Atom Probe Tomography: Semiconducting Materials

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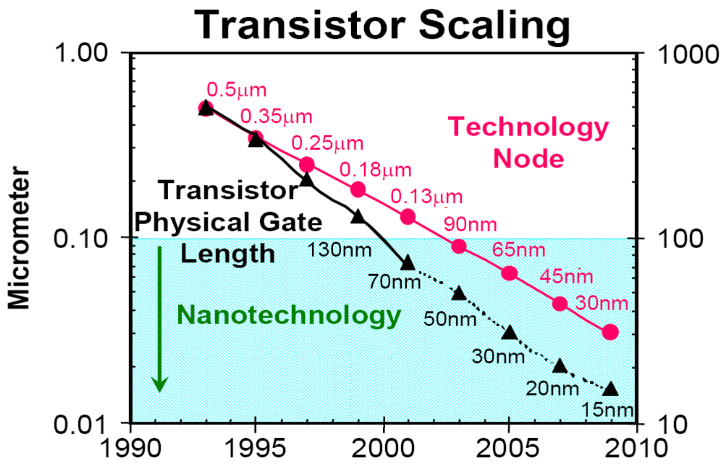
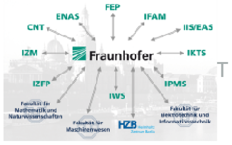
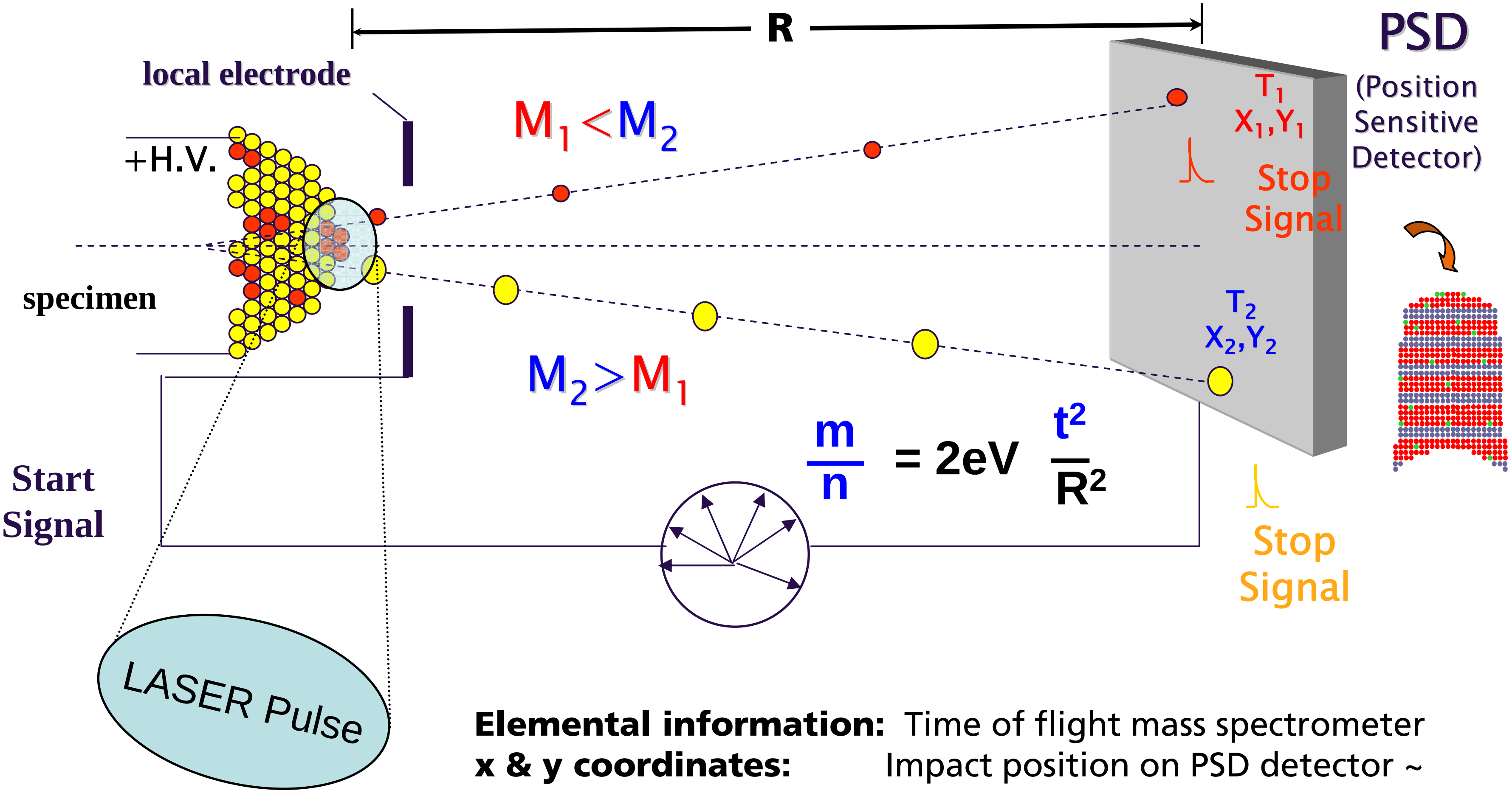




Atom Probe Tomography: Introduction



$$\frac{m}{n} = 2eV\,\frac{t^2}{R^2}$$

Elemental information: Time of flight mass spectrometer

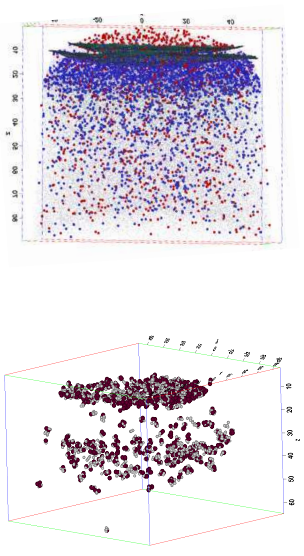
x & y coordinates: Impact position on PSD detector ~ 0.3nm

Z coordinate: Position in evaporation sequence ~ 0.2nm

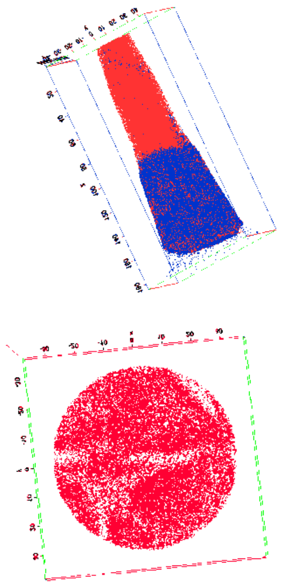
APT is performed on LEAP 3000XSi™

Agenda

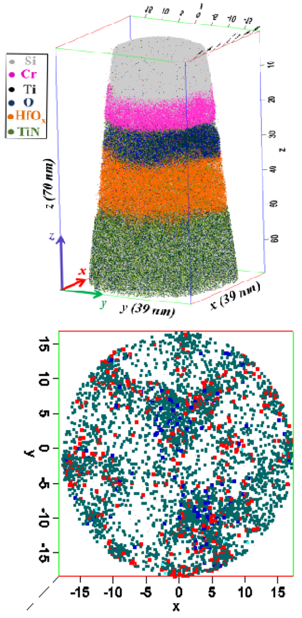
S/D



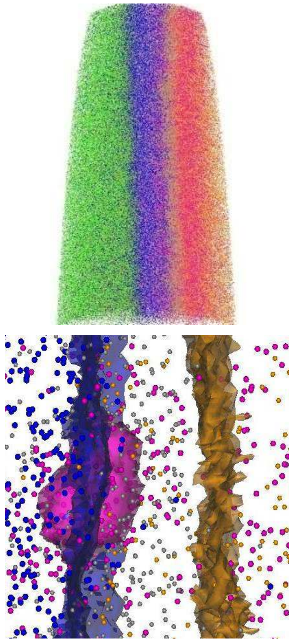
Metallization



MIM



Contact



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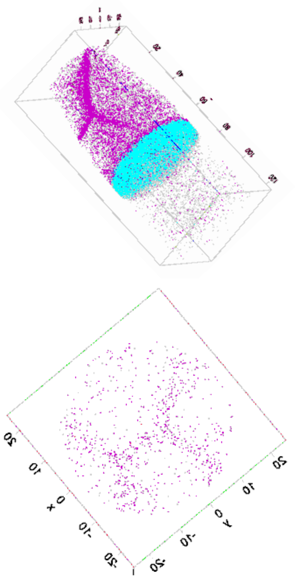
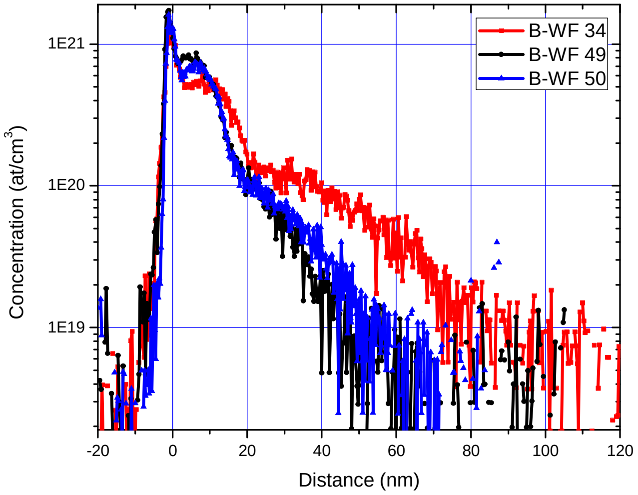


