Atomic layer deposition of P and Sb doping sources for the diffusion into 3D germanium structures

M. Silinskas, V. Begeza, D. Hagen, M.Lisker, B. Kalkofen, E.P. Burte – 09.03.2021

Outline

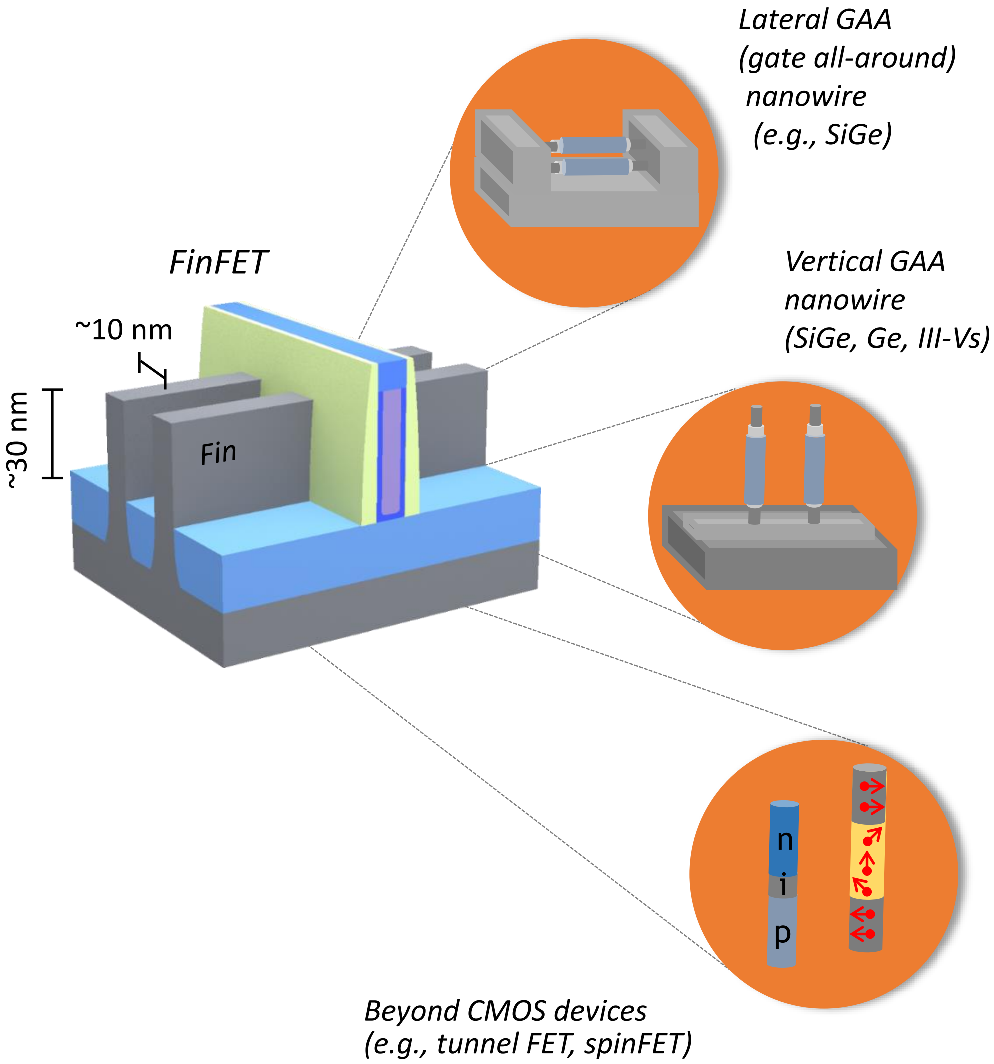
General overview

1. Motivation of ALD doping
2. Deposition technique
3. Results
   - Deposition
   - Characterization
4. Conclusions

1. Motivation

Transistor scaling

- FinFETs
  - State of the art technology
- Lateral Nanowire FETs
  - Most closely resemble current FinFET architecture
  - Require non-line-of-sight deposition and etch
- Vertical Nanowire FETs
  - Separates channel length from pitch
  - Could enable direct III-V growth on Si with minimal dislocations
- Beyond CMOS
  - 2D materials
  - Tunnel FETs
  - Spin FETs



