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Heterogenous nucleation of catalyst-free InAs NWs on silicon

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Outline

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- Introduction
- Semiconductor nanowires: definition and applications
- Catalyst-free growth of semiconductor NWs
- Nucleation and density control
- Conclusions

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Semiconductor nanowires (NWs)

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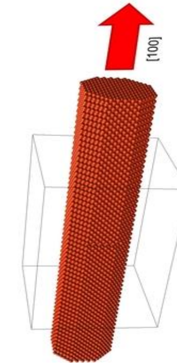
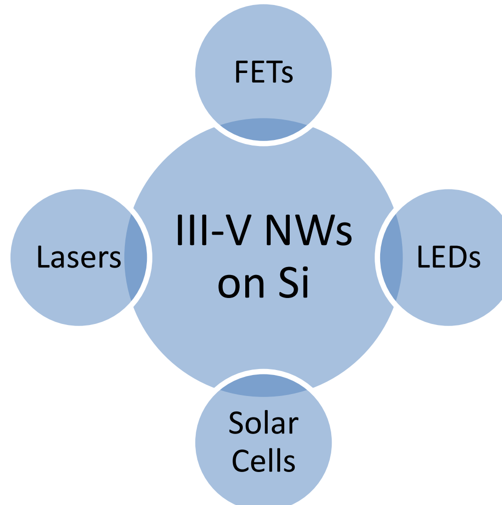
Quasi-one dimentional crystals



1D growth

- Novel properties:
  - high surface/volume ratio
  - carrier confinement
  - defect-free growth

- Integration of III-V NWs on silicon substrate → key research



Chemical Beam Epitaxy

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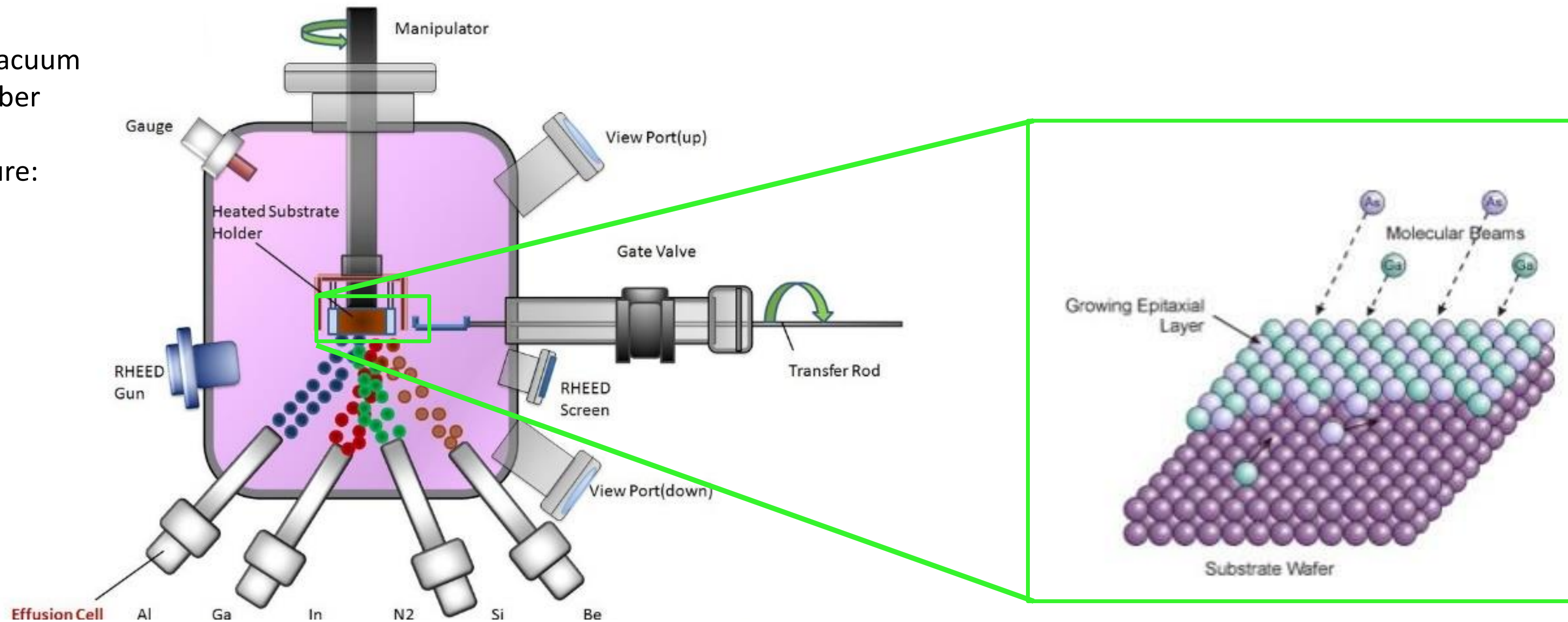
Ultra High Vacuum (UHV) chamber