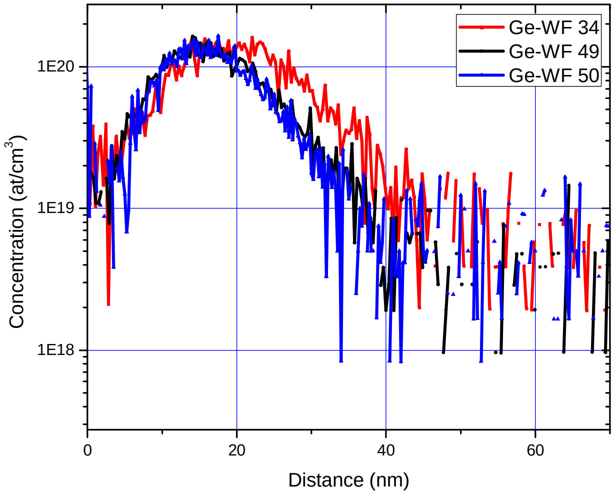
Atom Probe Tomography: S/D Hall mobility-Dopant redistribution

Hall mobility of carriers, $\mathbf{\mu = |V_H|/R_S IB = 1/ (qN_S R_S)}$
I – Current
B – magnetic field
q - elementary charge
V_H – Hall voltage
N_S – sheet concentration
R_S – sheet resistivity

B-Ge dopped Si substrate:
Three different annealing conditions

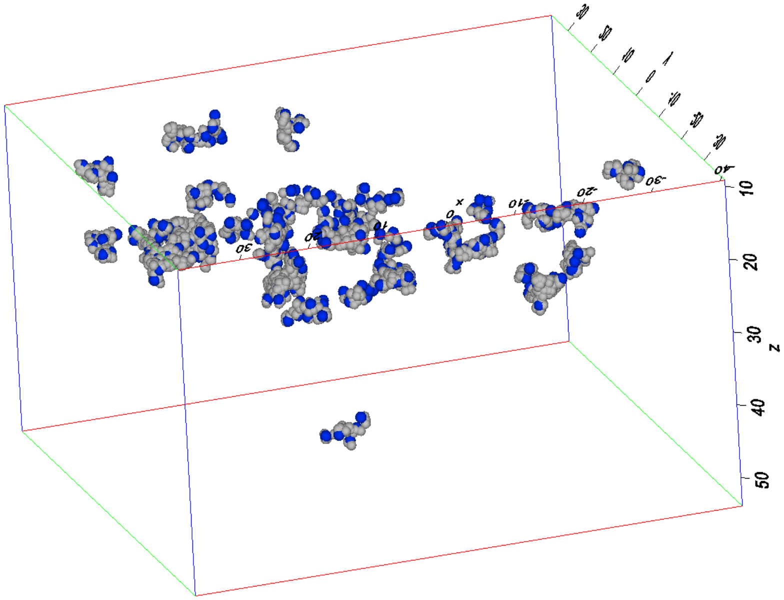
	#49	#50	#34
Implant (cm^{-2})	3×10^{15}	3×10^{15}	3×10^{15}
SIMS (cm^{-2})	$2,0 \times 10^{15}$	$1,9 \times 10^{15}$	$1,9 \times 10^{15}$
R_S (Ohm)	273	199	168
N_S (cm^{-2})	$6,6 \times 10^{14}$	$8,5 \times 10^{14}$	$9,9 \times 10^{14}$
μ ($cm^2 V^{-1}s^{-1}$)	34,9	36,8	37,6





Atom Probe Tomography : S/D USJ- B/C-Cluster implants

Boron clusers

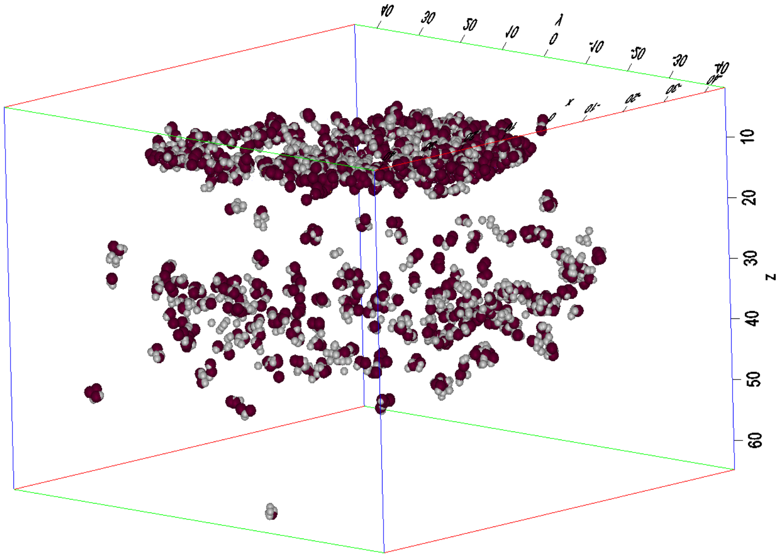


● C

● Si

● B

Carbon clusers

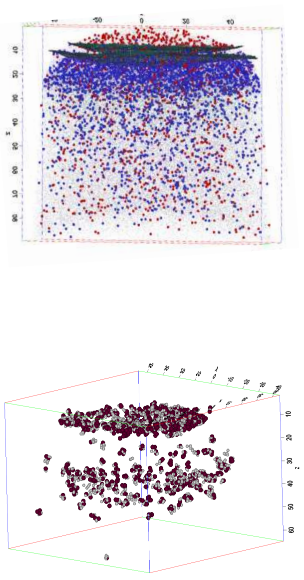


A significant amount of the boron & carbon are clustered in the surface near region

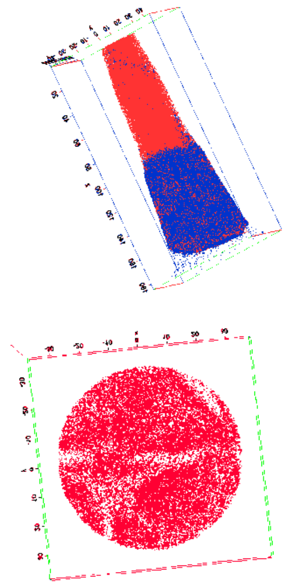
APT provides information regarding cluster density, composition and size

Agenda

S/D



Metallization



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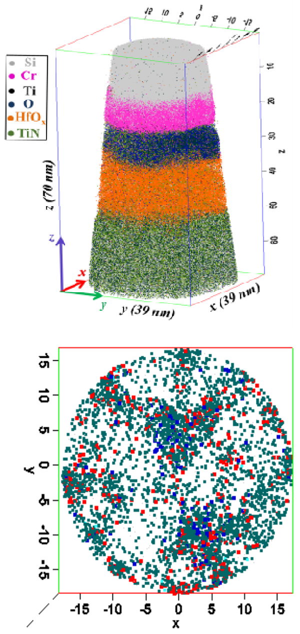

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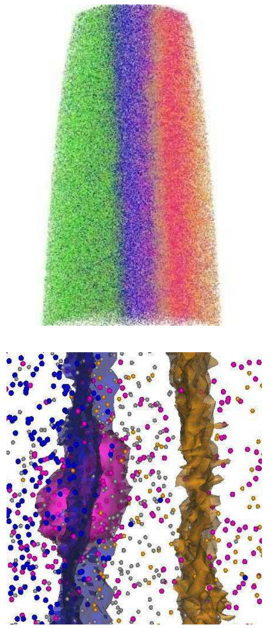

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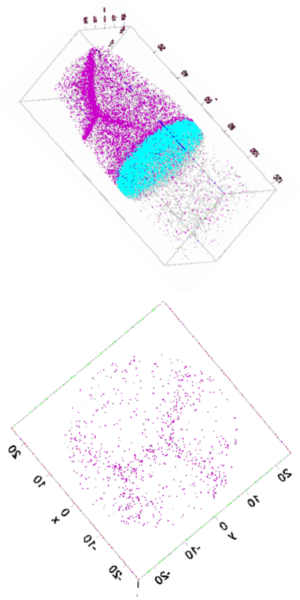

Agenda

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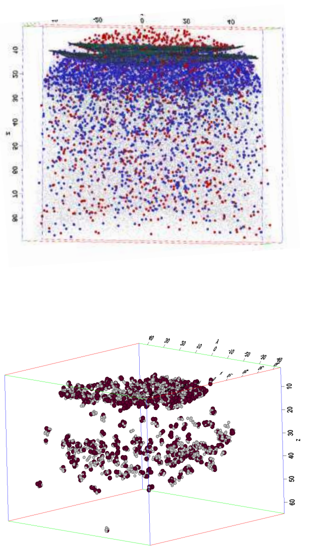

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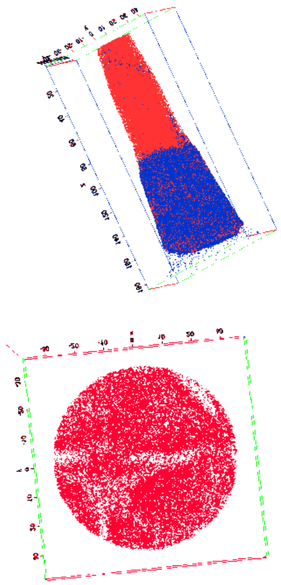

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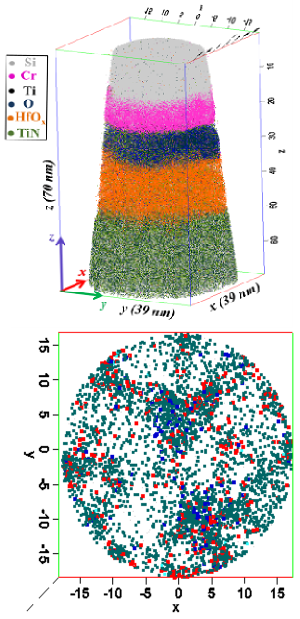