1. Motivation

Comparison of conformity for 3D USJ with different doping methods

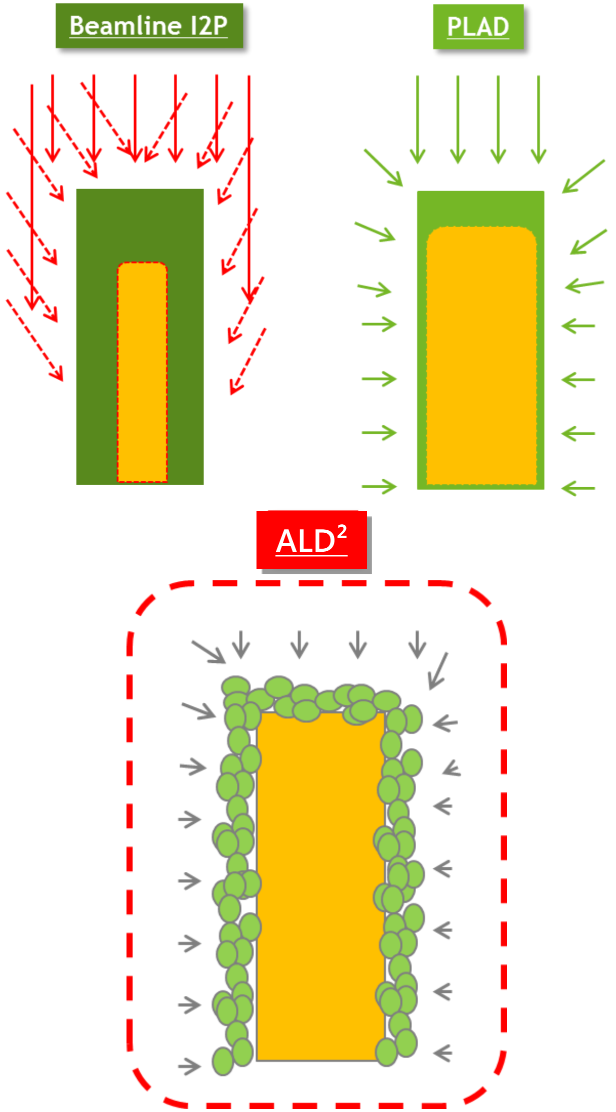
Doping on 3D structure will be a challenge due to its directionality during implantation

To form shallow junction on 3D structure, reducing ion energy & increasing ion scattering will be necessary

ALD doping by deposition of dopant will be an alternate option

Predeposition by atomic layer deposition (ALD)
+ Rapid thermal annealing

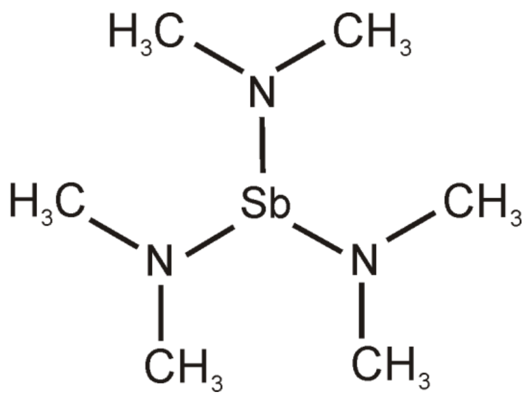
Atomic layer deposition for doping (ALD^2)



Plasma enhanced ALD (PEALD)

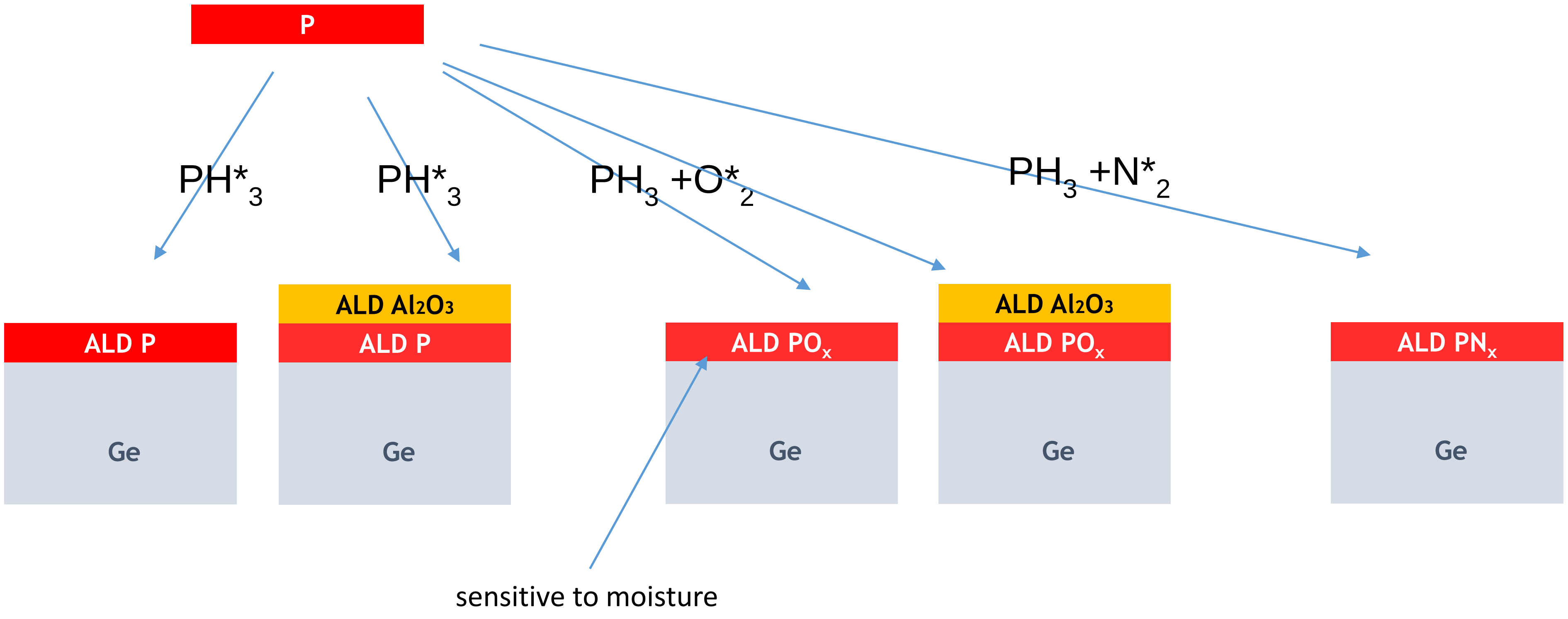
1. "Oxford FlexAL" for phosphorus doping with in-situ QCM
   - PH_3, N_2, O_2, O_3, H_2O

