Atom Probe Tomography for semiconductor applications

Frontiers of Characterization and Metrology for Nanoelectronics
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Atom Probe Tomography for Semiconductor Applications

- IBM / Imago: joint development of semiconductor applications for APT

- Application Space
  - Materials Issues
    - NiSi on doped Si**

Materials Characterization

- NiPtSi on arsenic-doped Silicon
  - Current technology issue
  - Impurity segregation with anneal

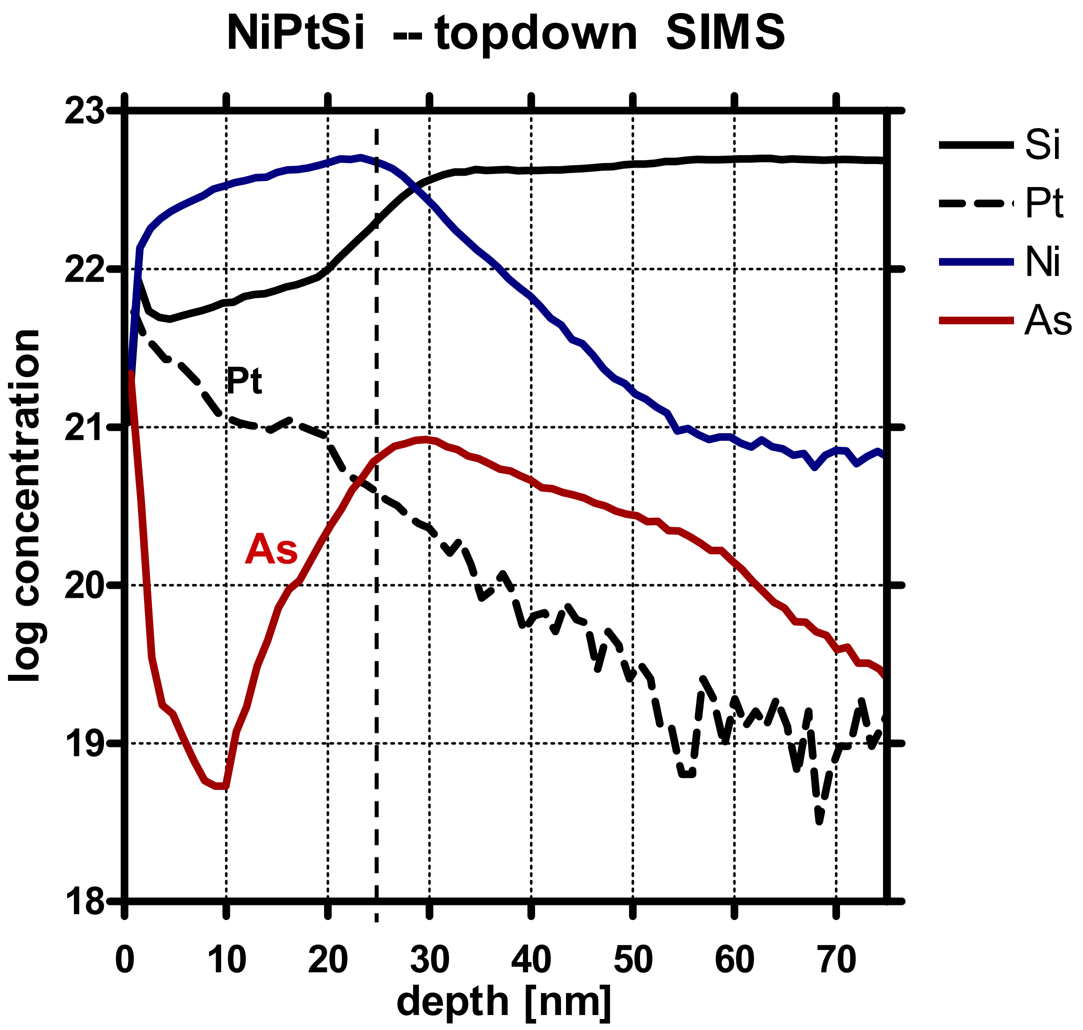
- Comparative analysis techniques
  - APT, SIMS, Analytical TEM

Sample description

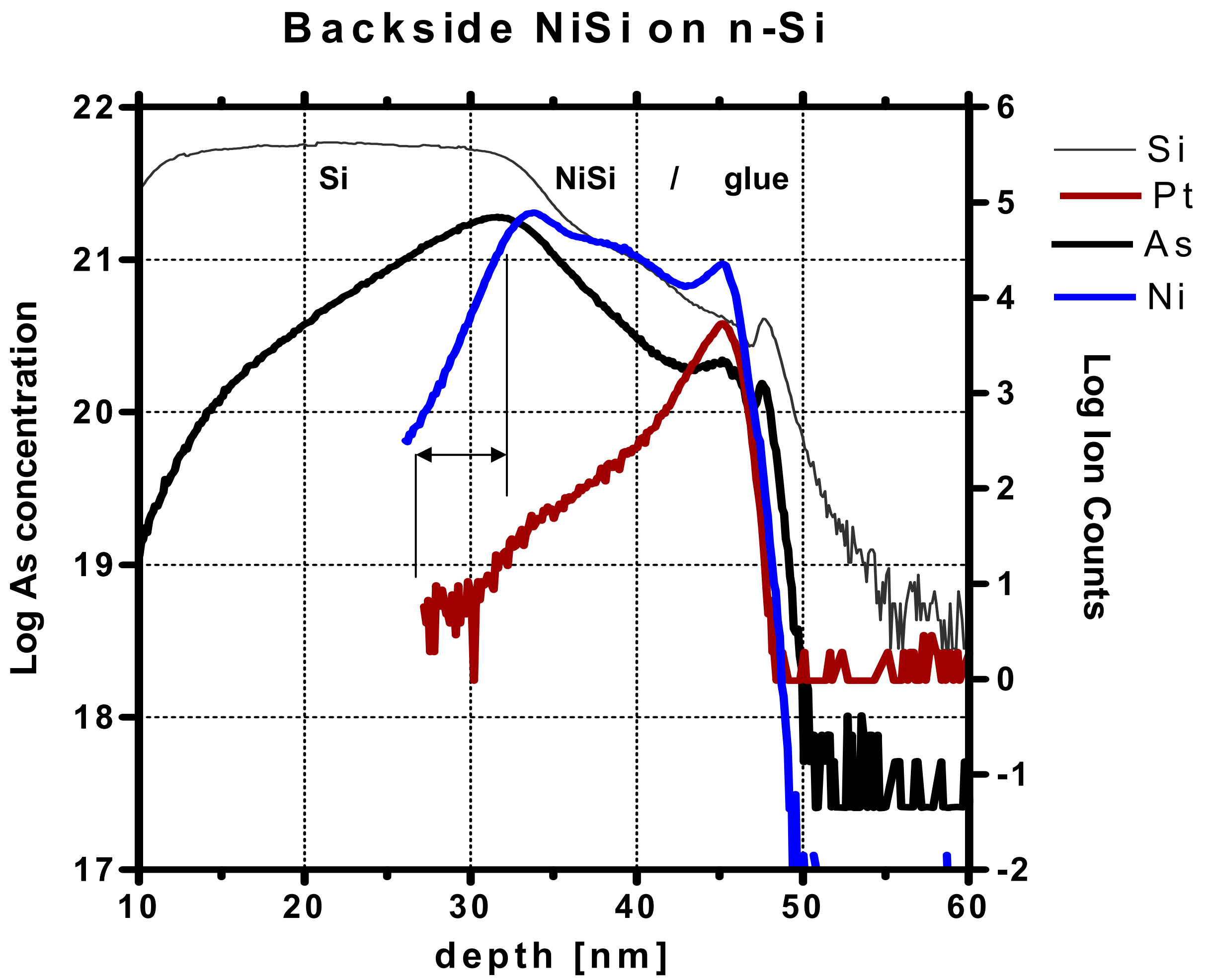
2 keV As implant and anneal
NiPt deposition with TiN cap
Anneal 1
Etch unreacted metal (Ni, TiN)
Anneal 2