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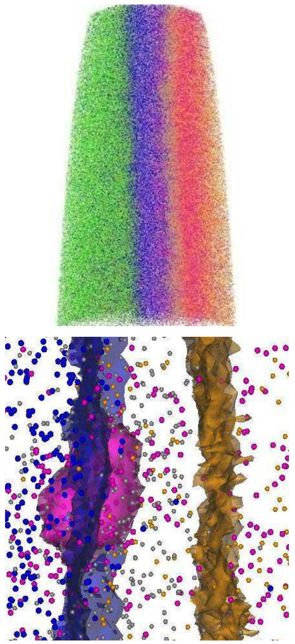

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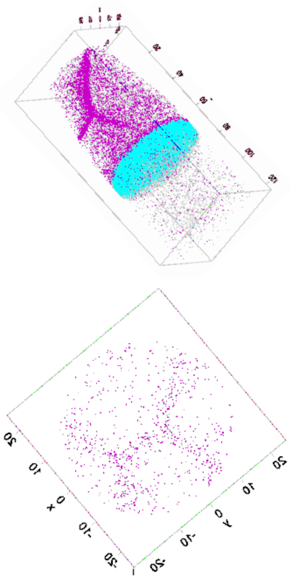
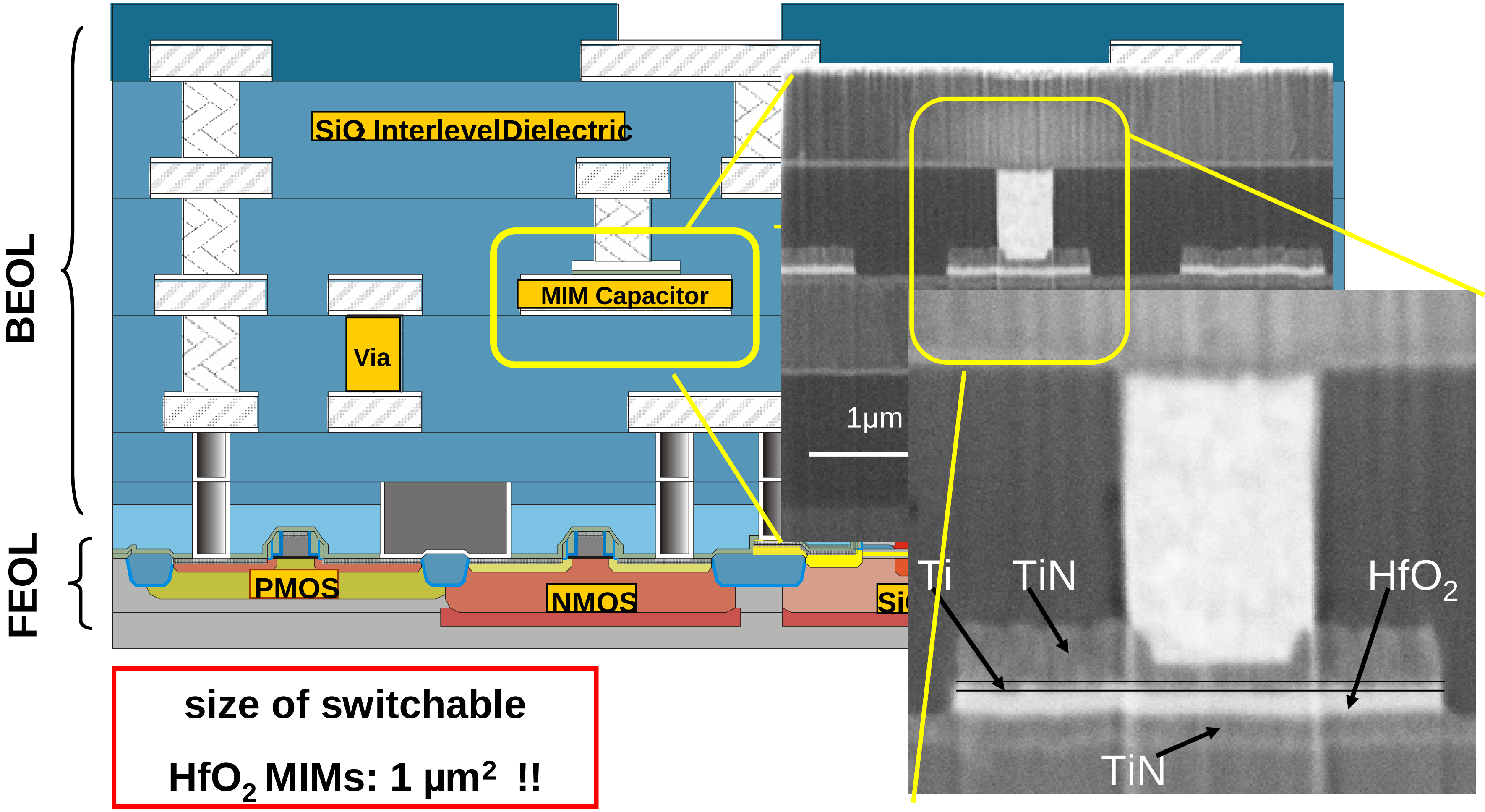


Atom Probe Tomography : BEoL RRAM-MIM Capacitor

BEOL Integration of resistive switching HfO_2 MIMs with Si CMOS compatible metal electrodes



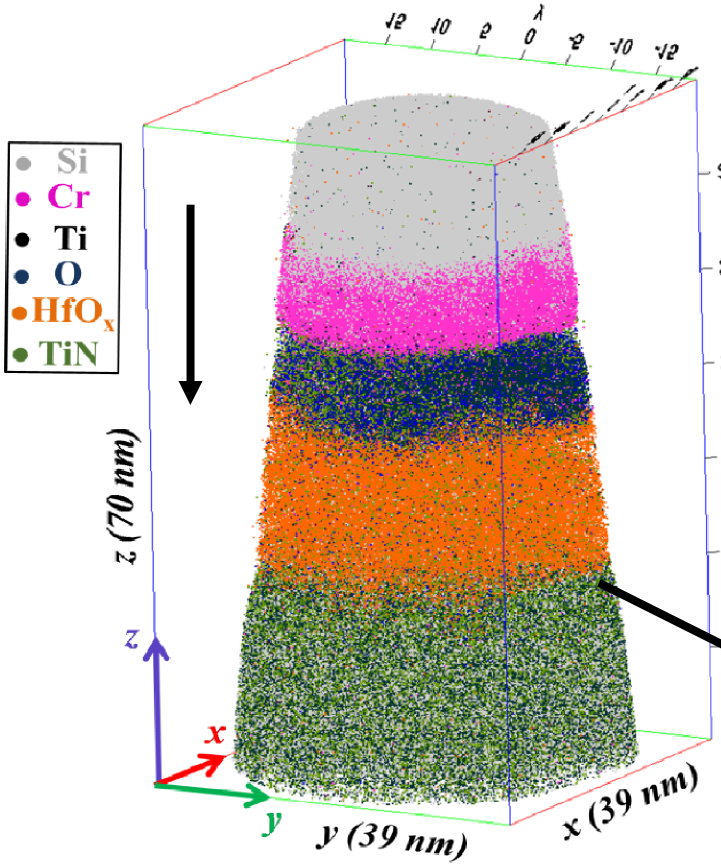
size of switchable

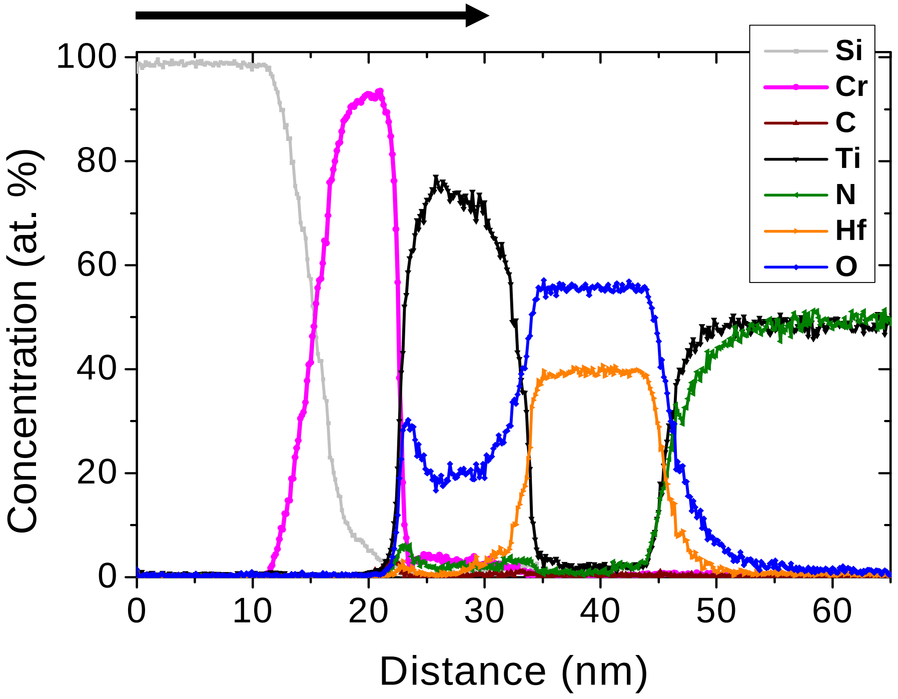
HfO_2 MIMs: 1 µm² !!

