A Plasma Doping Process for 3D FinFET Source/ Drain Extensions

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Outline

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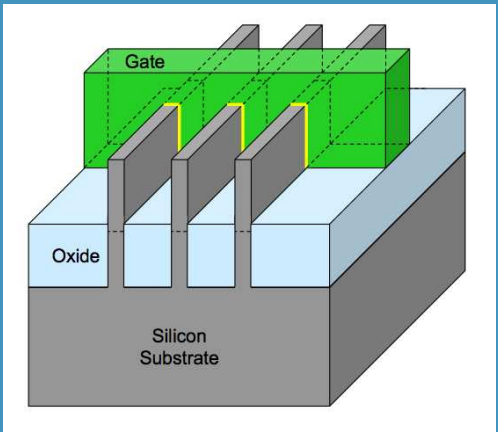
1. Plasma Doping for 3D FinFETs
2. Metrology for FinFET Doping Characterization
3. Doping Responses and Fin conductance
4. Summary and Acknowledgements

3D FinFET SDE Doping Challenges

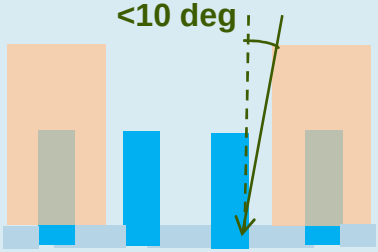
- **3D FinFET for device 20nm beyond**
- **Key Challenges**:
  - Conformal Doping
  - No Fin erosion
  - No residual defect
  - Low leakage



Beamline:

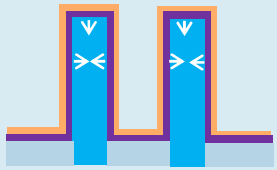
- Shadowing

Title angle of implantation
<10 deg



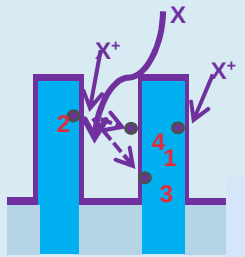
Deposition and Thermal Drive in

- Highly Conformal
- Not PR compatible
- Cap layer



Plasma Doping:

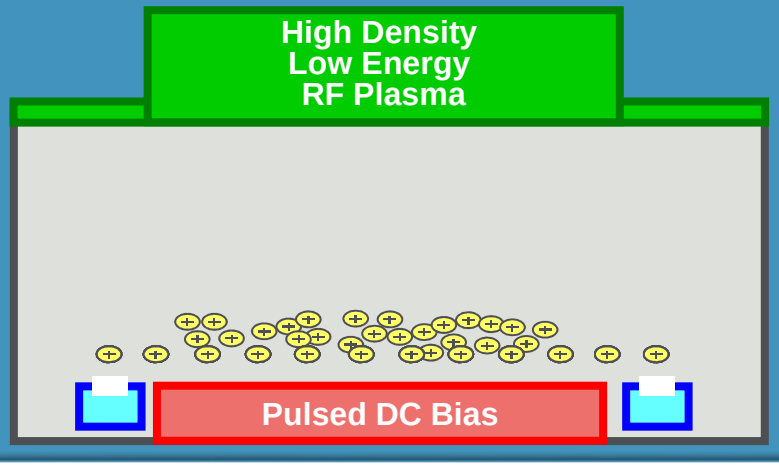
- Good conformality
- PR compatible

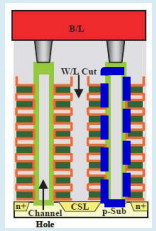


PLAD implant mode offers a simplified, photoresist compatible process

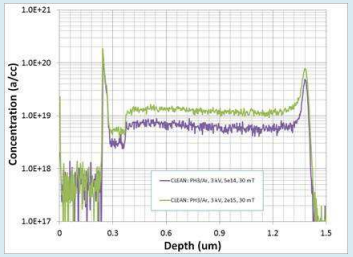
VIISta PLAD Advantages for Advanced Devices

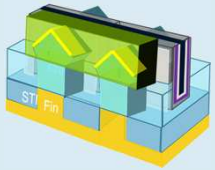
- **Production proven technology across memory, logic and CIS process spaces**
- **Plasma Doping Advantages:**
  - ✓ Pulsed DC bias allows for precision doping
  - ✓ Independent control of RF plasma generation and DC bias balances deposition and implant
  - ✓ Faraday dosimetry provides precision process tracking