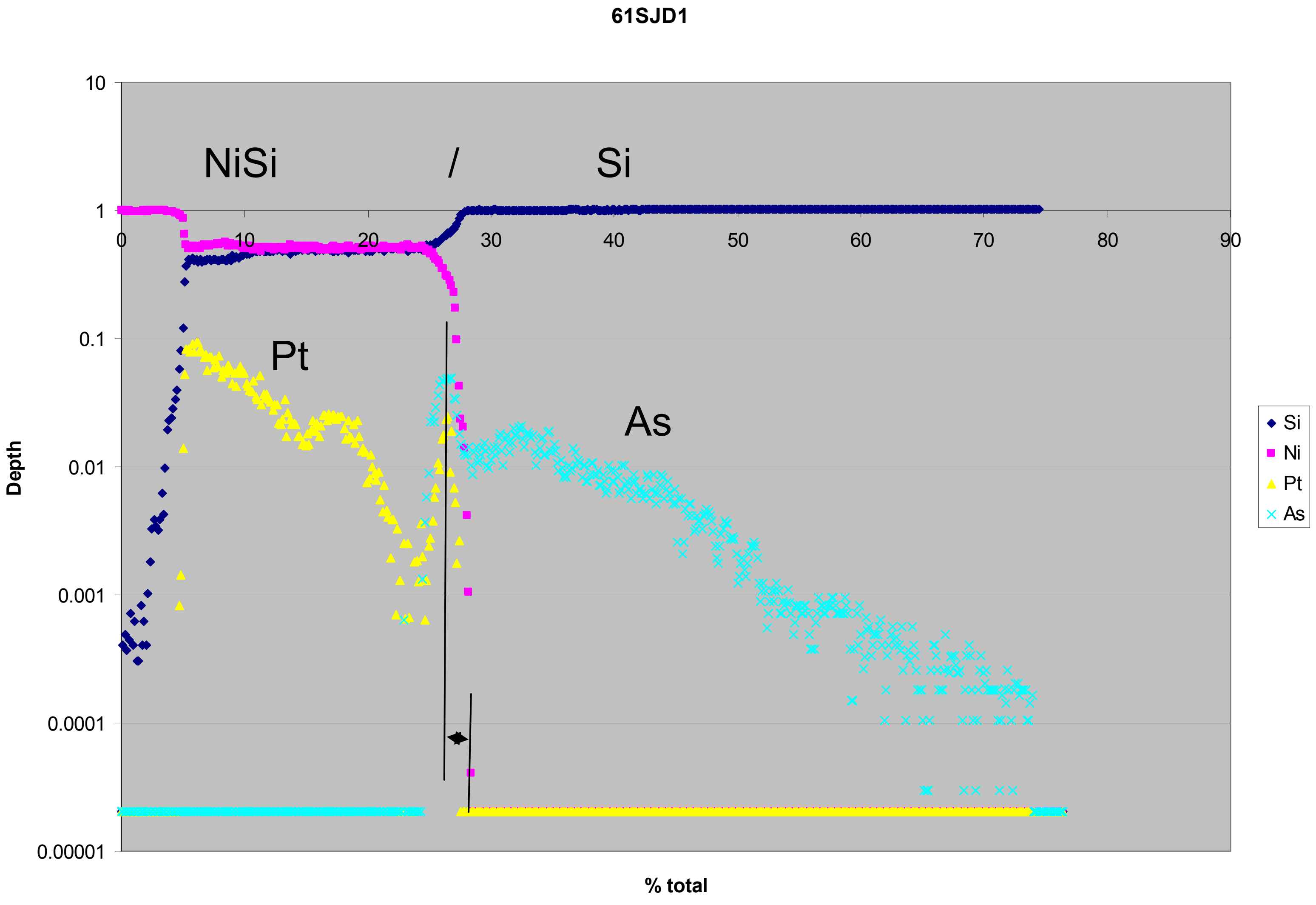
Wafer ID	Rapid anneal 1	Rapid anneal 2	Interface roughness
62SJA0	400	N	1.45
61SJD1	400	Y	1.27
60SJG2	360	Y	1.2
59SJD1	360	N	0.97