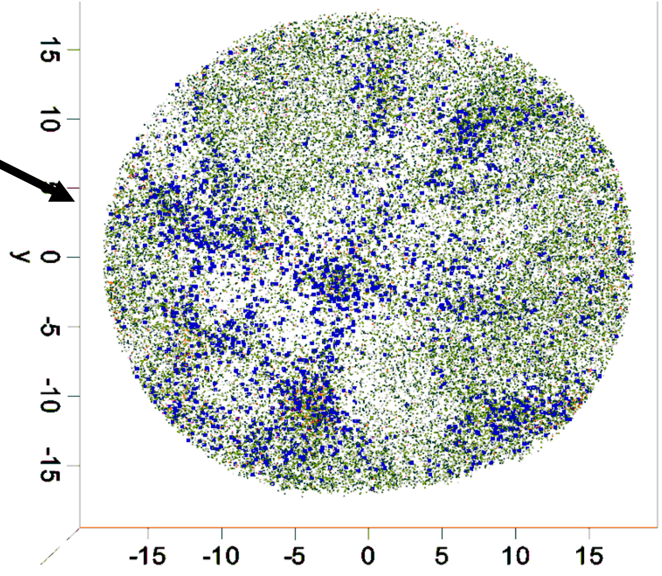
Embedded NVM for 0.13 µm SiGe:C BiCMOS

@ C. Walczyk IHP

Atom Probe Tomography : BEoL RRAM-MIM Capacitor



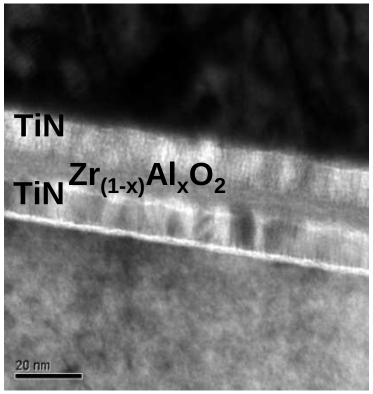


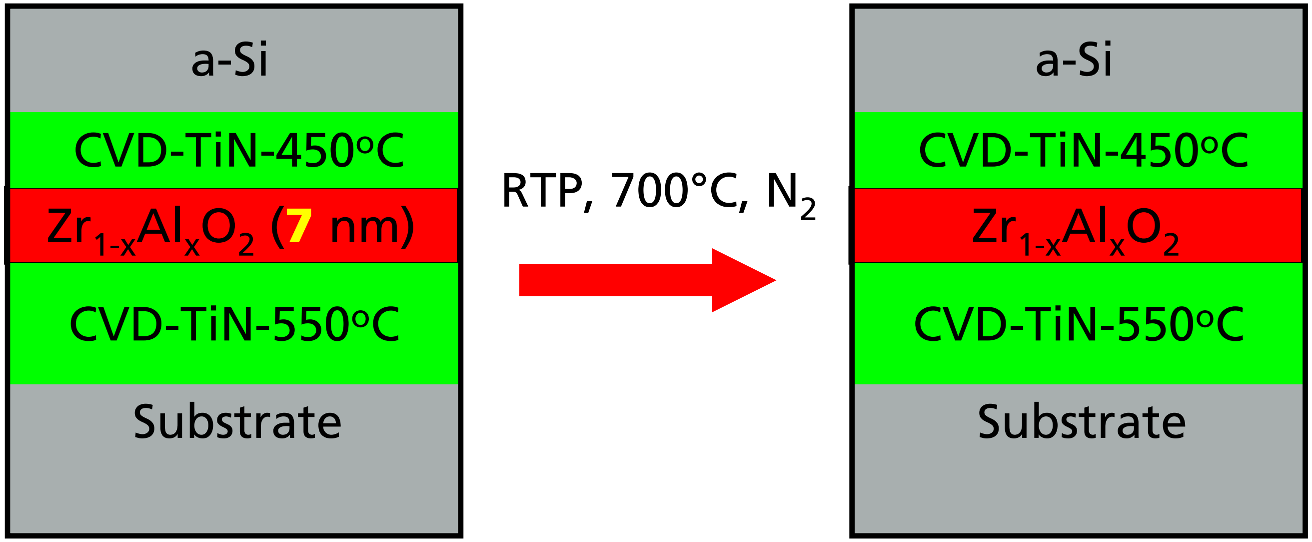


- Oxygen out-diffusion into Ti from HfO_2
- Oxygen rich Ti top electrode

@ C. Walczyk IHP

Atom Probe Tomography : another example: DRAM-MIM Capacitor





a-Si

CVD-TiN-450°C

$Zr_{1-x}Al_xO_2$ (7 nm)

CVD-TiN-550°C

Substrate

RTP, 700°C, N_2

a-Si

CVD-TiN-450°C

$Zr_{1-x}Al_xO_2$

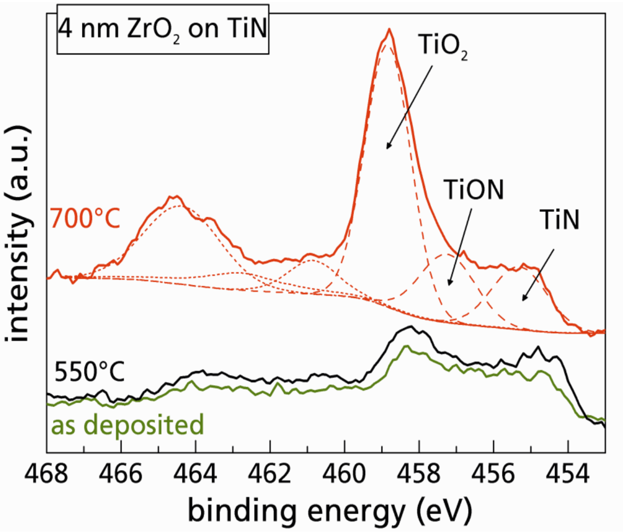
CVD-TiN-550°C

Substrate

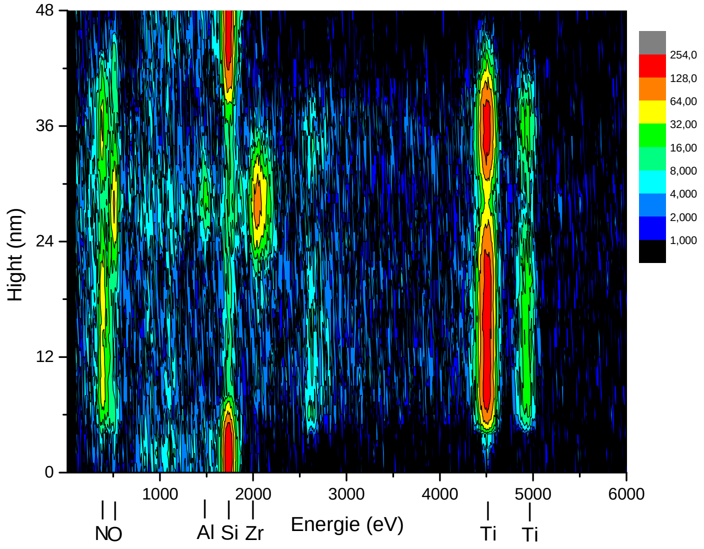
XPS

- TiO_2 even for as deposited stack
- a pronounced TiO_2 after annealing

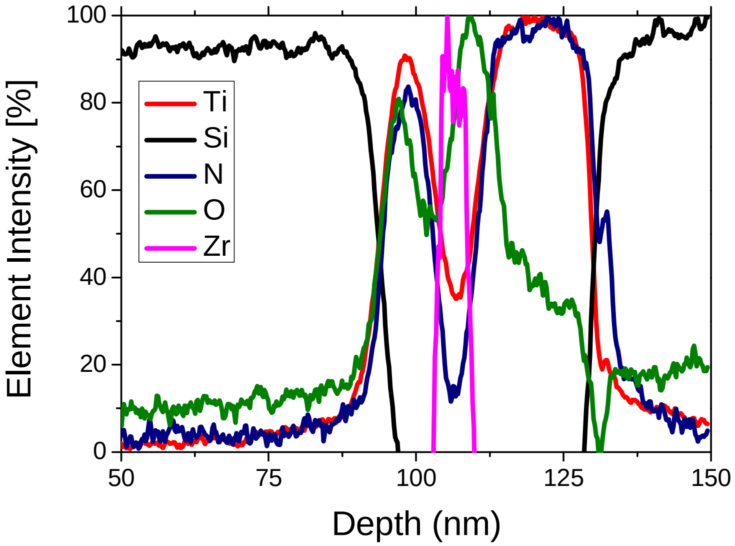
Track oxide in the columnar grains of TiN (bottom electrode) ?