2. "Sentech ALD" for antimony doping with in-situ ellipsometer
   - TrisDMASb (*(Sb(N(Me$_2$)$_3$)*, H_2, O_2



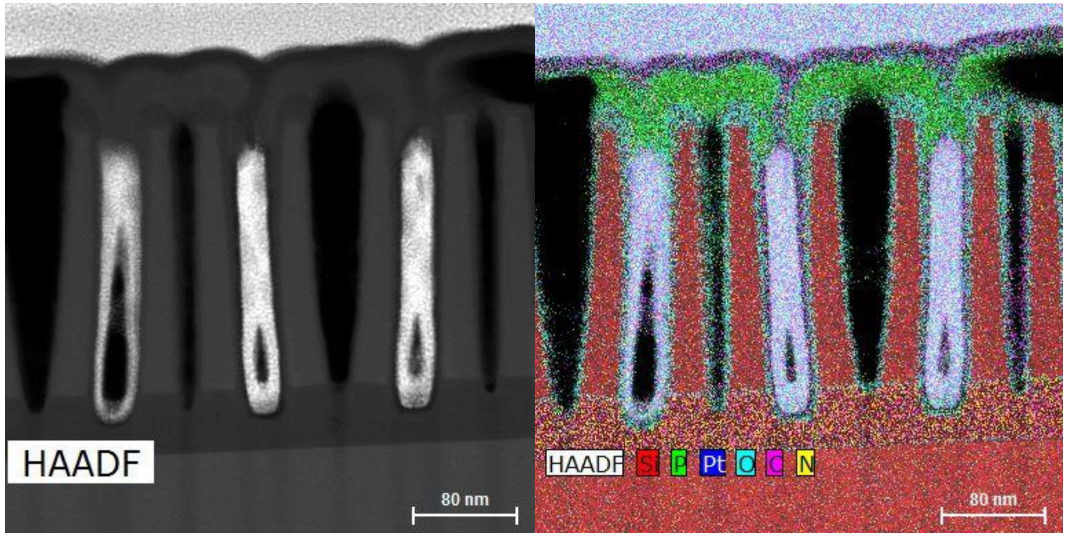
3. Results

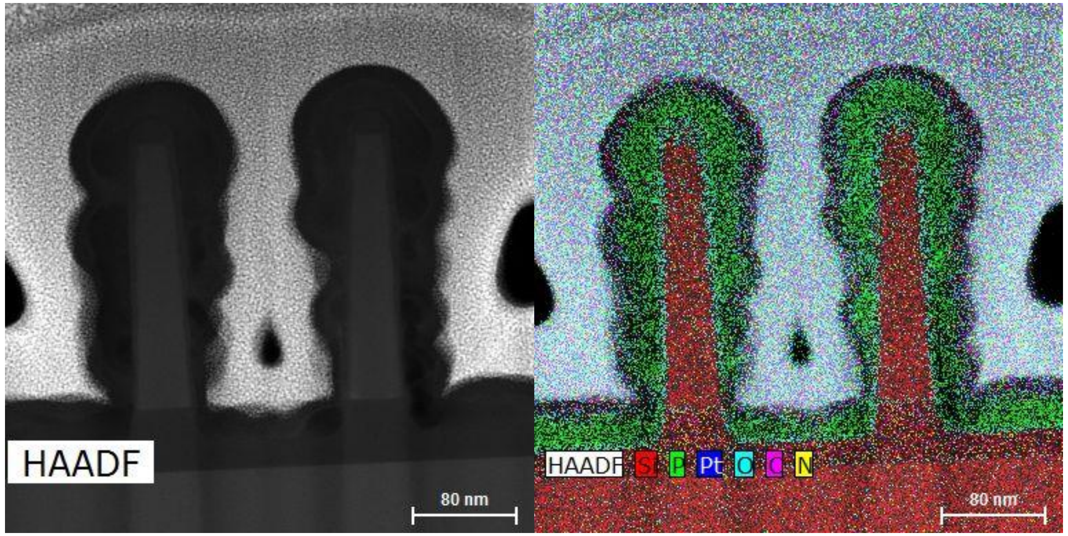
PEALD of phosphorus source



3. Results

PEALD of phosphorus source from PH_3 plasma