SIMS depth profile

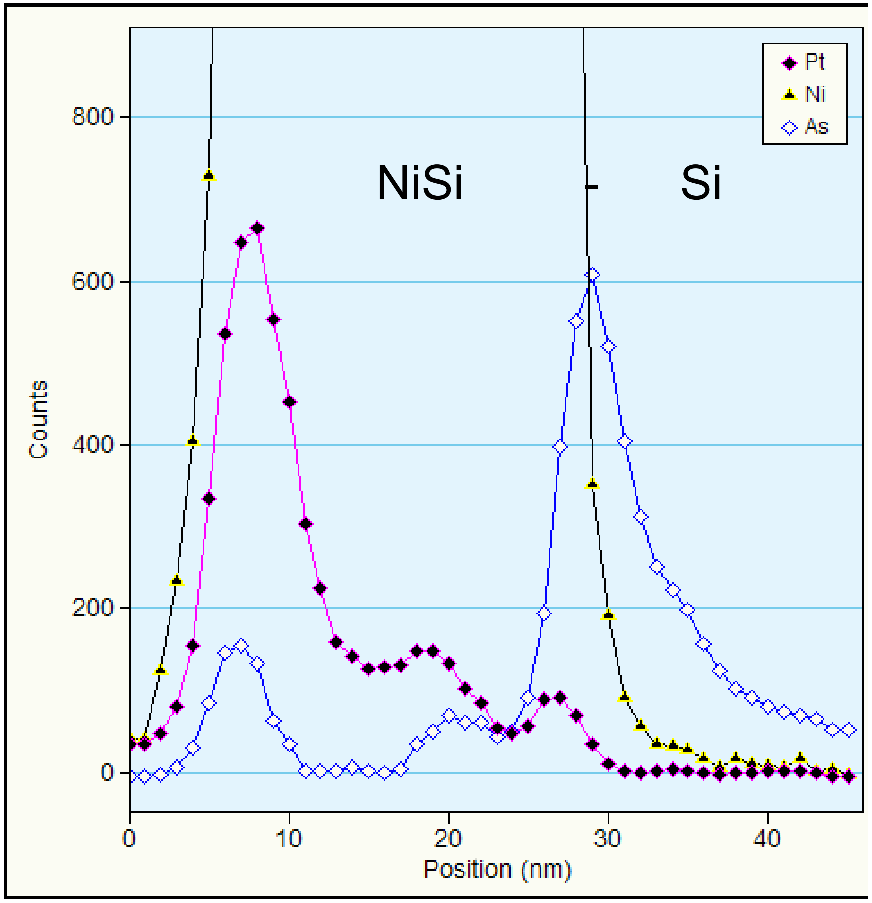


Backside SIMS

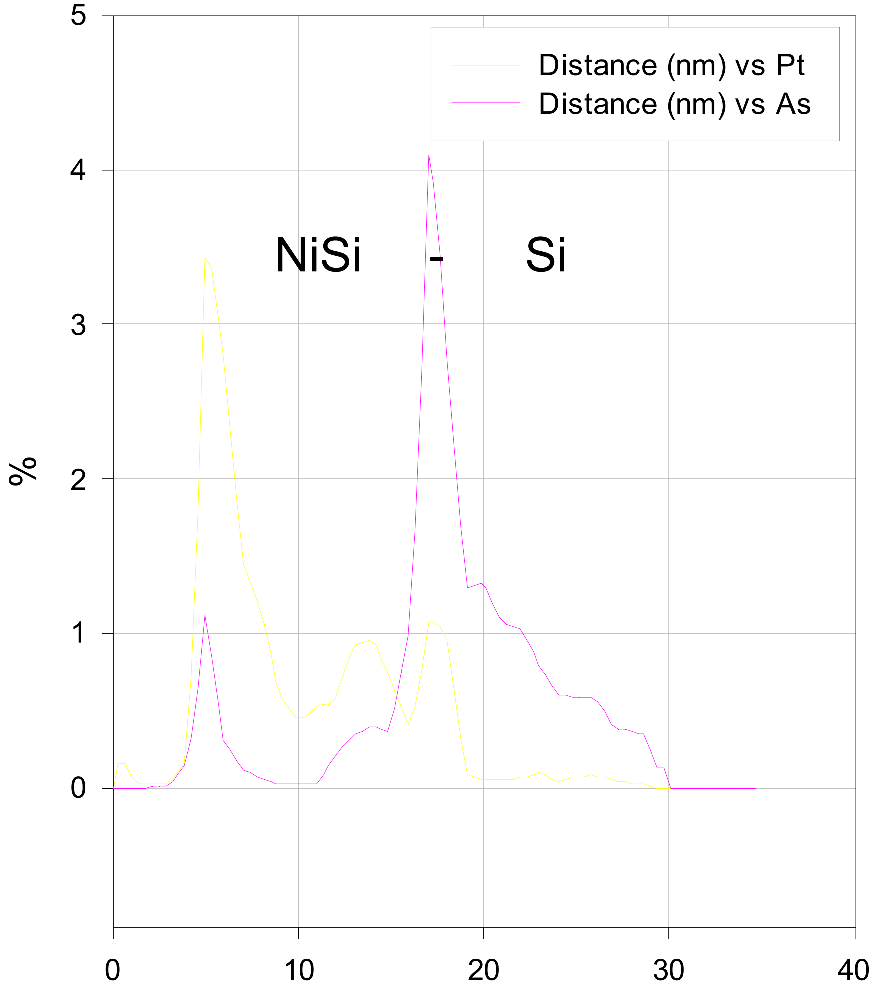



61SJD1
NiSi
/
Si
Pt
As
Depth
% total
10
1
0.1
0.01
0.001
0.0001
0.00001
0
10
20
30
40
50
60
70
80
90
Si
Ni
Pt
As