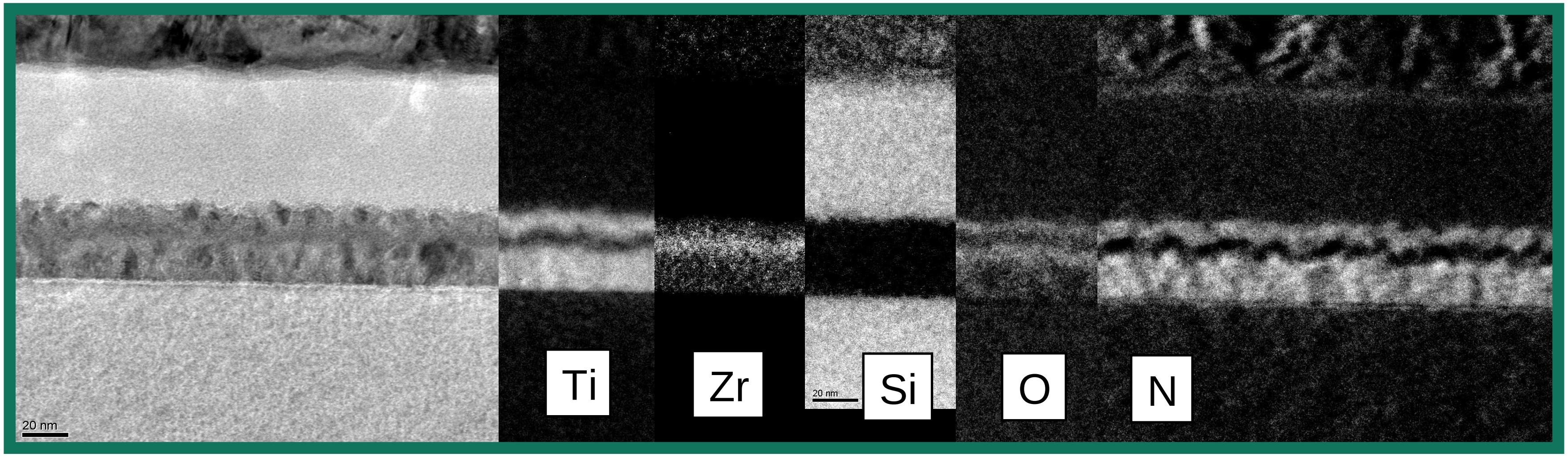
Atom Probe Tomography : MIM Capacitor EFTEM-EDX



Cross-sectional-EDX

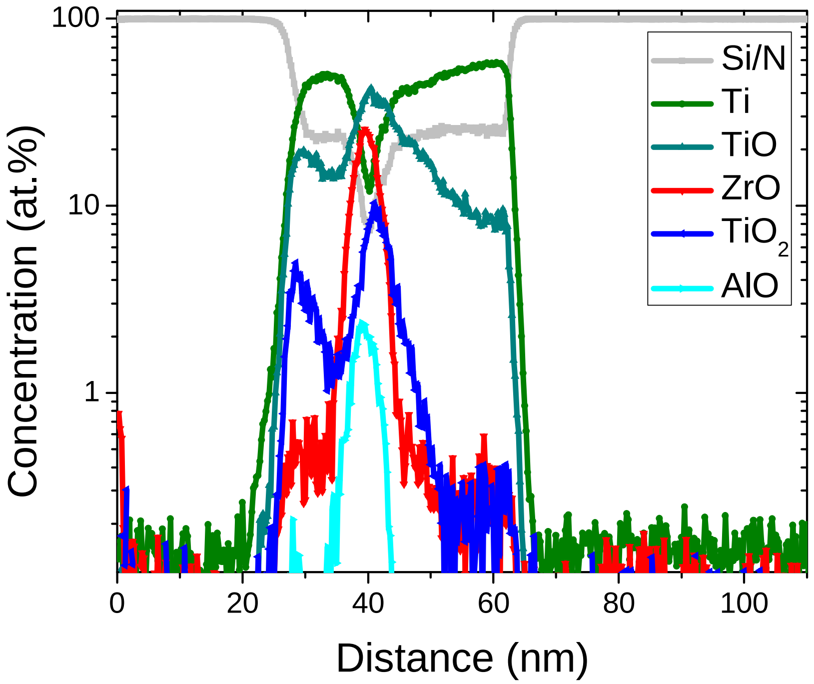


EFTEM/EELS

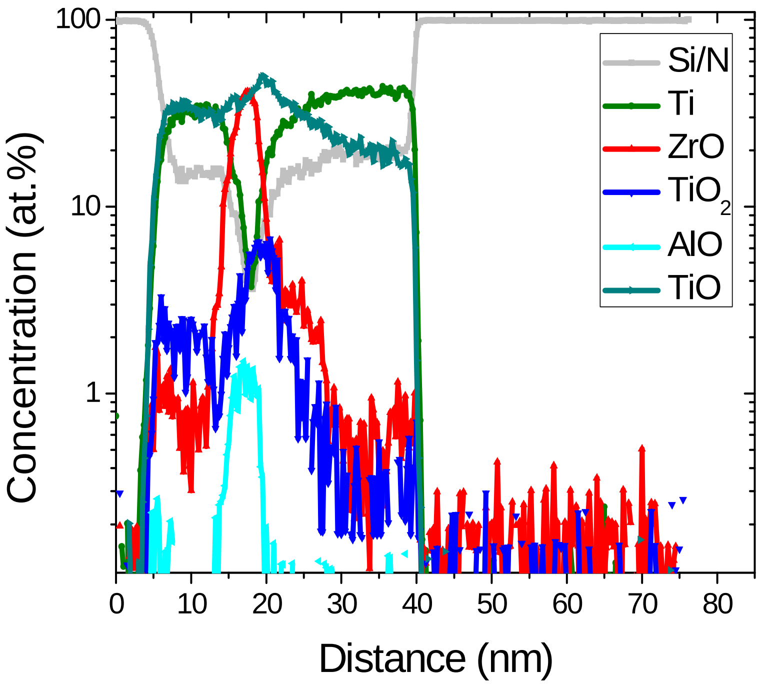


Atom Probe Tomography : DRAM-MIM Capacitor

As-deposited MIM



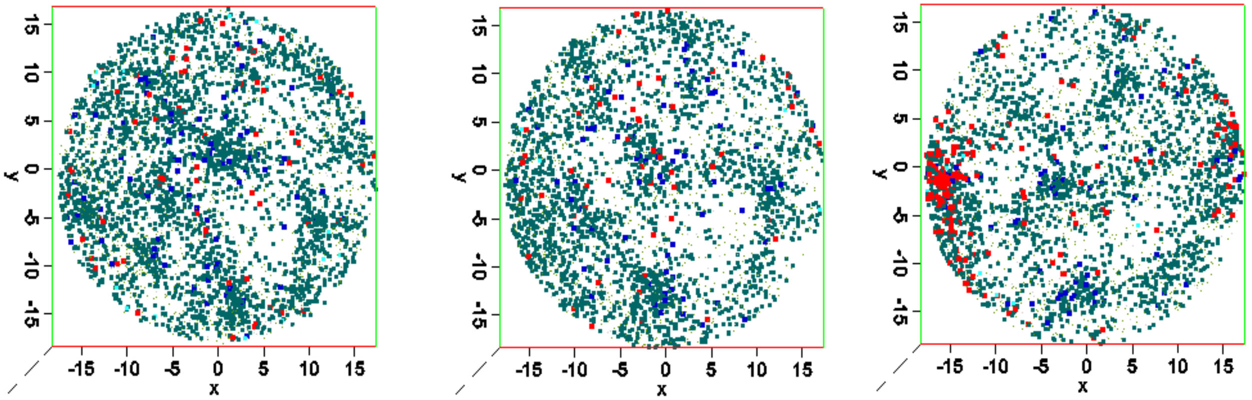
Postdeposition annealed MIM

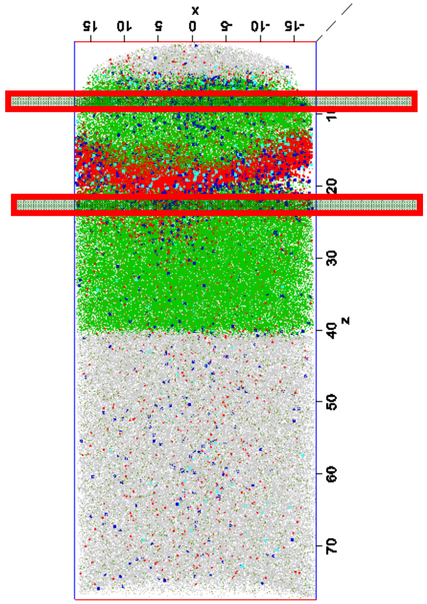


- A direct observation of titanium oxide by APT (earlier predicted from XPS)
- Redistribution of TiO_2 both on top and bottom electrodes
- Out diffusion of ZrO_x and TiO_2 on the TiN grains

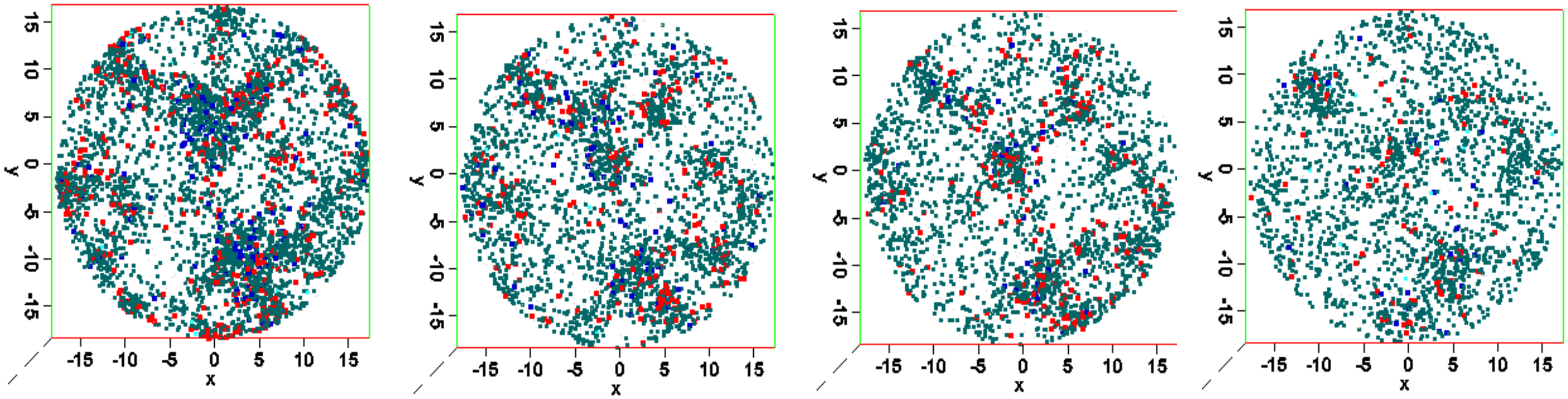
Atom Probe Tomography : DRAM-MIM Capacitor-Grain boundaries

