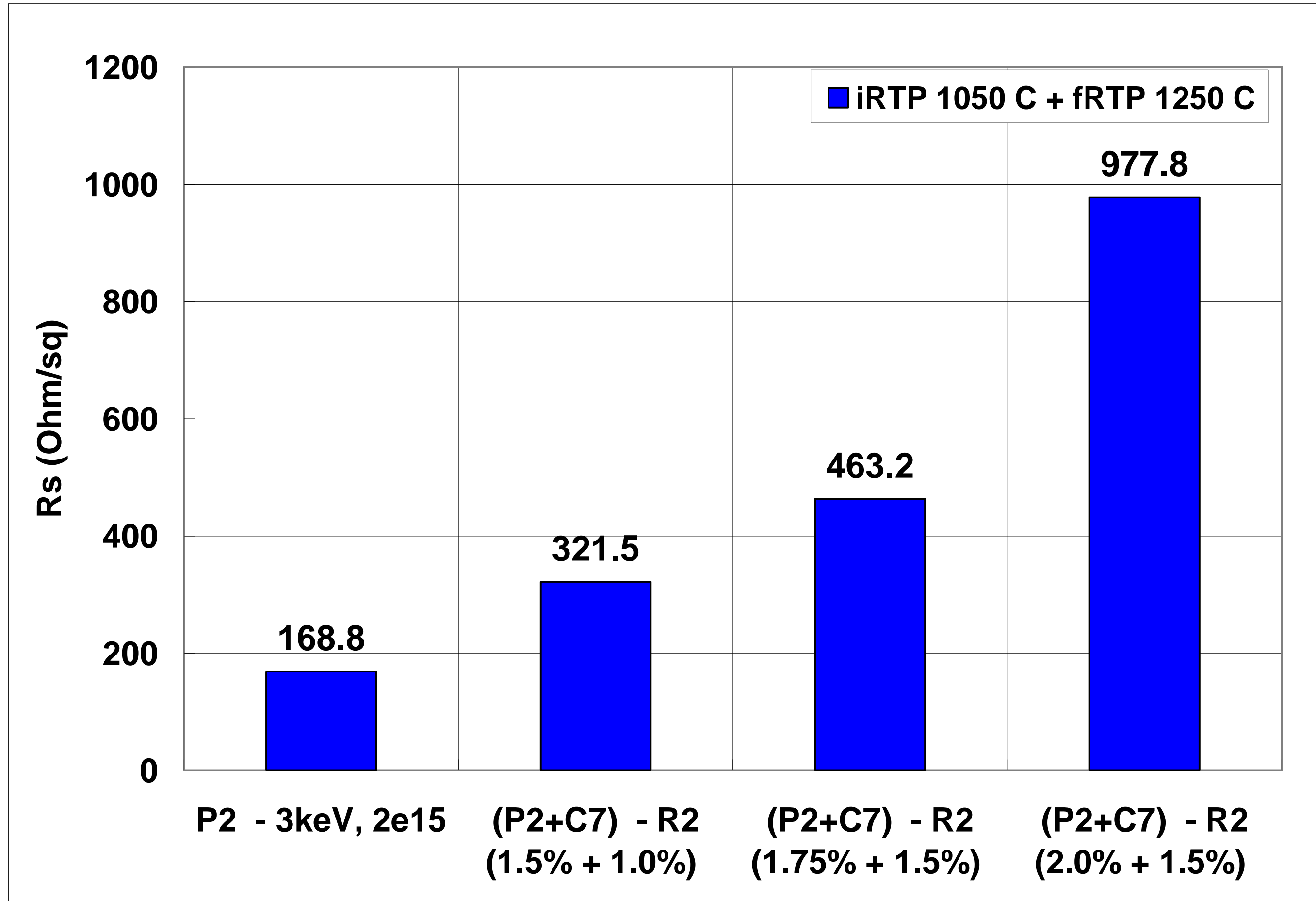
Rs – 4PP (P_2+ C_7)

(Comparison 1.5% vs 2.8% atomic carbon)