TEM and Atom Probe Data

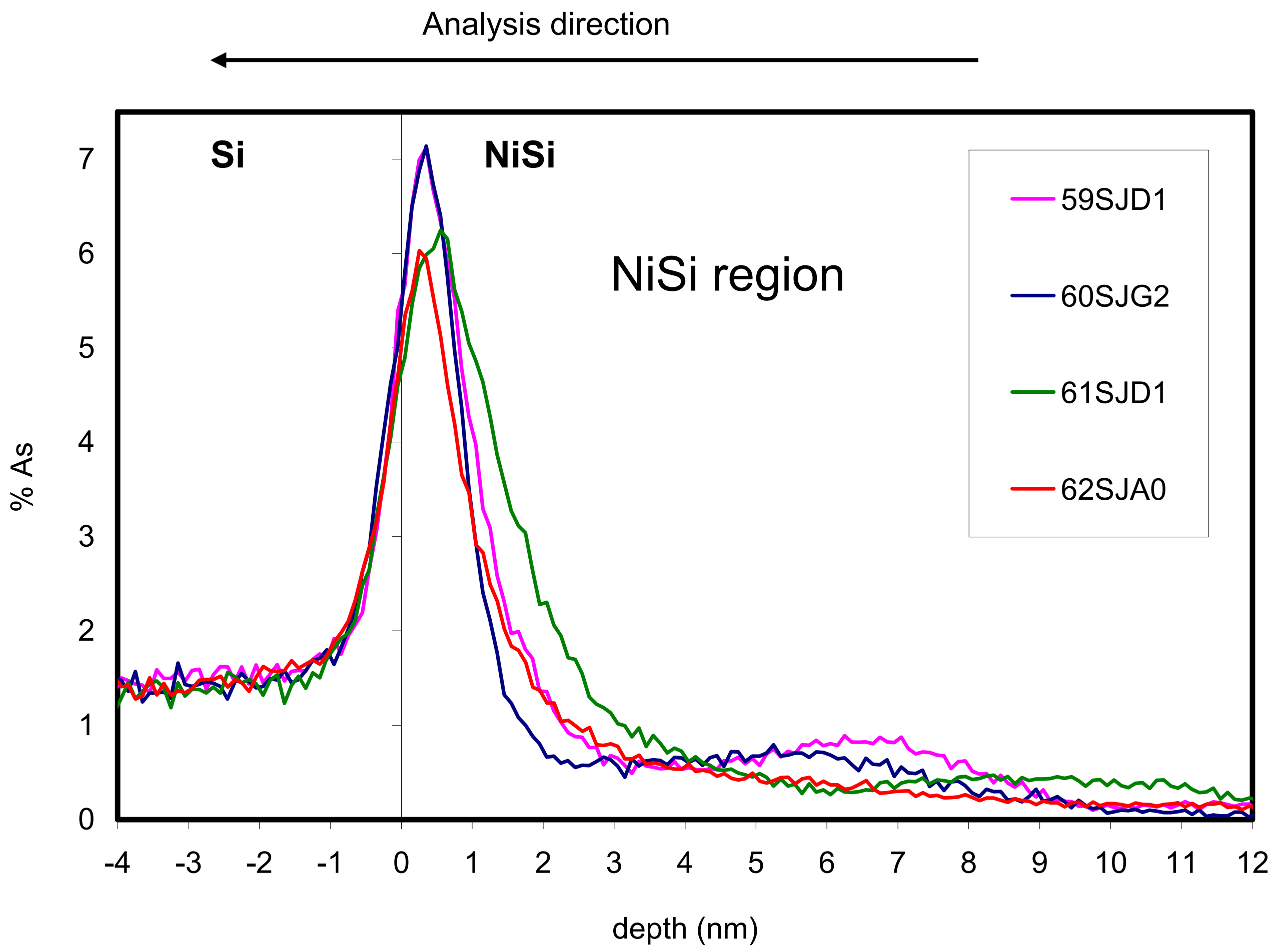


TEM

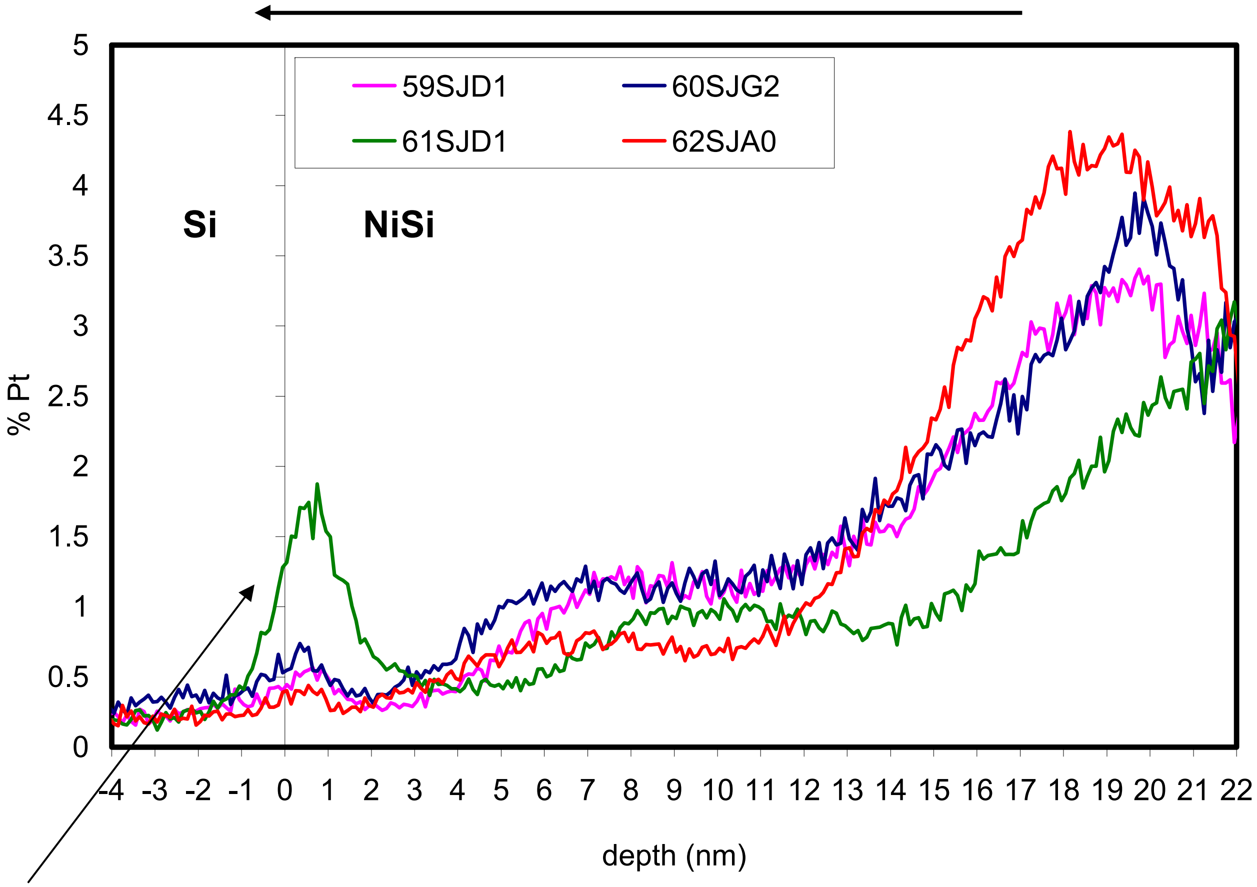


Atom Probe

Arsenic segregation at NiSi/Si interface

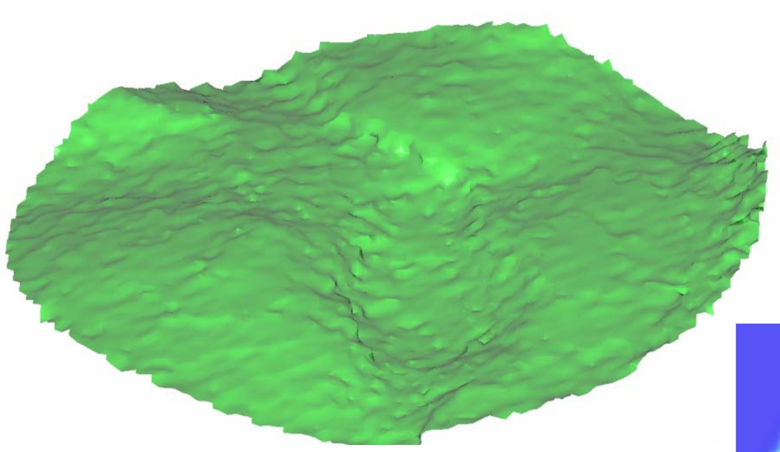


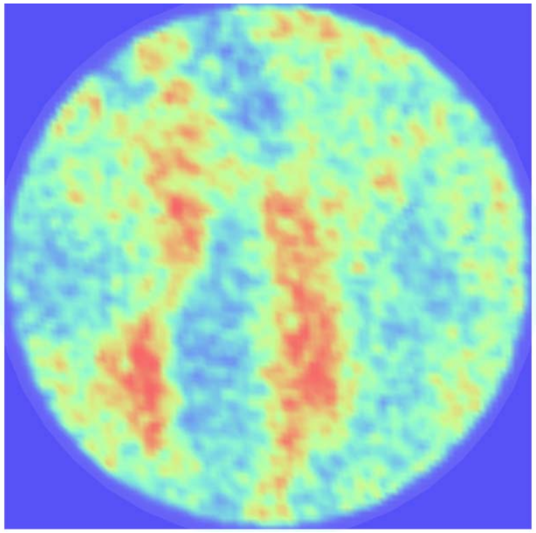
Pt distibutions



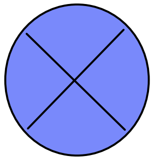
Analysis direction

Highest anneal case

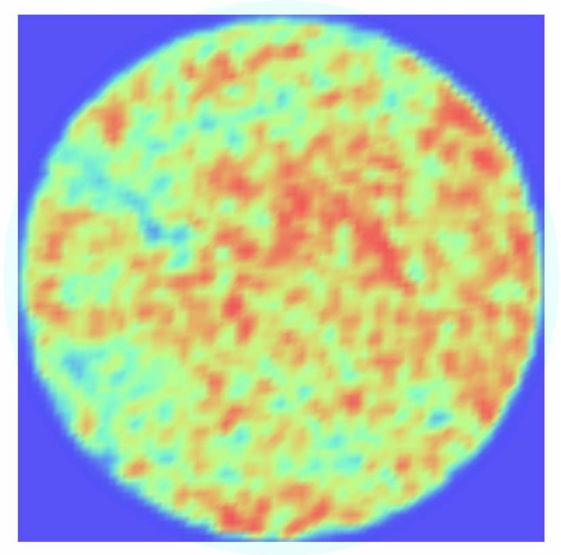




As
Max = 1



Analysis direction



Pt
Max = 0.5

Chemical isosurface obtained from sample 61SJD1. As and Pt distributions as viewed in 2-D projections down the analysis direction.