(base pressure: 10^{-9} Torr)



CBE for III-V semiconductor growth

Metal-organic precursors:

Group III : TM**In**, TE**Ga**, TM**Al**

Group V : TB**As**, TB**P**, TDMA**Sb**, TM**Sb**

n-doping: TB**Se**

Advantages +++

- Low impurity conc. thanks to the UHV
- Monolayer control
- High flexibility in material combination

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Growth mechanisms of semiconductor NWs

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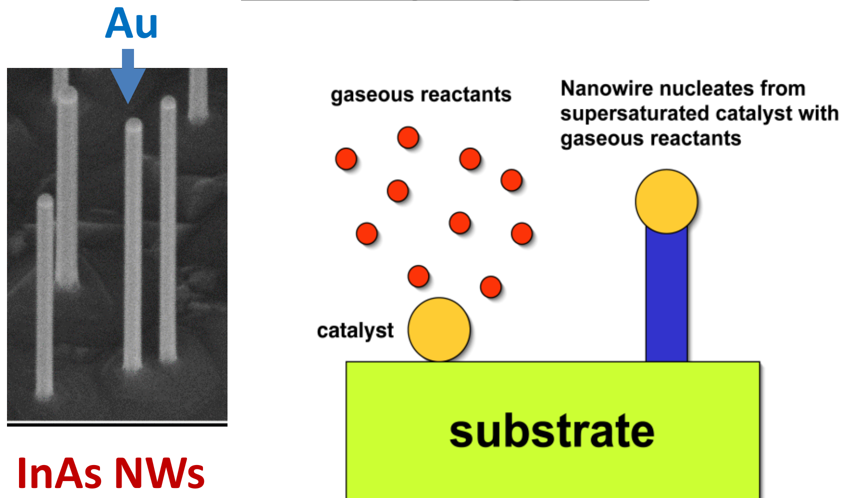
Gold-assisted growth:

Vapour-liquid-solid (VLS) mechanism

Au-catalyzed growth



× The incorporation of metal catalyst can be detrimental for the applications

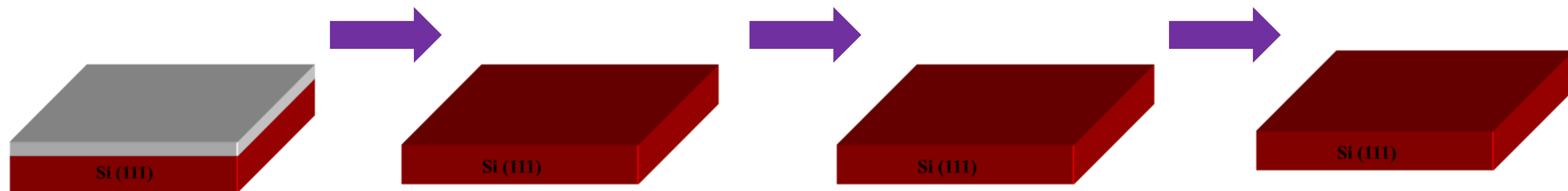
Catalyst-free growth:

InAs NWs

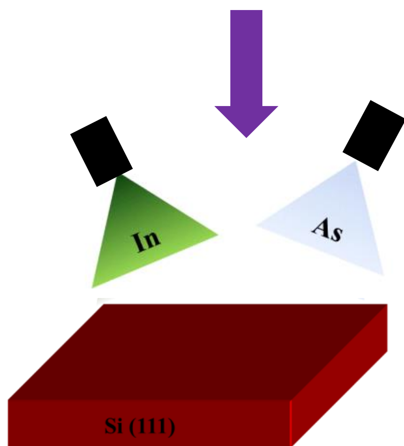
- ✓ Absence of foreign metal contamination
- ✓ Integration of III-V NWs and silicon

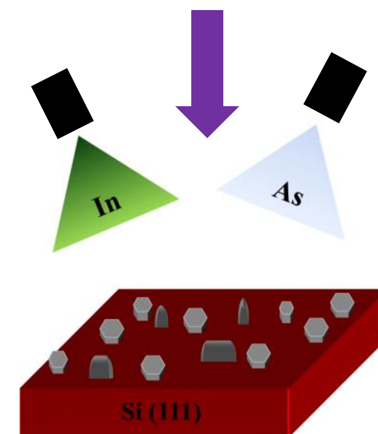
Catalyst-free growth of InAs NWs on Si (111) substrate

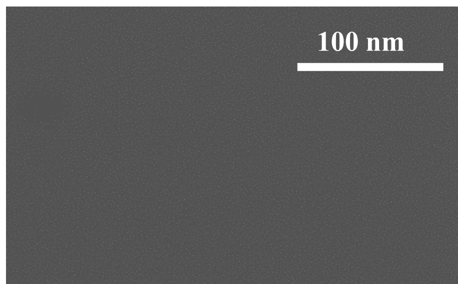
Substrate preparation

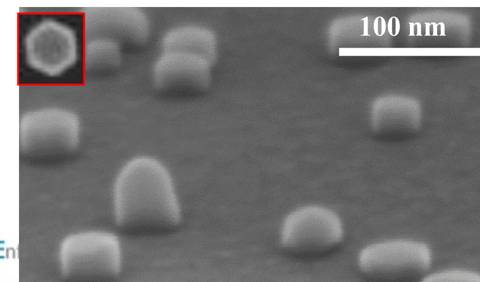


III-V Growth









U. P. Gomes, D. Ercolani, V. Zannier, S. Battiato, E. Ubyivovk, V. Mikhailovskii, Y. Murata, S.Heun, F. Beltram and L. Sorba, Nanotechnology , 28, 065603 (2016).

Catalyst-free and growth of InAs NWs on silicon substrate

Nature of nucleation sites

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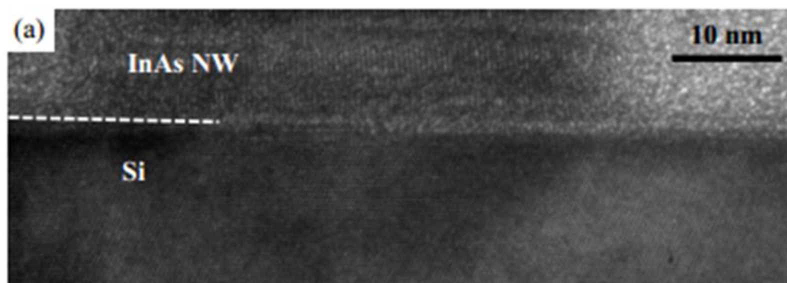
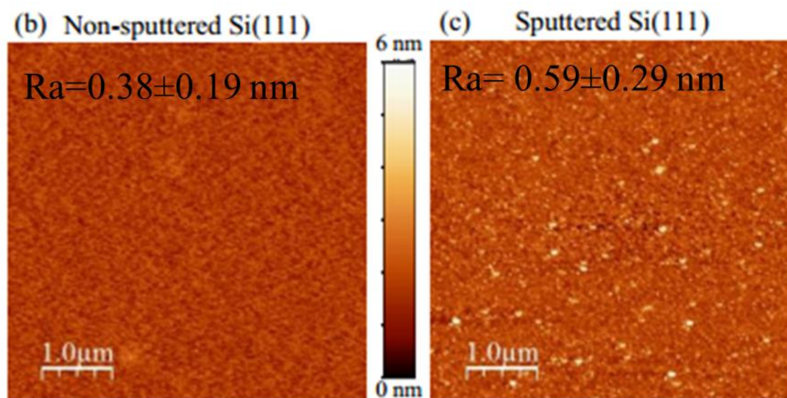