Top electrode: TiN





Bottom elctrode: TiN



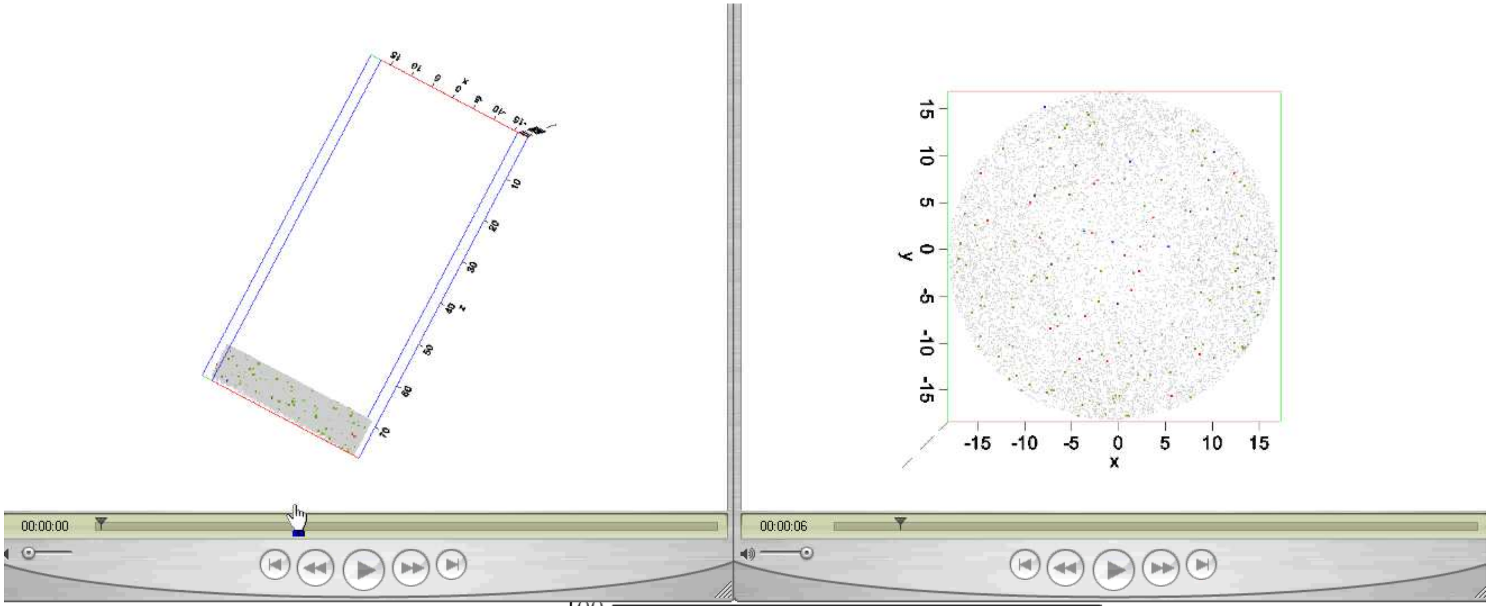
● TiO

● ZrO_2

● TiO_2

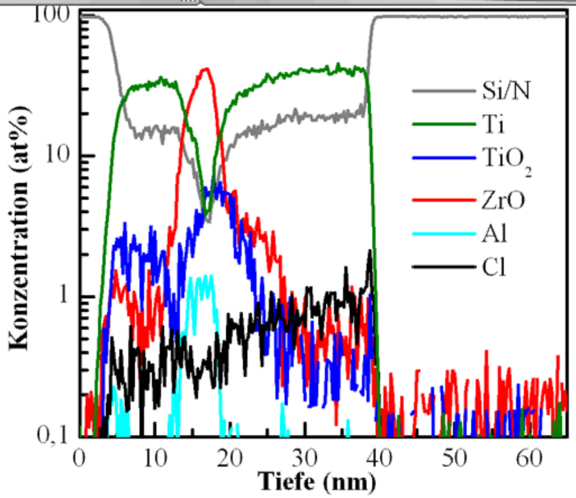
Fraunhofer
CNT

Atom Probe Tomography : DRAM-MIM Capacitor



MIM capacitor layer stack

Si/TiN/ZAZ/TiN/Si



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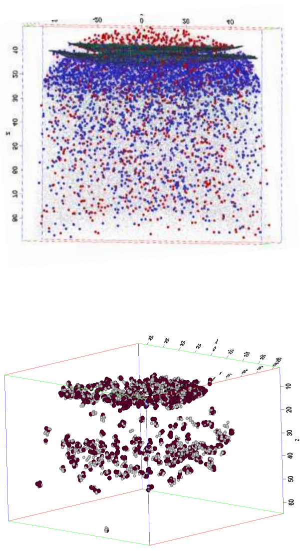
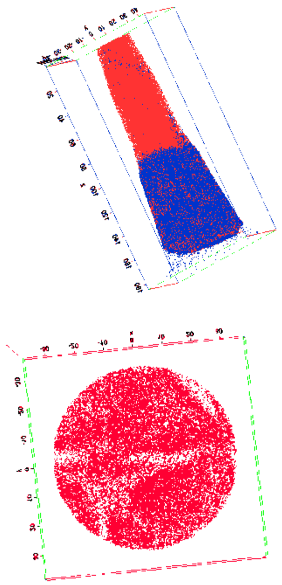
Agenda

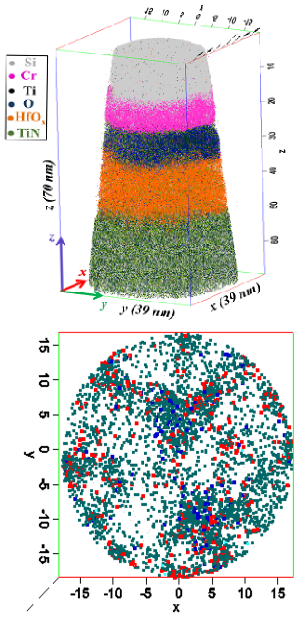
S/D



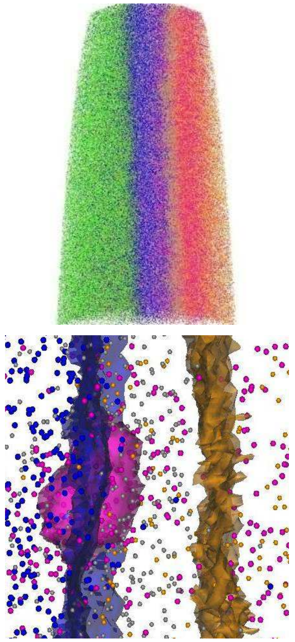
Metallization



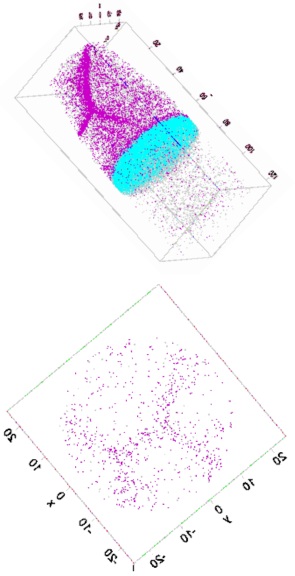
MIM



Contact

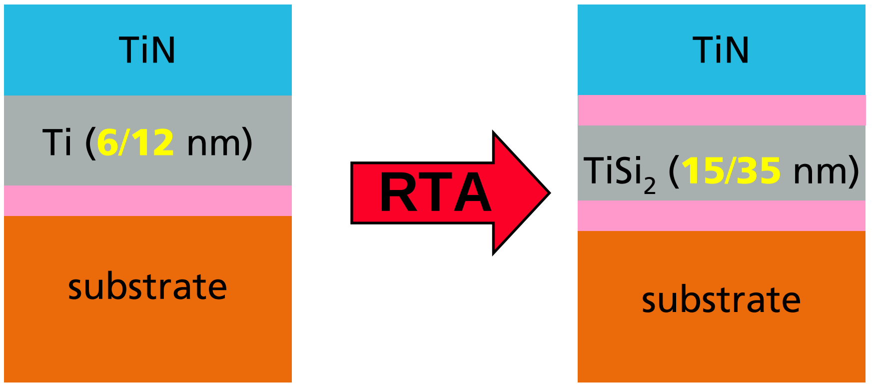


SONOS



Atom Probe Tomography : Contact Materials-silicidation of Ti metal

Contacts on the base of $TiSi_2$ /



Boron redistribution during silicidation

The contact resistance is determined by the Schottky-Barrier height, hence by the dopant concentration at the metal-semiconductor

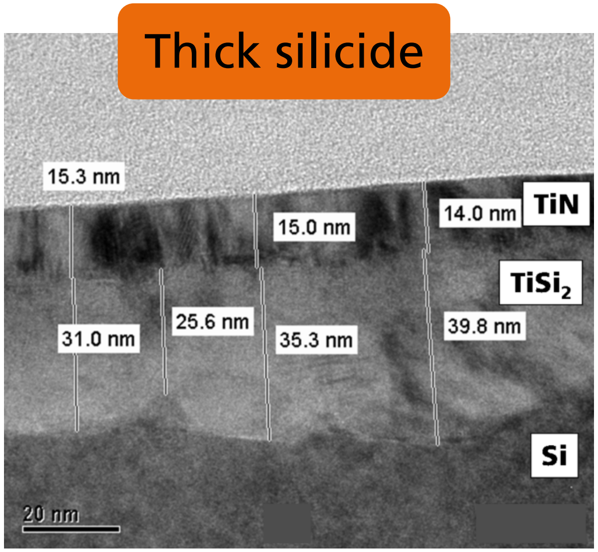
$$R_C \propto \exp\left(\frac{q\,\Phi_{Bn}}{E_{00}}\right) \qquad E_{00} \propto \sqrt{N}$$