Summary

- Atom probe: narrow As distributions at silicide/silicon interface
- TEM confirms the As/Pt segregation using 1 nm probe
- SIMS has sensitivity, but large area analysis averages local variations

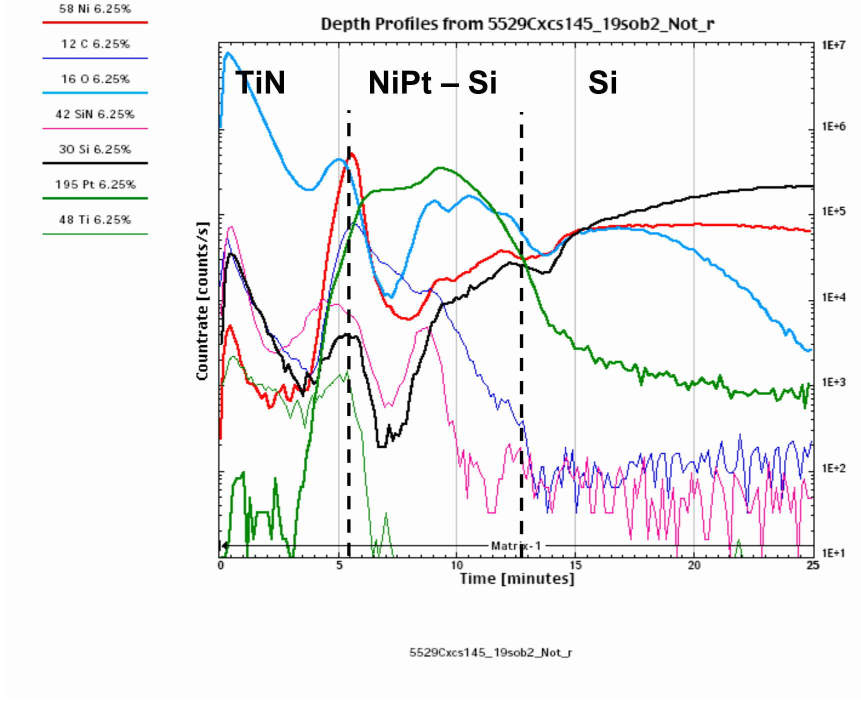
NiPtSi formation with interfacial oxygen

- Oxidation of doped silicon surface prior to Ni deposition
- Ti films used to break up oxide
- Role of oxygen in impurity segregation, NiSi formation

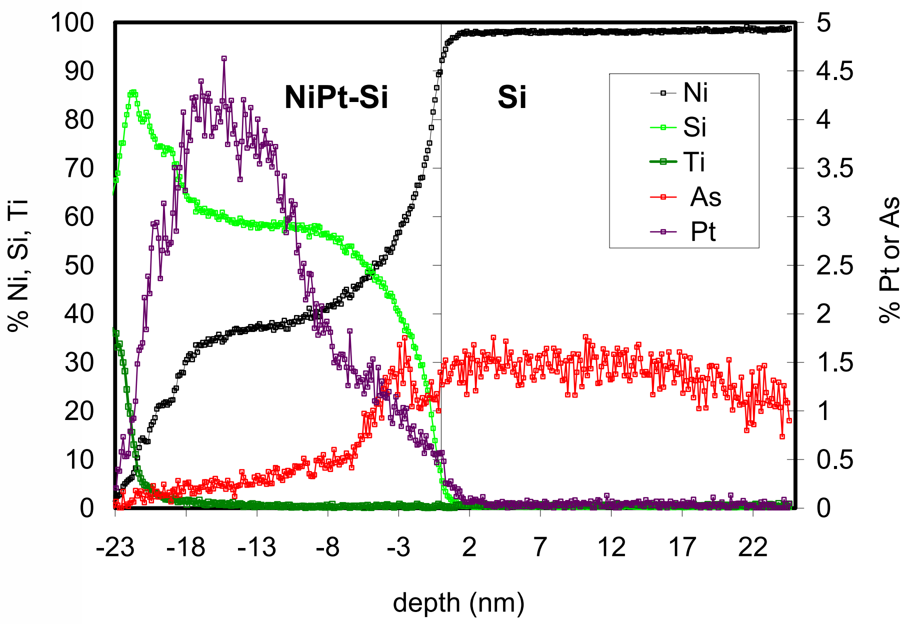
Sample Description:

Arsenic implant with anneal in SOI substrate
split experiment with surface oxidation (extended exposure in tool)
NiPt with TiN cap: deposition at 200 C
Anneal to form NiSi

Analysis direction



Analysis direction



SIMS and LEAP 1-D chemical analysis results: **Sample with low oxidation** prior to NiPt deposition - after 200^{o}C drive-in anneal.