Rs increases with increase in carbon concentration

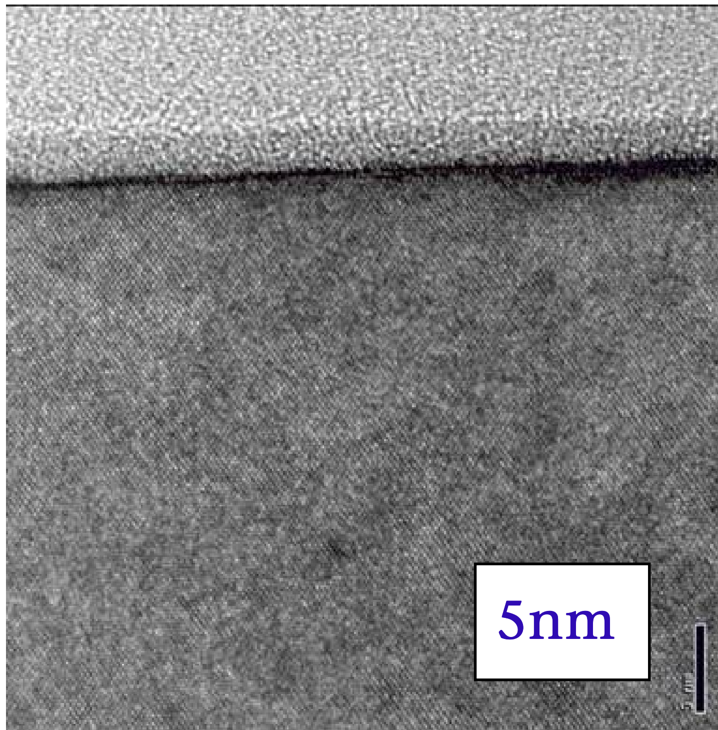
$P_2 + C_7H_7$ Rs results
(iRTP 1050°C + fRTP 1200°C)



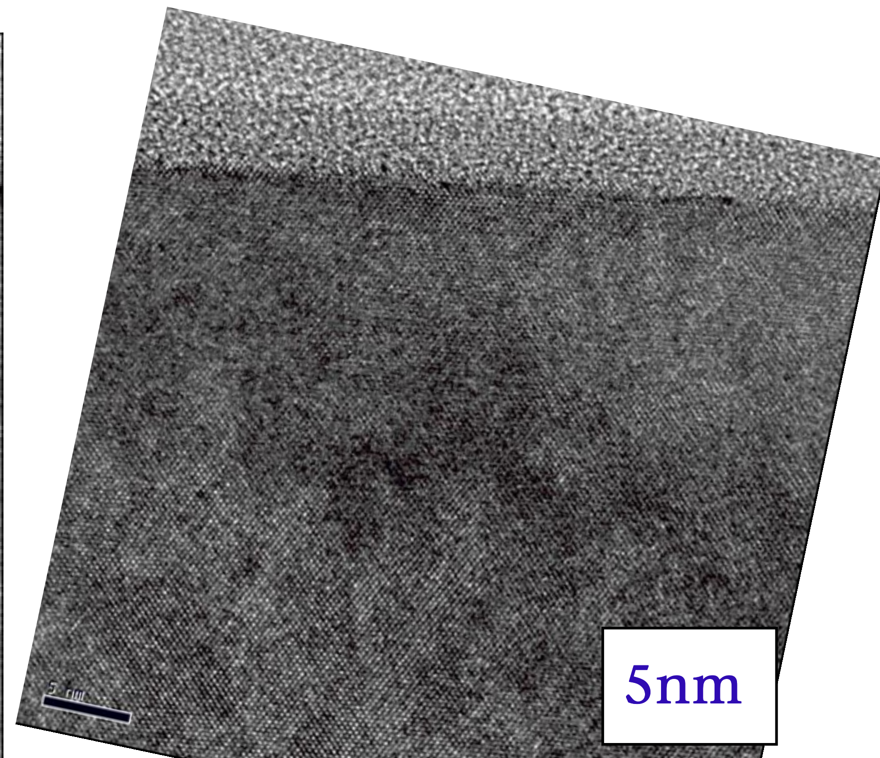
Dramatic increase in Rs beyond 1.75% atomic carbon.

XTEM 1.5% atomic carbon
C_7H_7 vs (P_2 + C_7H_7)

C_7H_7 fRTP 1200°C + iRTP 1050°C



P_2 + C_7H_7 fRTP 1200°C + iRTP 1050°C



No regrowth defects after iRTP 1050°C for both C_7 and P_2+C_7 cases.

Intermediate Results

- C_7 implant is effective in producing Si:C layers without residual damage
- $[C]_{sub}$ greater than 2% achievable
- MSA produces highest $[C]_{sub}$
- Spike anneal degrades $[C]_{sub}$

- Next Steps
  - Interaction with dopants
  - MSA plus spike combination

Summary

- ClusterCarbon creates appropriate stress layers for NMOS enhancement.
- Moderate doses of carbon are appropriate for achieving low resistance phosphorus junctions.
- Process design must include carbon and phos implants and anneal conditions to achieve good results.