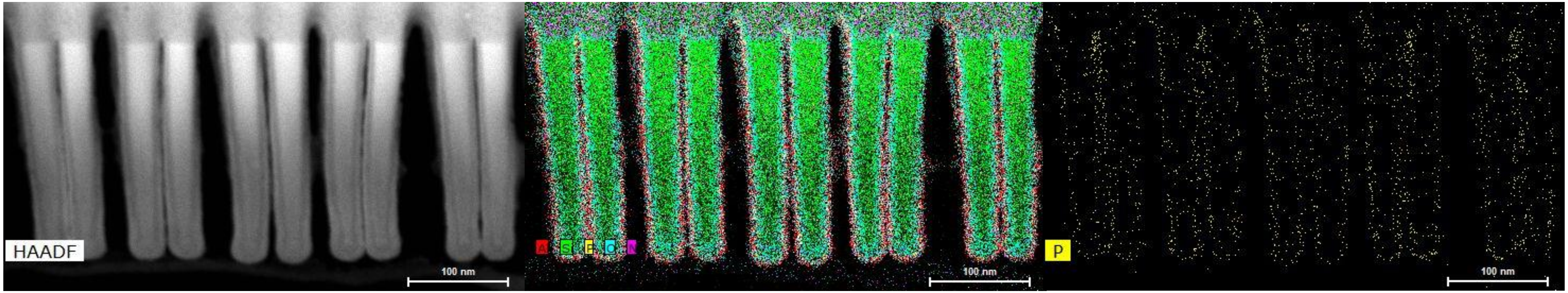


1) Relative high deposition rate – 0.1 nm/cycle
2) Not sufficient conformity: for gaps (16 nm wide and 240 nm deep)

d_{Bottom}/d_{Top} and $d_{Wall(200nm)}/d_{Top}$ - less than ~0.2

3.Results

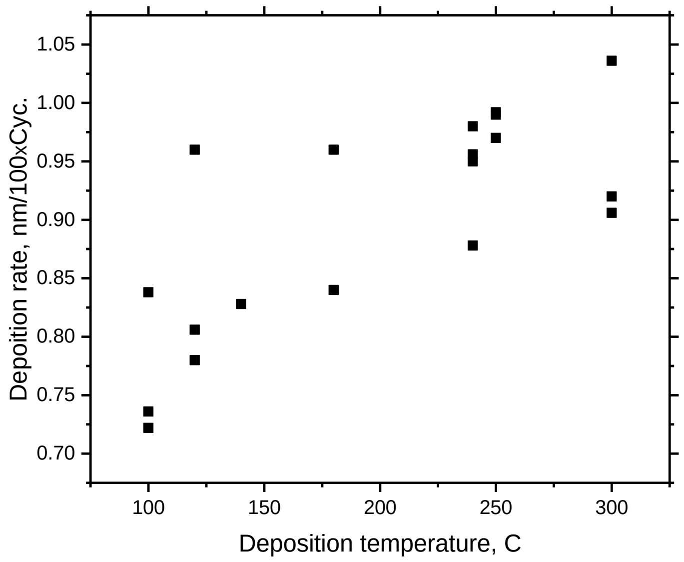
PEALD of phosphorus source from PH_3 and O_2 plasma