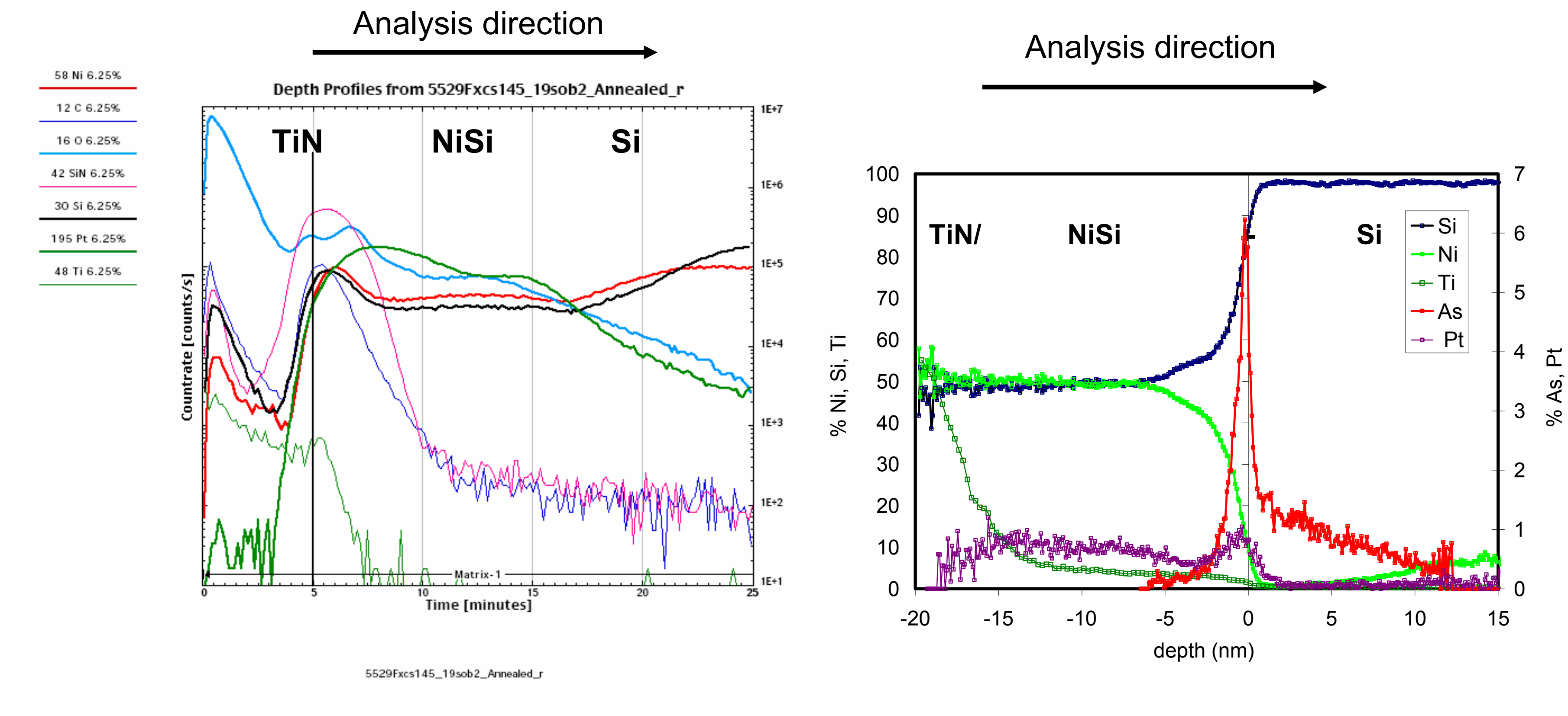


Figure 4. SIMS and LEAP 1-D chemical analysis results after phase forming anneal.

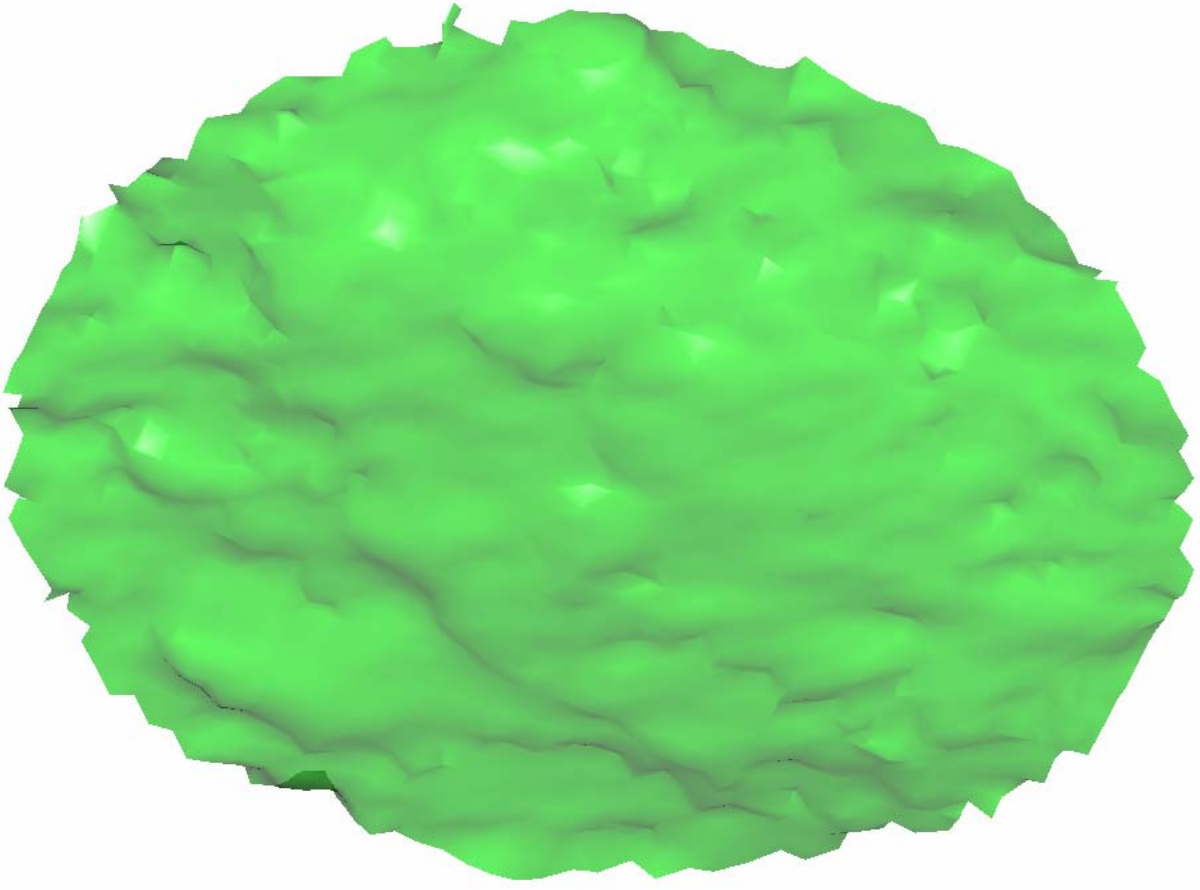
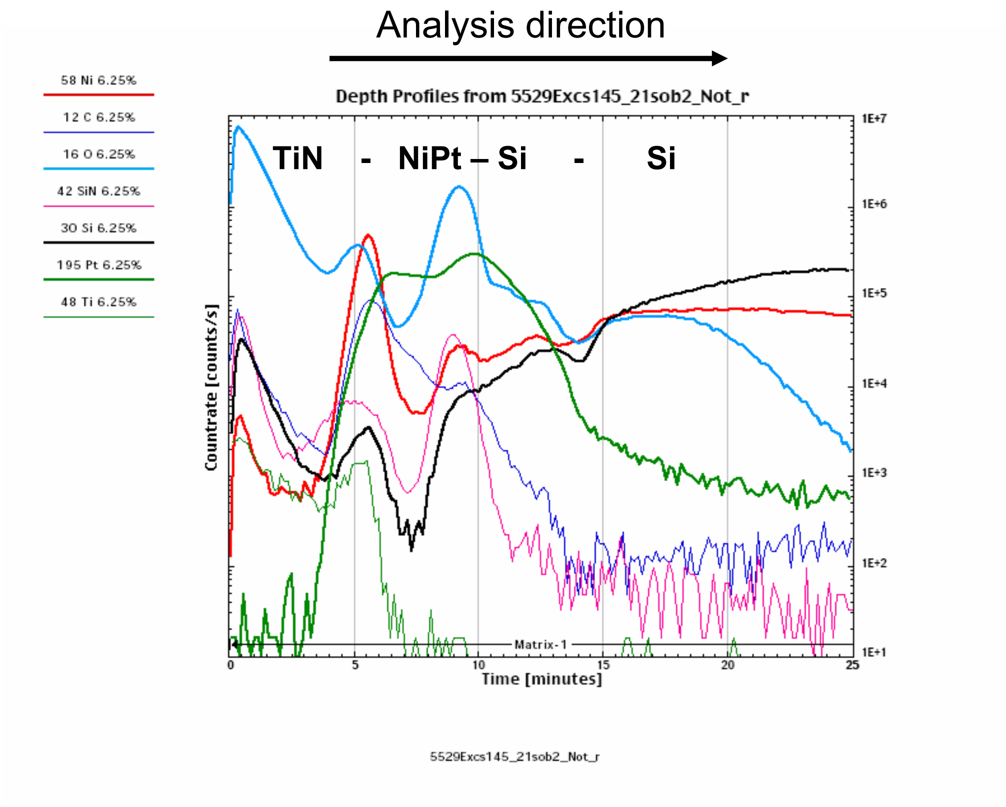


Figure 5. LEAP reconstruction of silicide – Si surface after phase forming anneal with low oxygen presence. Measured roughness is 0.56 nm

NiSi – type C



SIMS 1-D chemical analysis after drive-in anneal with **high oxygen exposure** immediately prior to the Ni deposition.