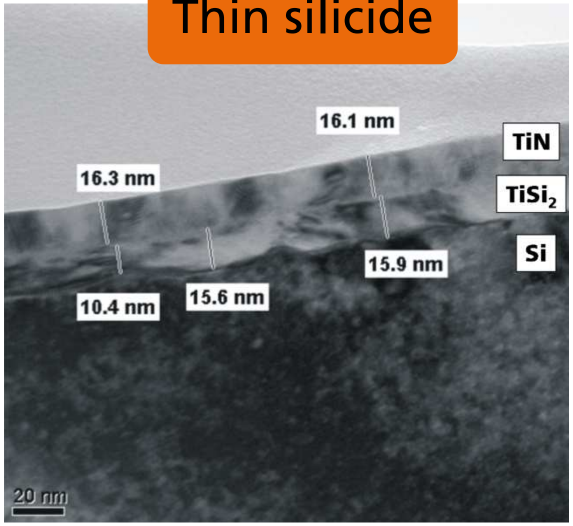
Atom Probe Tomography : Contact Materials-silicidation of Ti metal

Thick silicide

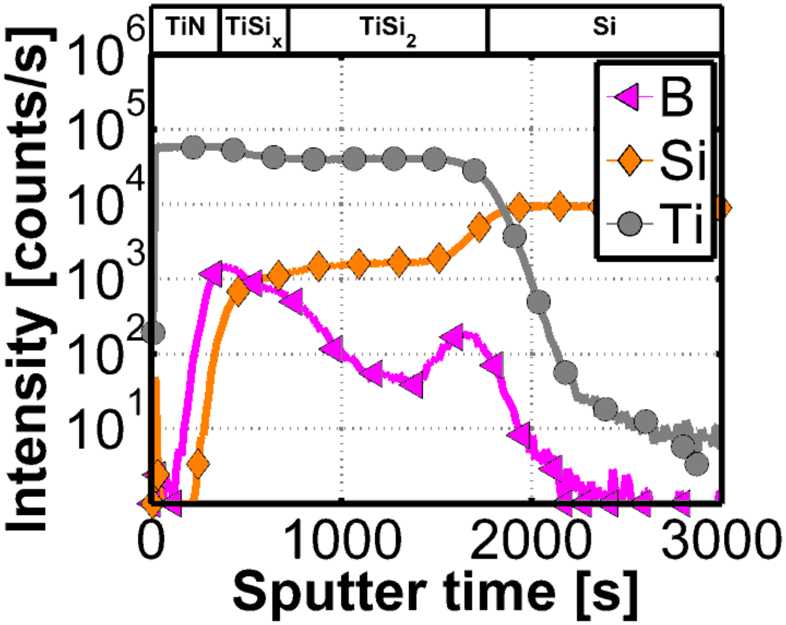
Thin silicide

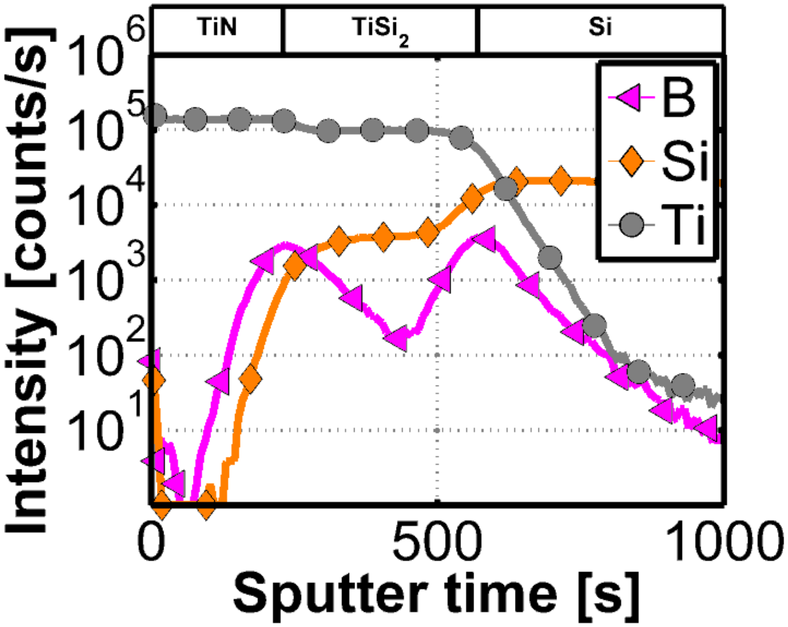
TEM





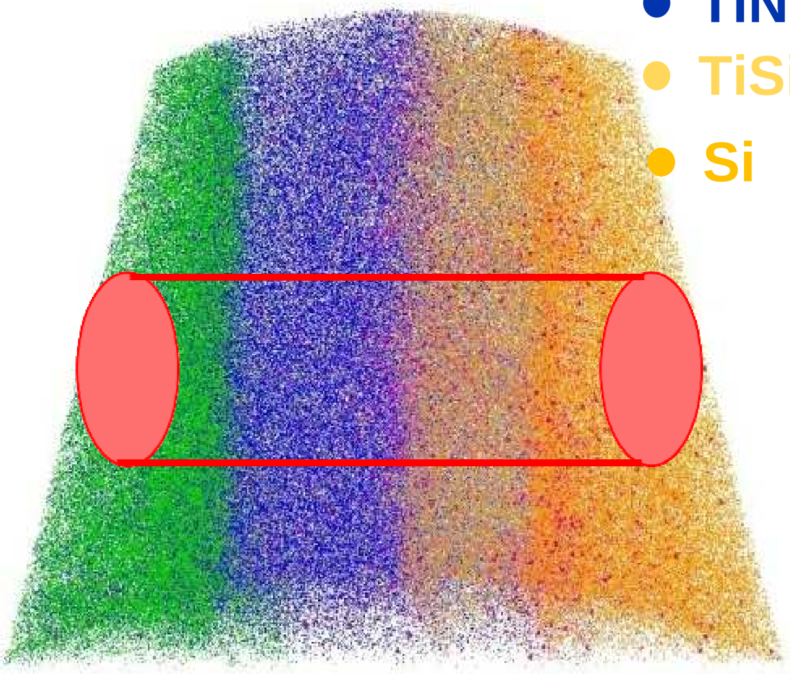
SIMS





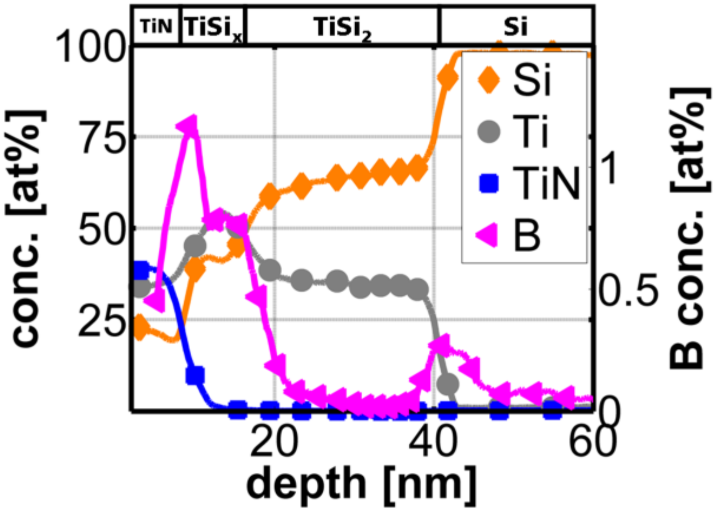
Atom Probe Tomography : Contact Materials-silicidation of Ti metal