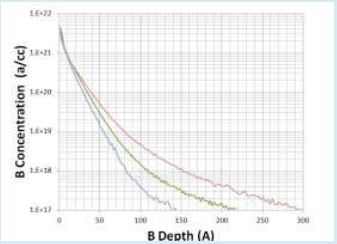


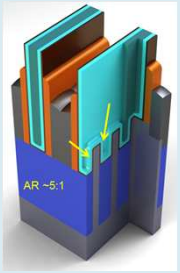
Sidewall doping for advanced 3D devices: FinFET's, VNAND, and CIS



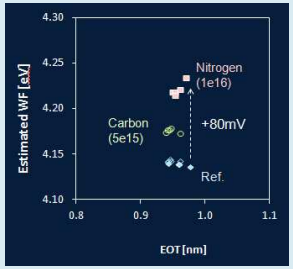


Shallow doping to reduce contact resistance and passivate surfaces





High dose implants to modify material properties: workfunction, etching rate, & conductivity.



All future devices are 3D
PLAD can modify properties of vertical sidewalls

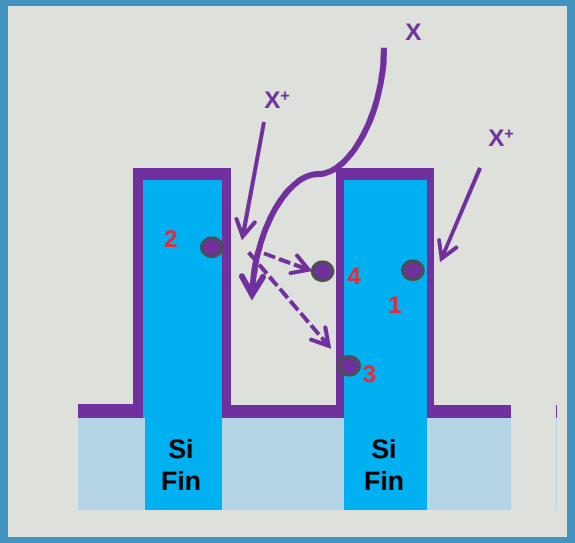
Benefits and Challenges for PLAD FinFET Doping

1: DIRECT IMPLANT

2: DEPOSITION and KNOCK-IN

3: REFLECTED ION IMPLANT

4: SPUTTERING



- **Various Process parameters:**
  - Power, Pressure, gas mixture ratio
  - Energy, Dose, PW, Frequency
- **Multiple Mechanisms:**
  - Direct implant
  - Deposition and knock in
  - Reflected implant
  - Sputtering/Etching
- **Wafer Results:**
  - Conformality
  - Minimize fin erosion
  - Eliminate residual defects

Doping of Si Fin structures is a driven by multiple mechanisms and competing effects

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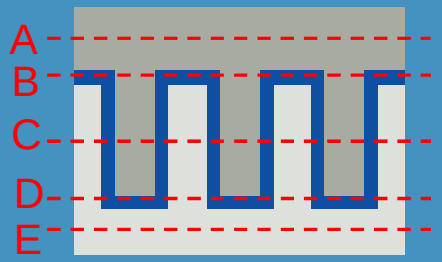
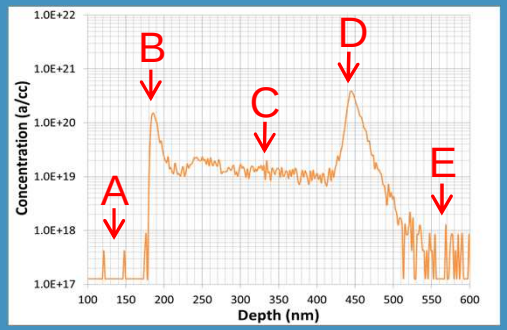
Dopant Characterization Metrology

1.5D SIMS

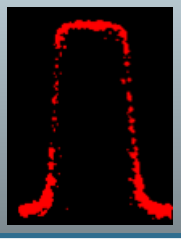
1. Lower detection limit
2. Results can be quantified
3. Average over number of fins
4. No lateral resolution