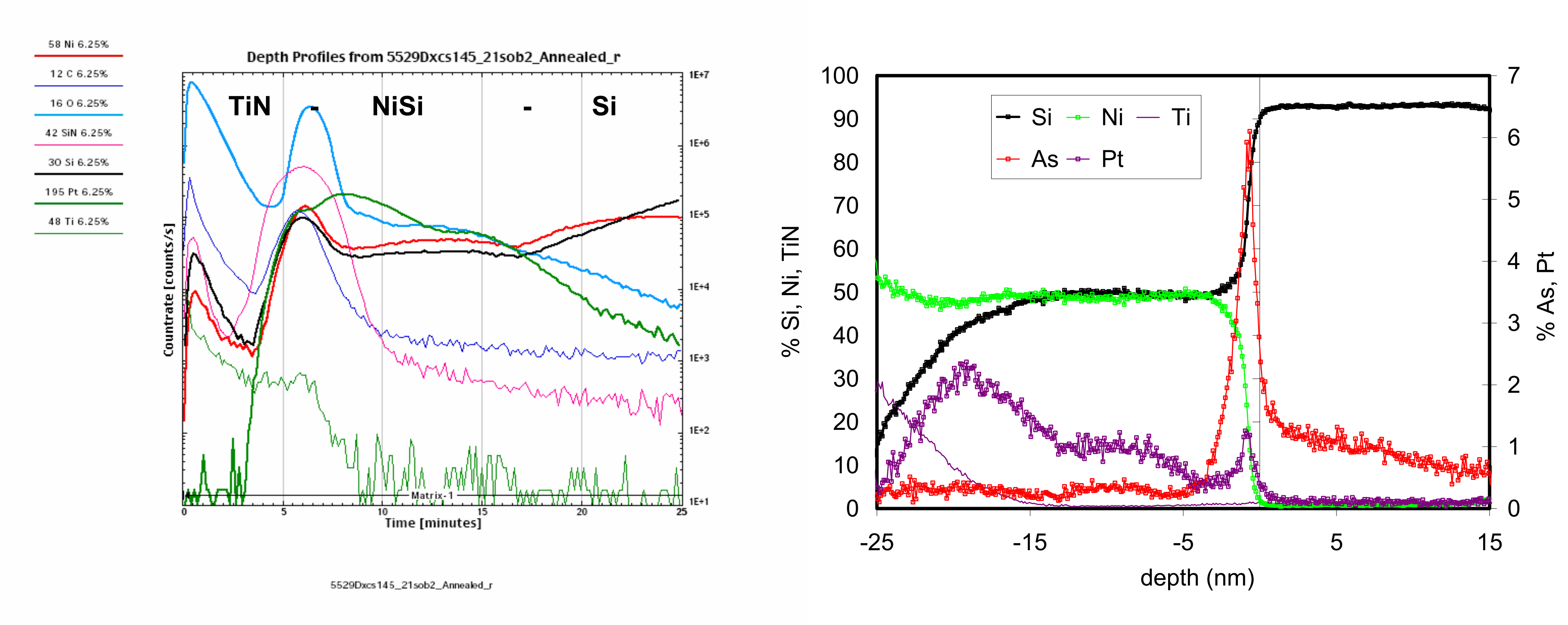
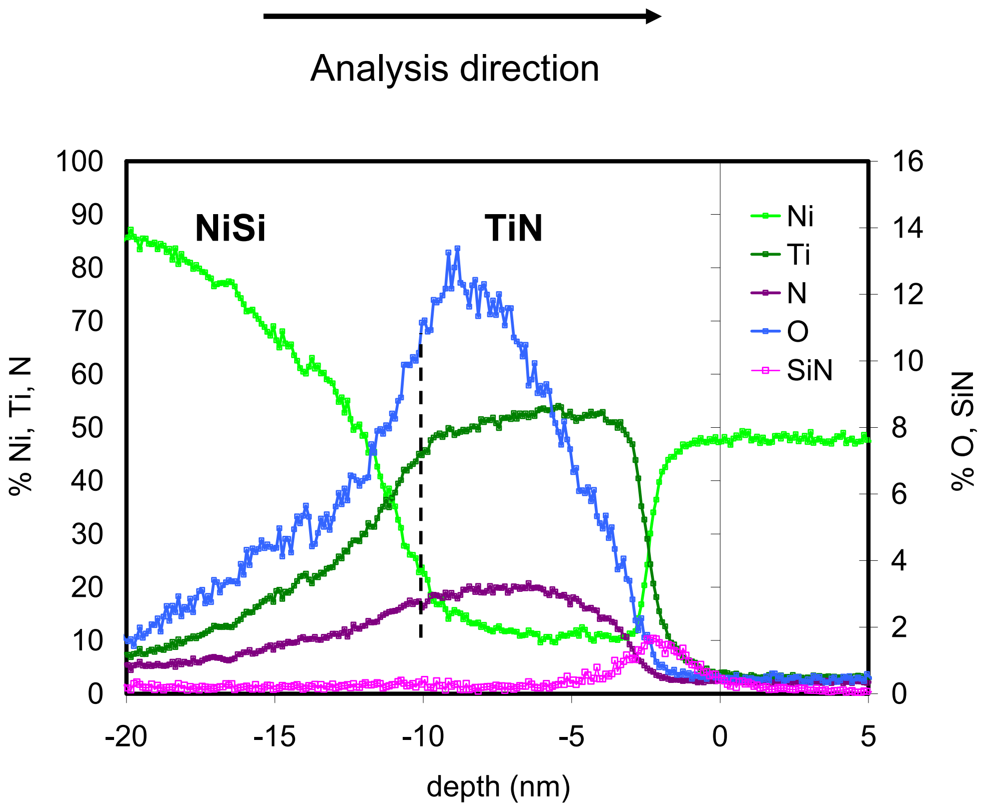