● Ni
● TiN
● $TiSi_2$
● Si

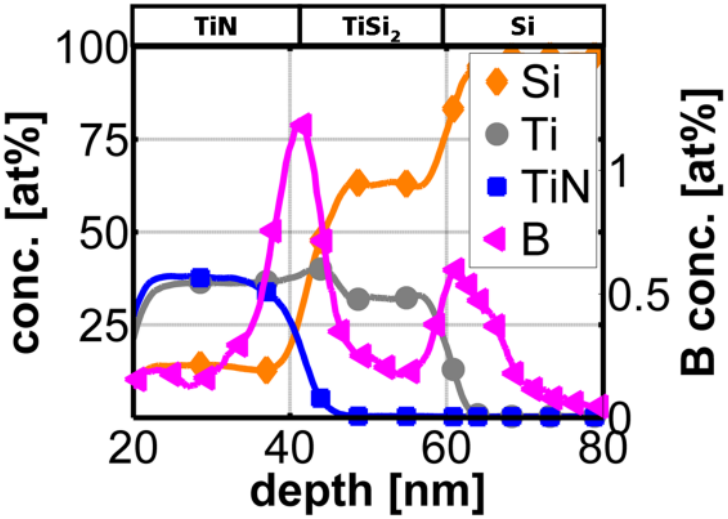


Intermediate $TiSi_x$ is evident from the depth profile

Thick silicide

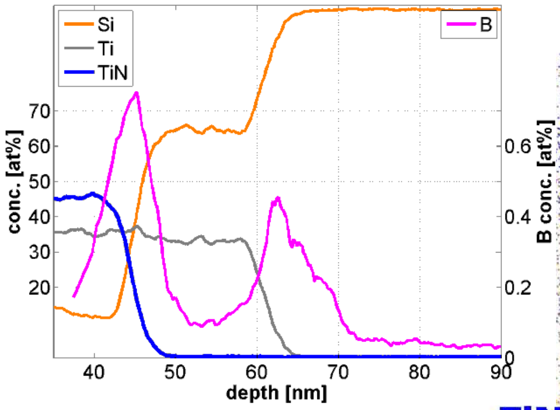


Thin silicide

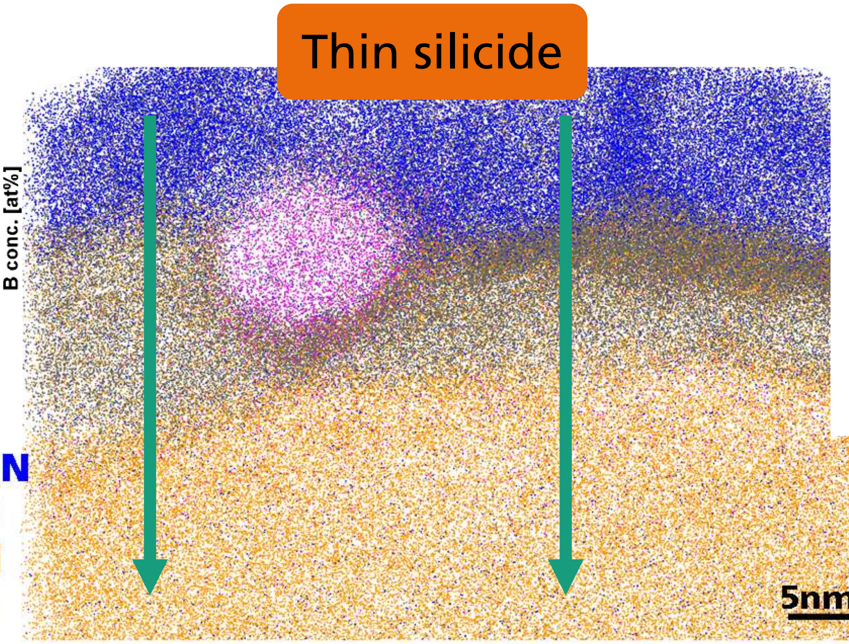


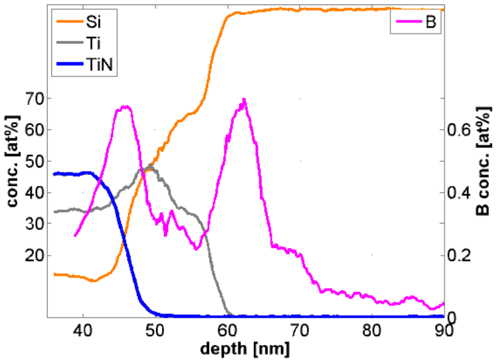
Atom Probe Tomography : Contact Materials- VRML

Atom Probe Tomography : Contact Materials-silicidation of Ti metal

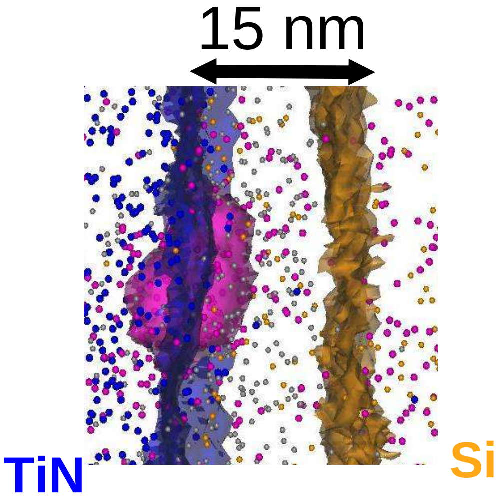


Fully silicided grain

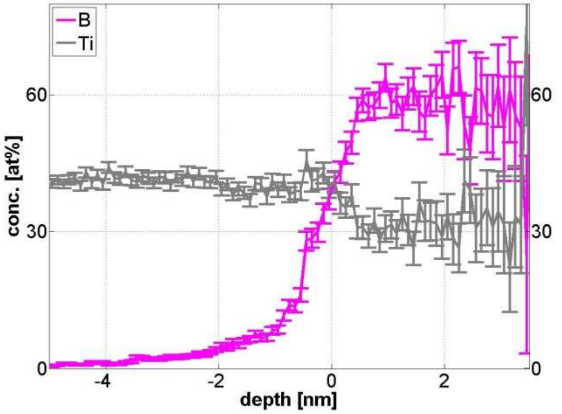




$TiSi_2$ grain with small additional metal rich phase



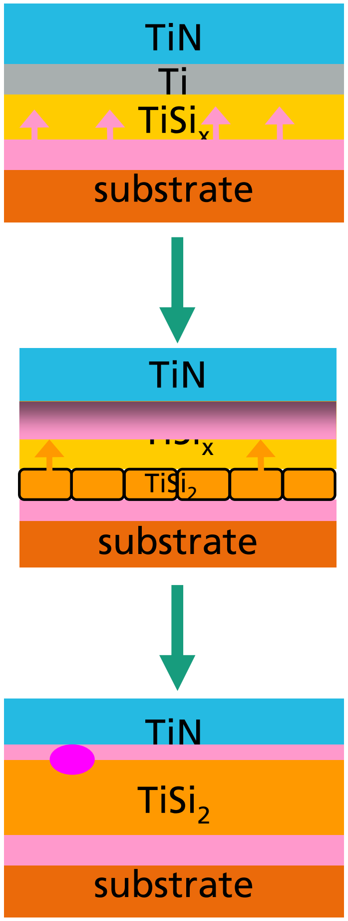
Precipitation of TiB_2



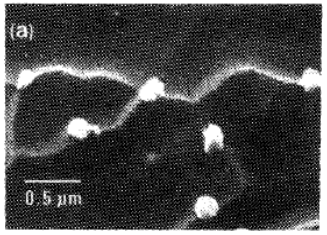
Fraunhofer
CNT

Atom Probe Tomography : Contact Materials-silicidation of Ti metal

The samples were prepared in a realistic process window of present device structures



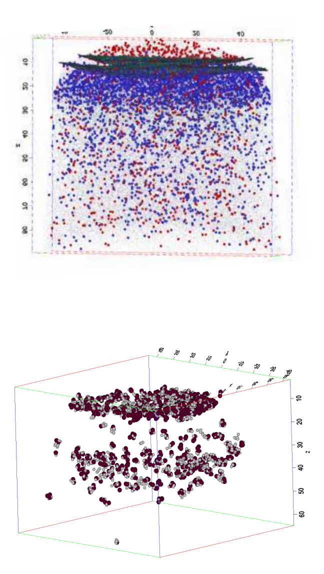
- An intermediate TiSi$_x$ film is formed initially during silicidation
- Boron: low solubility in TiSi$_2$, high solubility in TiSi$_x$
- TiSi$_x$ moves towards the TiN during slicidation carrying boron
- Boron precipitates revealed
  - Either TiB$_2$ (larger precipitates)
  - or TiB (smaller precipitates)
- APT provides further insight into the silicidation process



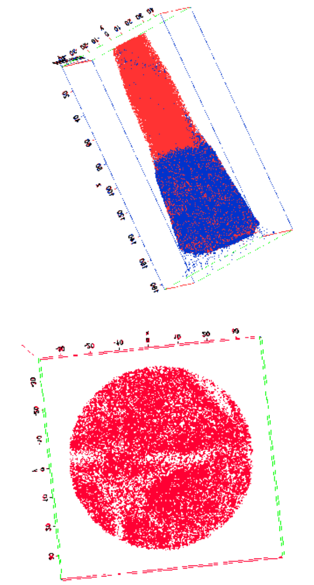
* Probst JAP 70 (2) 1991

Atom Probe Tomography : **Summary**

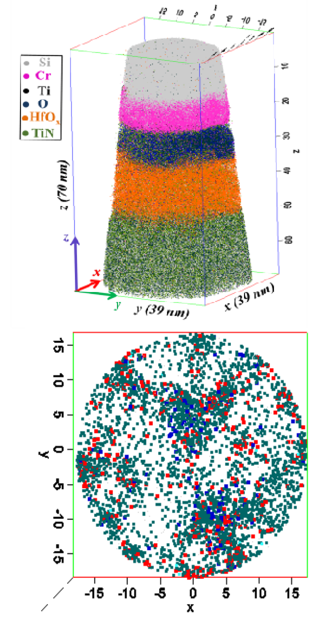
S/D



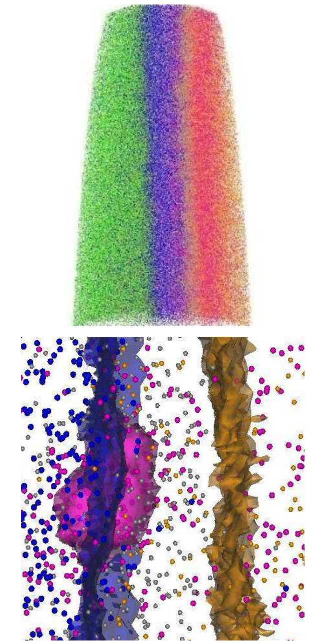
Metallization



MIM



Contact



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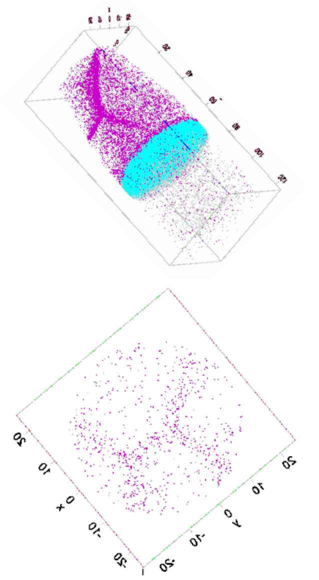

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Thank you for your attention!

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Interested in APT measurements!

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