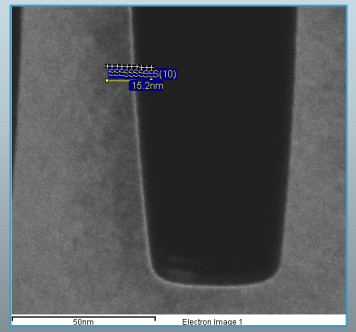




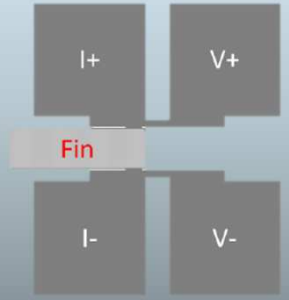
EDS mapping/EDS line scans

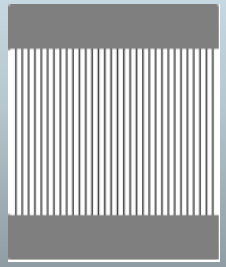
1. 1% detection limit
2. Lateral resolution
3. Hard to quantify





Fin resistor: active dopant





Each metrology has its limitations and the characterization results need to be interpreted carefully

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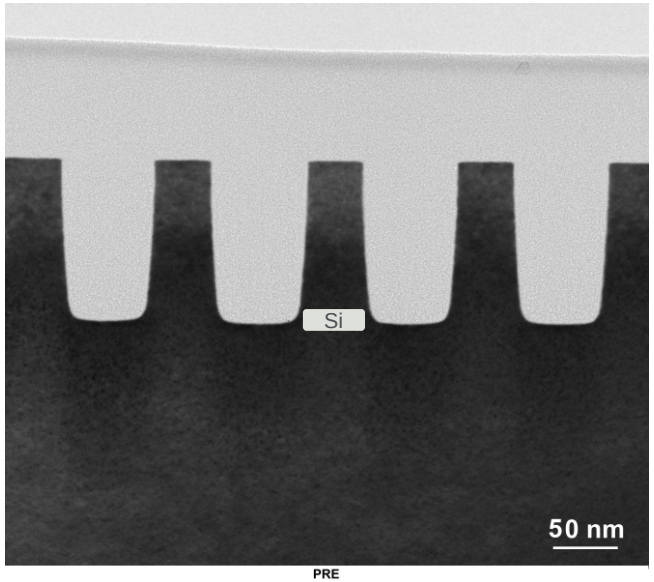
Process Flow and Structure of Samples