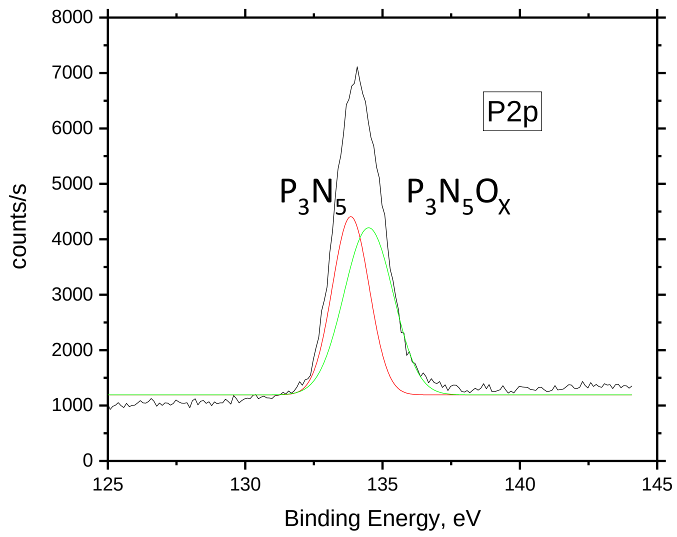


1) Very low deposition rate – 0.002 nm/cycle
2) Very good conformity: for gaps (16 nm wide and 240 nm deep) d_{Bottom}/d_{Top} and $d_{Wall(200nm)}/d_{Top}$ - (~1)
3) Sensitive to moisture

3.Results

PEALD of phosphorus source from PH_3 and N_2 plasma





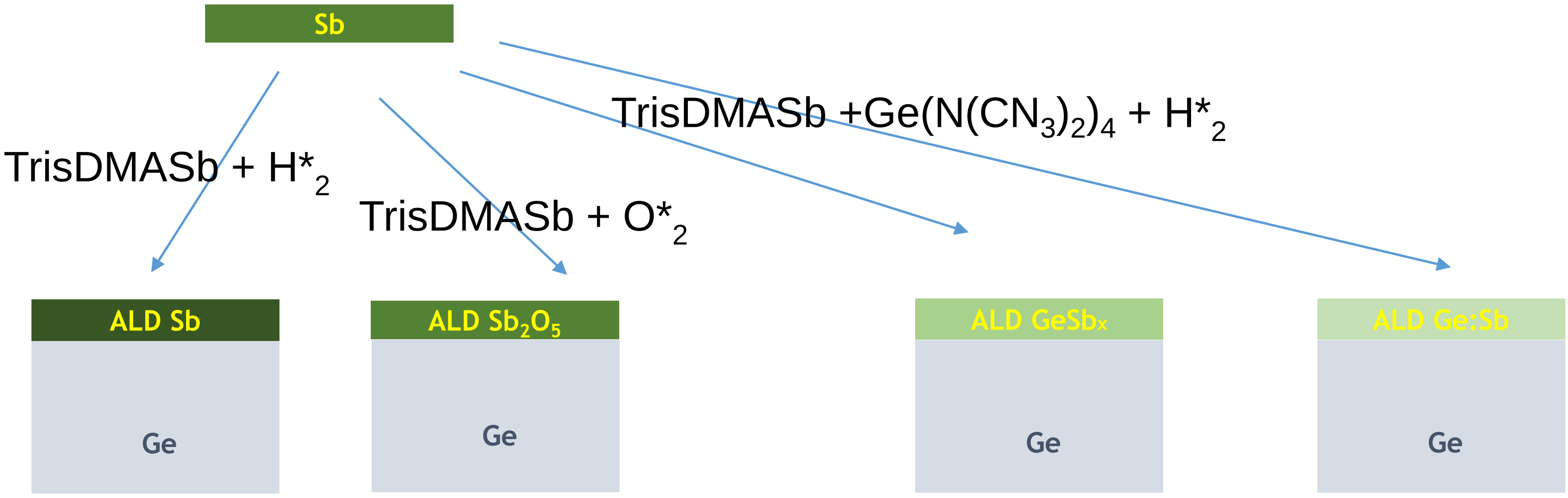
XPS (no sputtering): P_3N_5 ($P_3N_5O_X$)