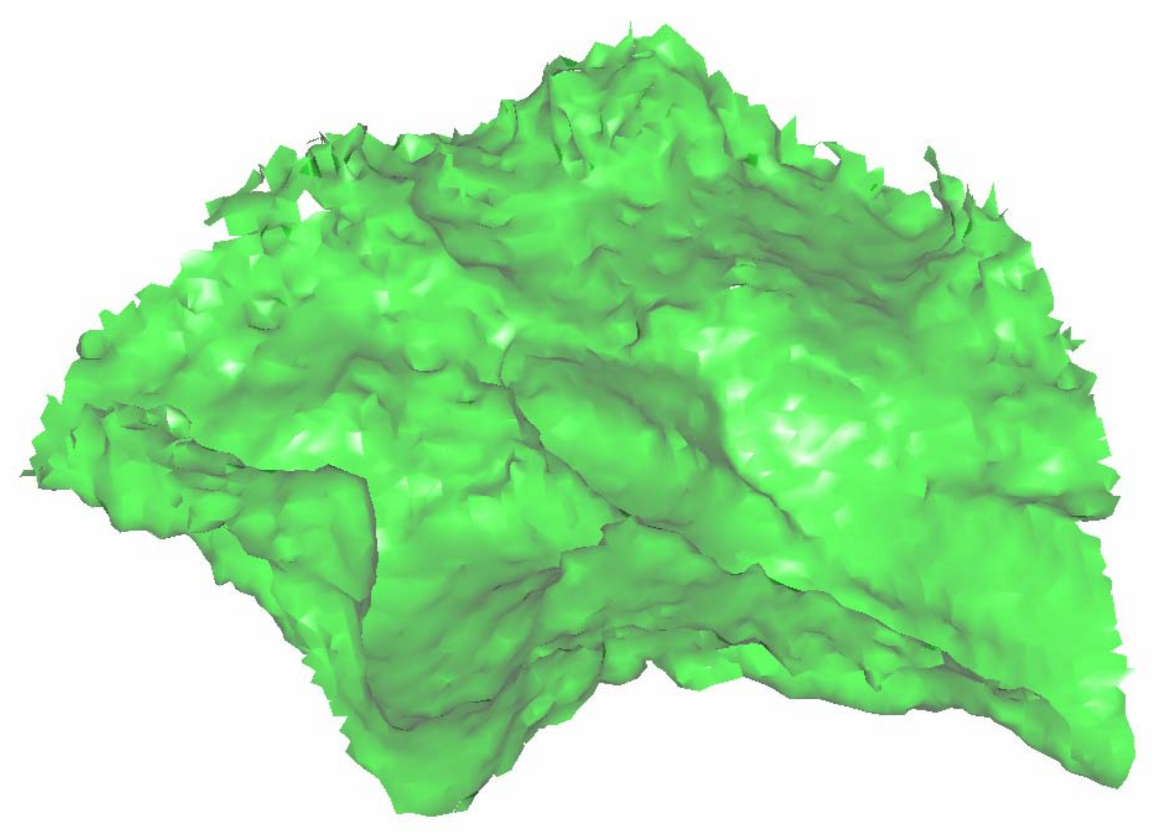
Figure 7. SIMS and LEAP 1-D compositional analysis results after phase forming anneal with high oxygen presence

F – As and Pt seg, rough, silicide



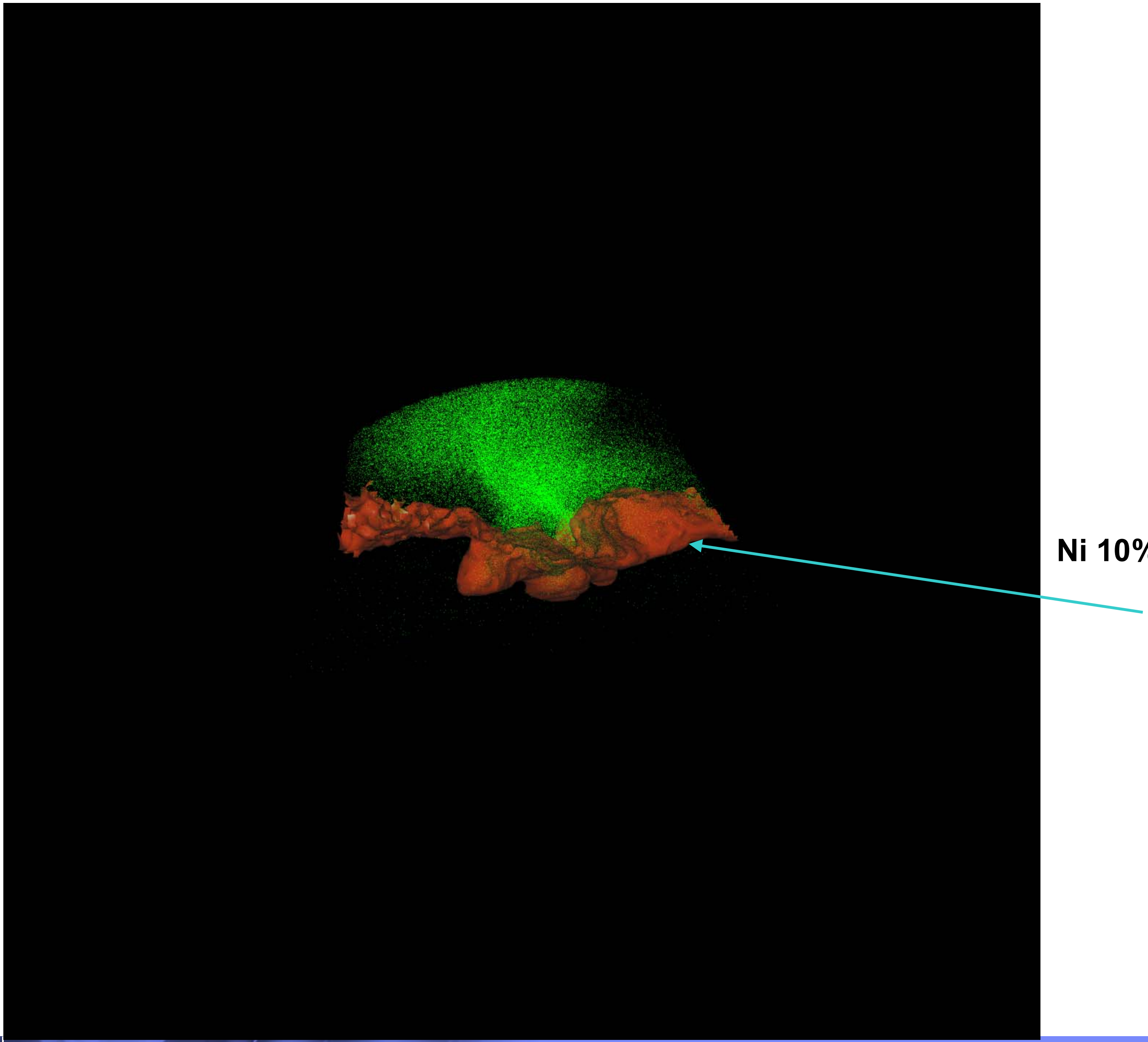
LEAP 1-D chemical analysis results after phase-forming anneal with high oxygen exposure immediately prior to the Ni deposition.

Ni diffusion into TiN, O at front of TiN, As, Pt and SiN at TiN-NiSi interface



LEAP reconstruction of silicide – Si surface after phase forming anneal with high oxygen exposure immediately prior to the Ni deposition. The measured chemical roughness is 3.5 nm

NiSi – type F



Ni 10% isosurface

Summary

- SIMS:
  - Oxygen profile before and after phase formation

    Diffusing Ni leaves oxygen at original interface, which eventually

    merges with the TiN interface

- Atom Probe:
  - Interfacial oxide correlated to silicide roughness, protrusions
  - Arsenic segregates to interface with silicide
  - Oxygen collects just inside TiN film during anneal

Conclusions

- Complementary analysis supports tomographic atom probe results
- APT materials characterization capability demonstrated
  - Advantages in nanometer scale resolution for interface analysis
  - Mass resolution sufficient for many materials
  - 3D visualization useful to understand materials properties
- Additional work to establish precision of atom probe in impurity concentration measurements