PLAD Implant Approach

- Start Wafer
- PLAD Implant + Passivation
- SPM clean
- Anneal
- Post DHF

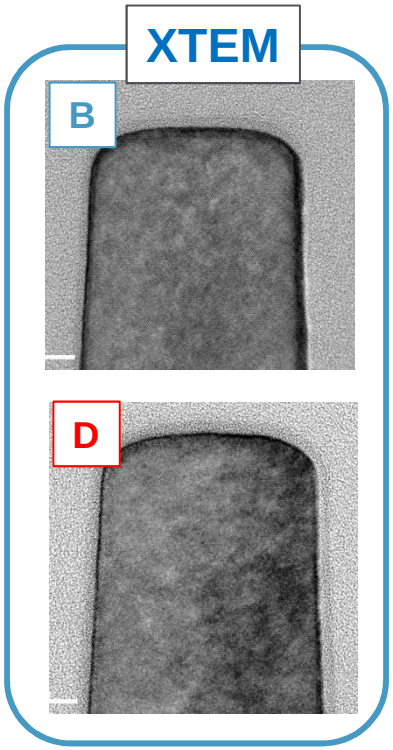


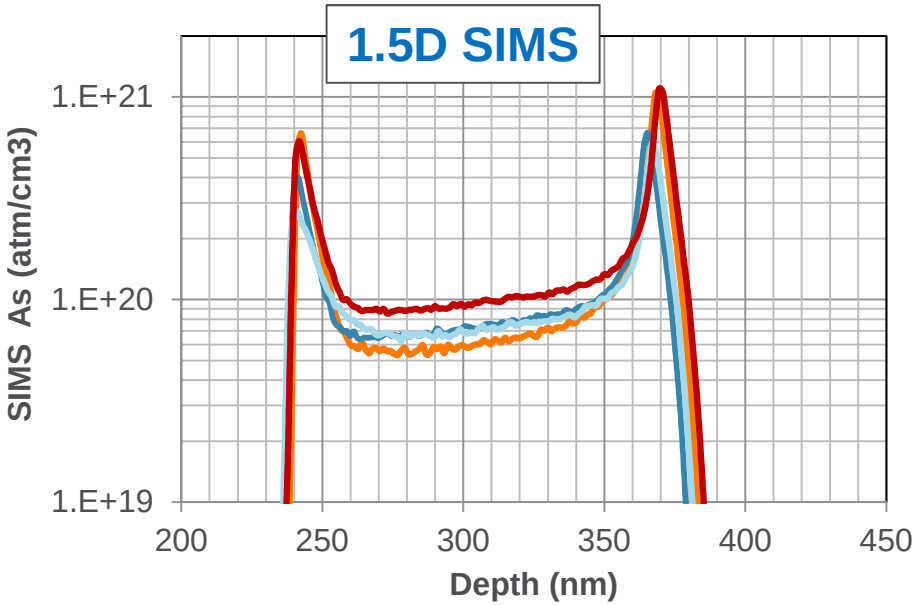
Applied Materials Maydan Center Fin Structure

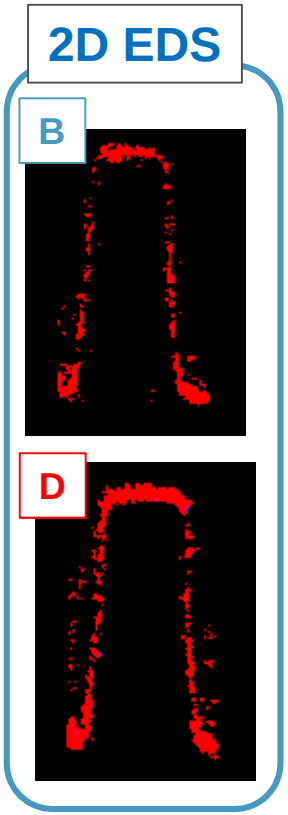
Fin height: ~130nm
Fin width: ~50nm
Fin pitch: ~110nm

PLAD implant mode offers a simplified, photoresist compatible process

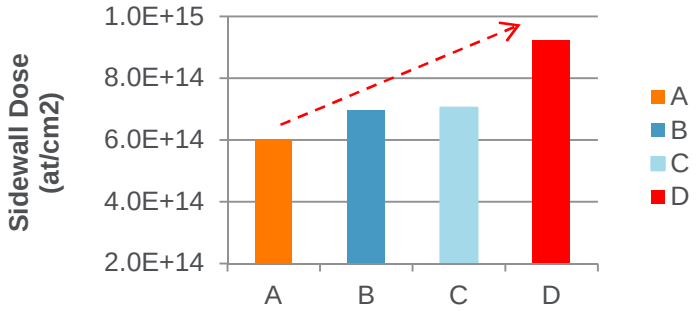
Implant Approach: Energy and Dose Tuning of Fin Doping







- A: Low Energy, Low Dose
- B: Low Energy, High Dose
- C: High energy, Low Dose
- D: High Energy, High Dose