1) Higher deposition rate – 0.01 nm/cycle
2) Not sensitive to moisture

Further investigations needed

3. Results

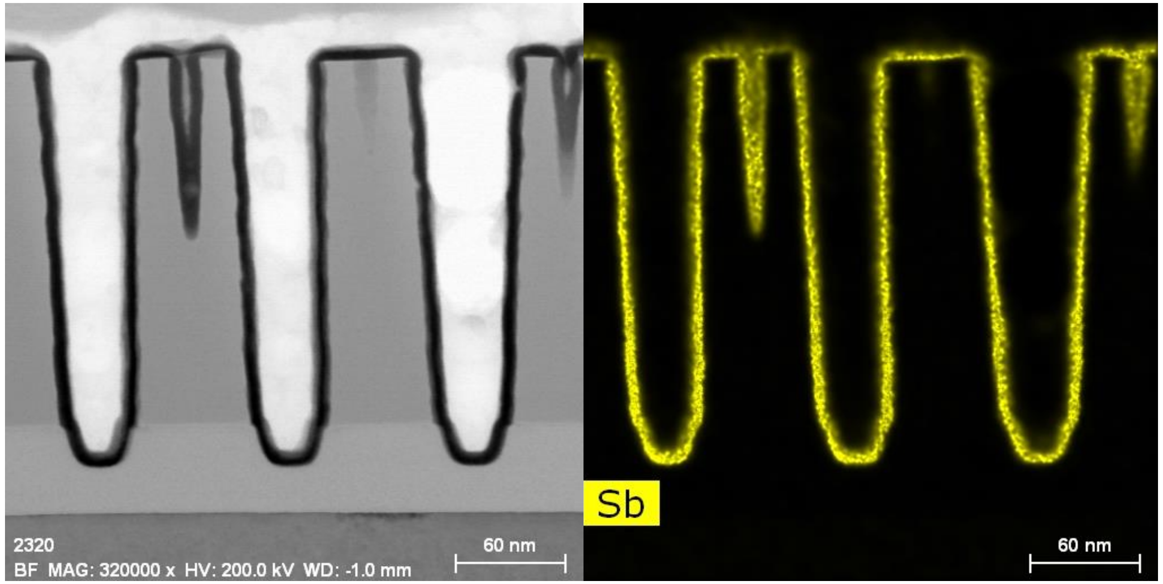
PEALD of antimony source

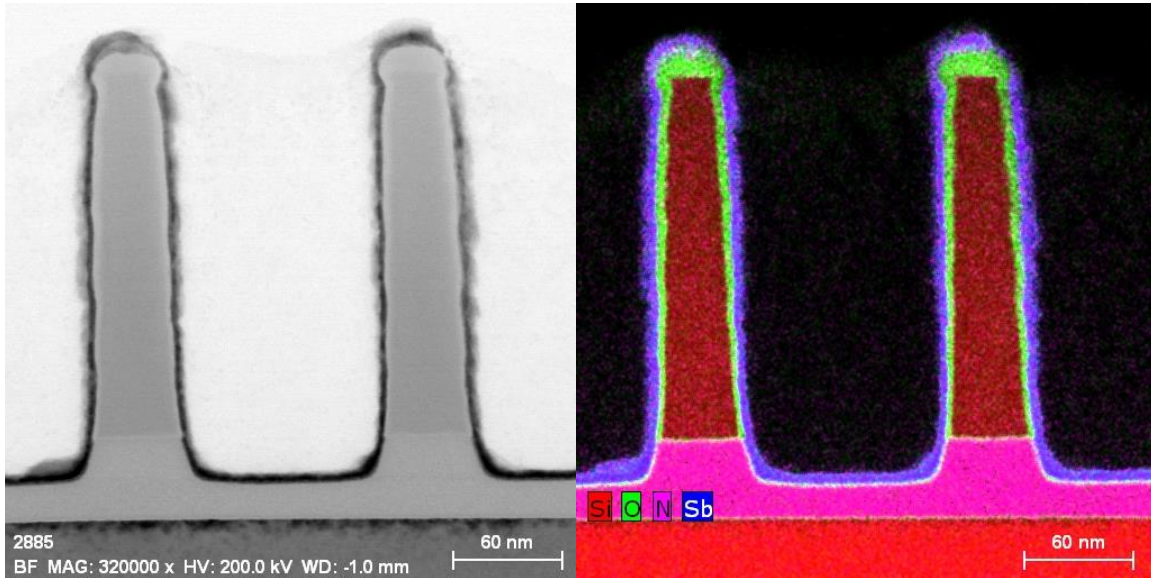


Higher reflectivity
(difficult to flash)

3. Results

PEALD of antimony source (SbO_X)

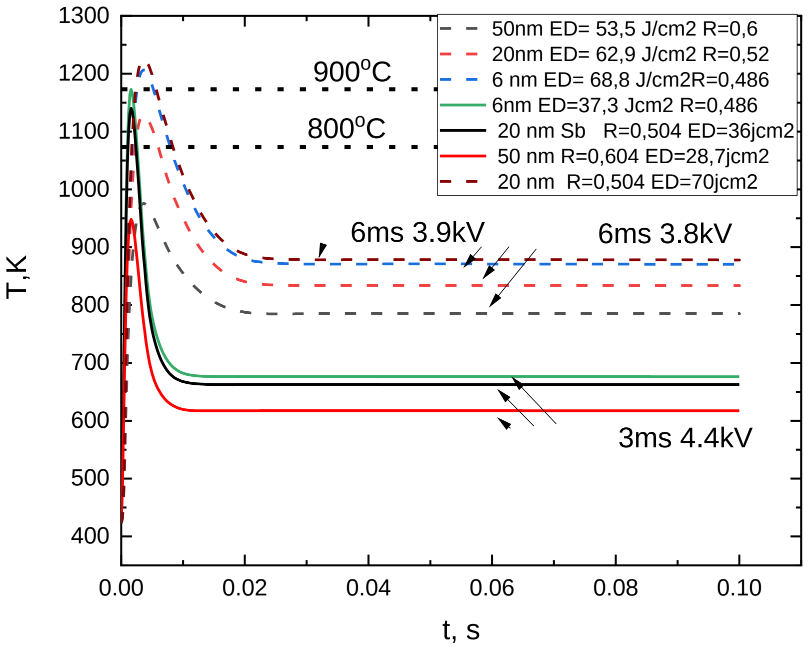




1) conformal deposition for gaps (40 nm wide and 200 nm deep)
2) d_{Bottom}/d_{Top} and $d_{Wall(200nm)}/d_{Top}$ - ~1
3) high deposition rates
4) not sensitive to the air

3.Results

Flash lamp annealing



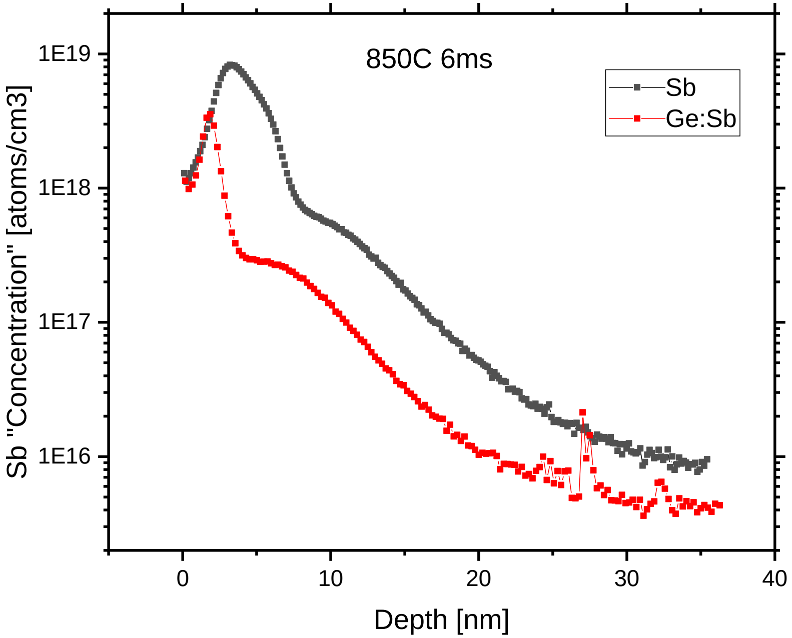
Simulated temperature

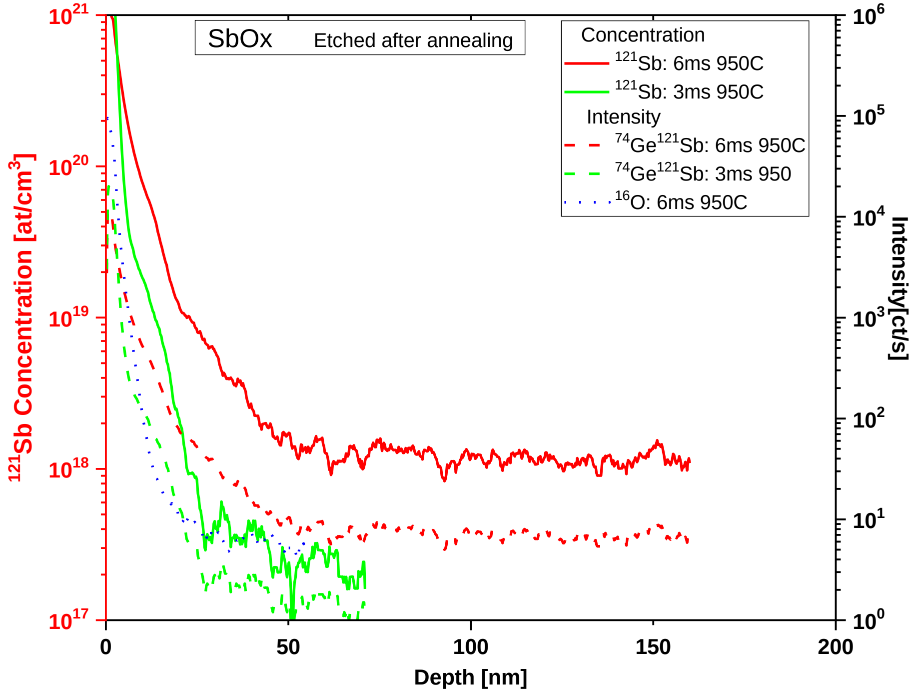
1) Doping layer temperature (simulated) depends on
- film thickness
- film reflectivity
- flash pulse length (duration) and power