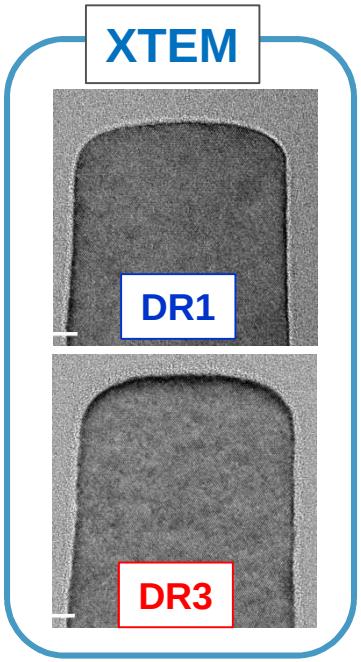


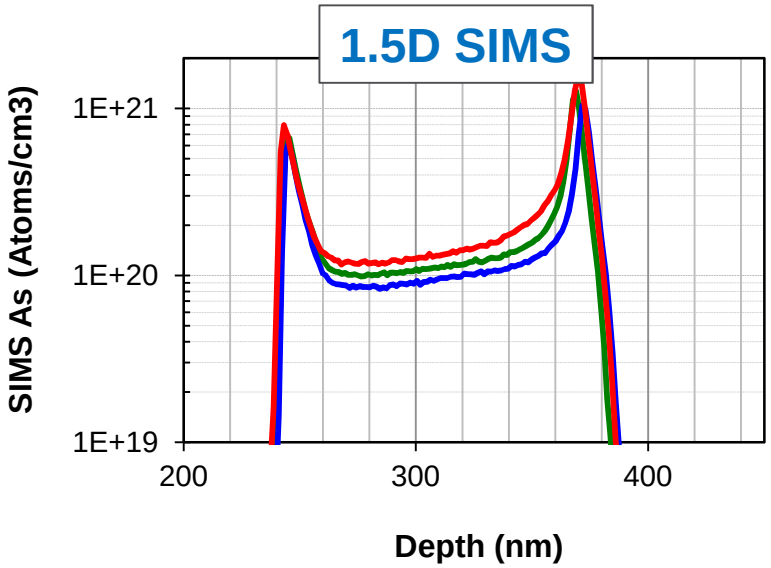
~50% increase in Average Sidewall Dose

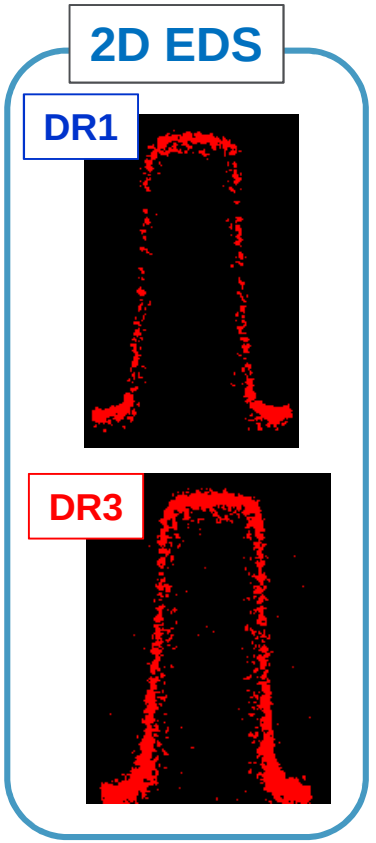
Fin height: ~130nm, Fin width: ~50nm, Fin pitch: ~110nm

Tunable Fin doping is demonstrated by energy and dose control

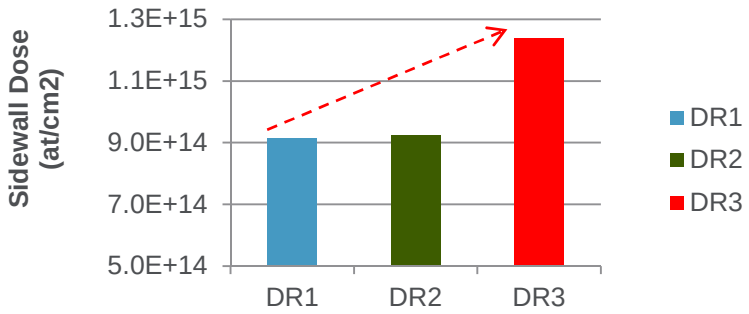
Implant Approach: Plasma Process Parameter Tuning of Fin Doping







- **DR1: Dose Rate 1**
- **DR2: Dose Rate 2**
- **DR3: Dose Rate 3**

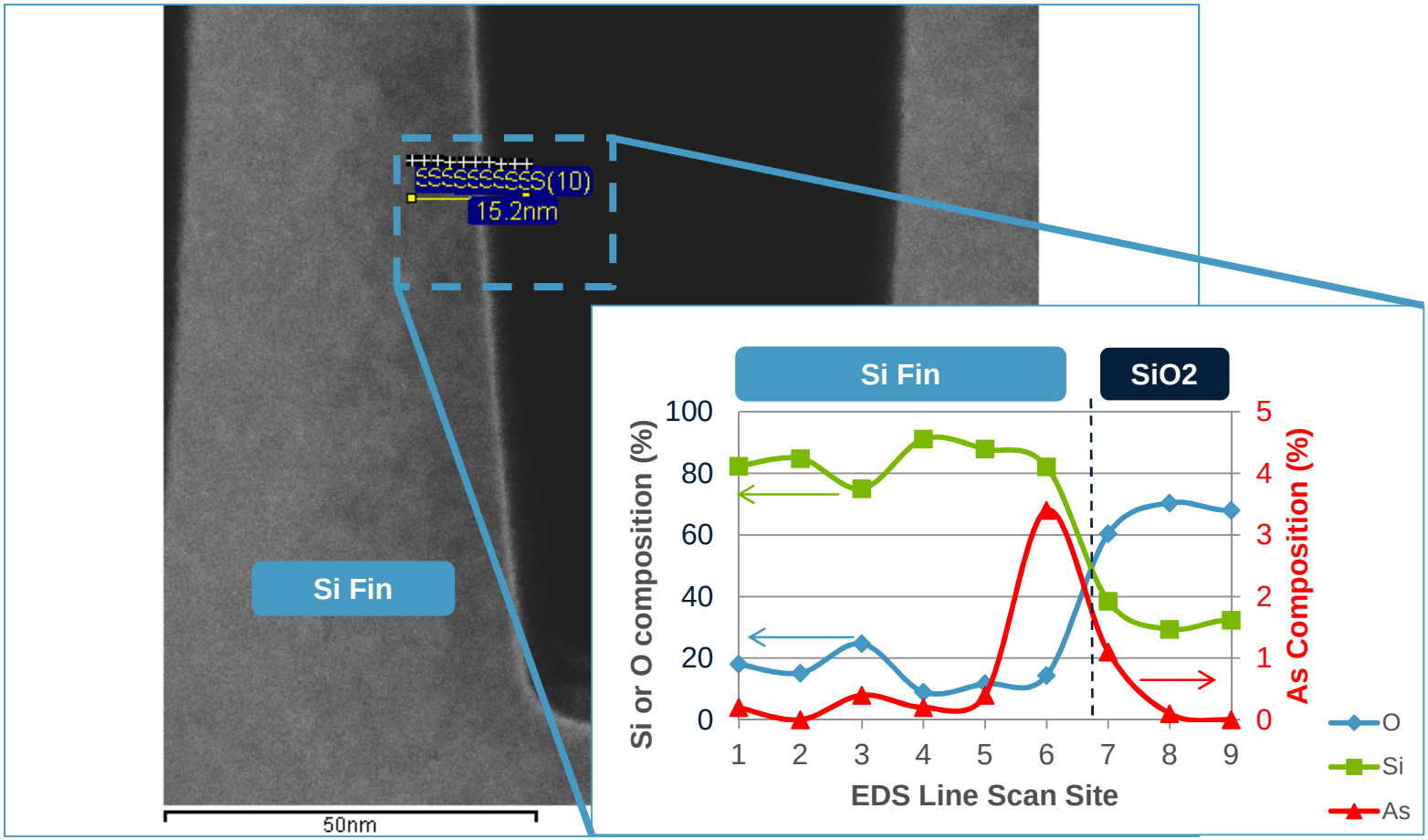


~36% increase in average sidewall Dose

Fin height: ~130nm, Fin width: ~50nm, Fin pitch: ~110nm

Fin doping can be further optimized by plasma parameter tuning

Implant Approach: EDS Verification of Dopant into Fin Sidewall



Fin height: ~130nm, Fin width: ~50nm, Fin pitch: ~110nm

EDS as-implanted line scan demonstrates As doping into fin sidewall

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Summary

- Plasma doping of Fin structures by an implant based approach has been demonstrated
- The application of plasma doping into logic device technology is rapidly accelerating
- Efforts to enhance fundamental understanding and to enable predictive approaches are in progress
- As 3D transistor technology continues to be implemented, PLAD will be required for doping and material property modification

Acknowledgements

- Appreciation is extended to Alexander Pagdanganan, Martin Hilkene, and Matthew Castle for providing the poly-silicon deposition and process flows at the Maydan Center

- We would also like to thank Peter Ryan for his support of the plasma doped sample preparation