2) Germanium crystal annealing (simulated) depends on
- flash pulse length
- doping layer temperature

3. Results

SIMS: Sb

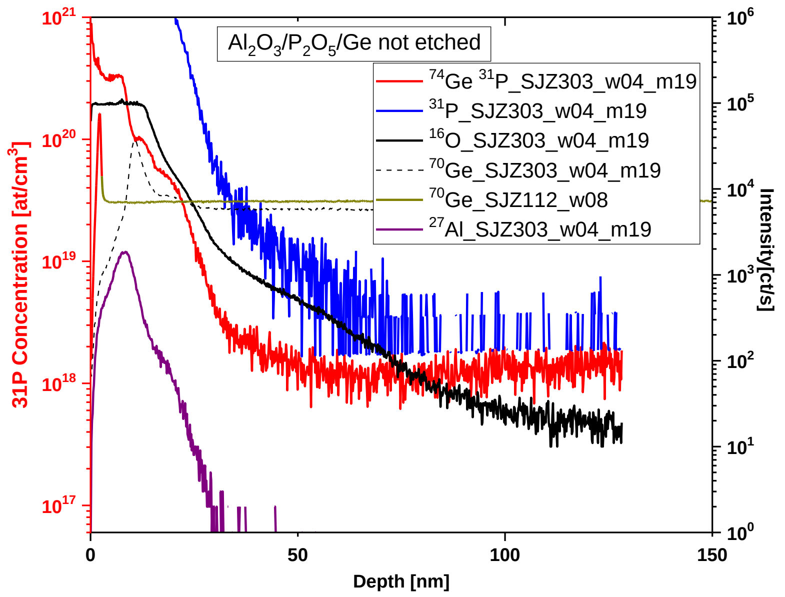




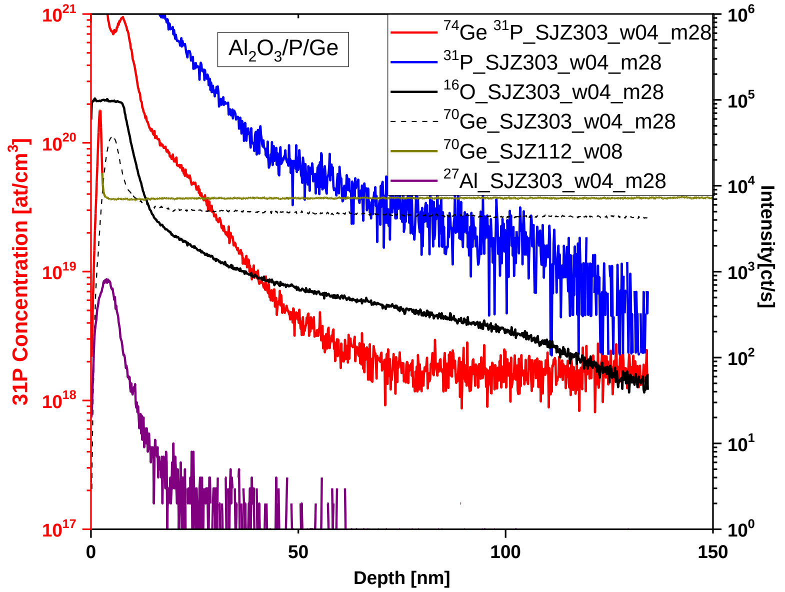
1) Doping profile depends on the temperature and pulse time
2) Sb shallow doping (5 - 10 nm)
3) Surface layer concentration - about $10^{21} – 10^{20}$ at/cm^3

3. Results

SIMS: P



850^{o}C 6ms



1) Doping profile depends on the temperature and pulse time (not shown)
2) P source (compare with P_2O_5) – little higher doping level and doping depth
3) P shallow doping (10 - 20 nm)
4) Surface layer concentration - about 10^{21} – 10^{20} at/cm^3

4. Conclusions

Conclusions

1. Plasma ALD is a suitable technique for conformal deposition of the P and Sb doping sources.

2. Doping level $10^{21} – 10^{20}$ atom/cm^3 can be achieved using flash lamp annealing.

Thank you for your attention.

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