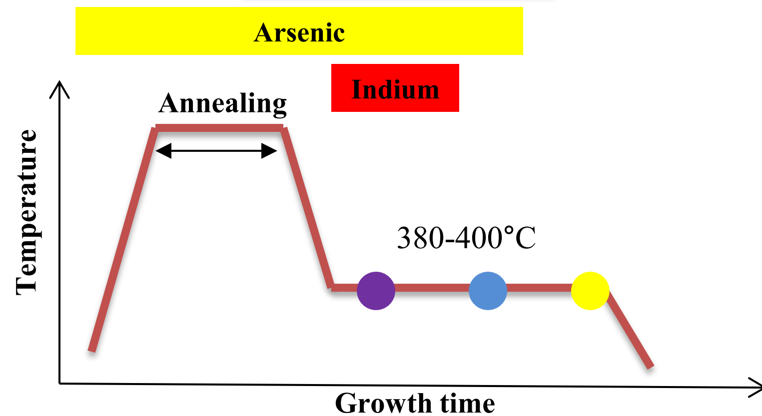
HRTEM analysis shows defect-free crystalline order of the sputtered Silicon substrates after growth.
Amorphization is unlikely to be the source of nucleation sites.

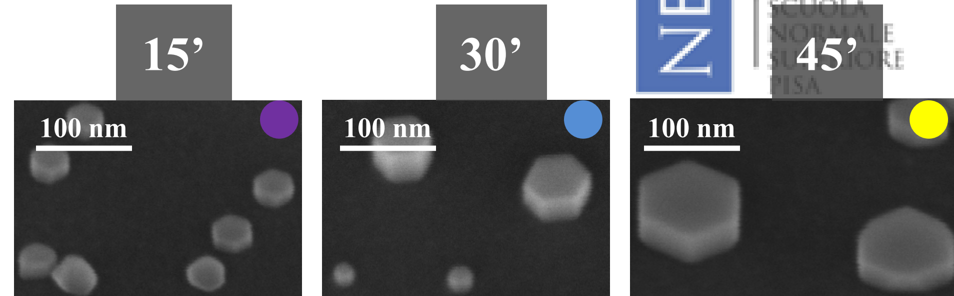
AFM scans show comparable surface roughness.
Roughness is unlikely to be the source of nucleation sites

- ✓ Sputtering probably creates defects
- ✓ Defects serve as nucleation sites

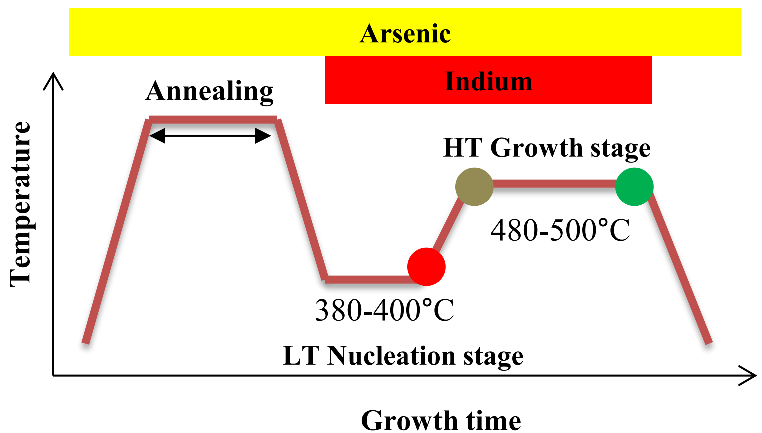
Catalyst-free growth of InAs NWs on silicon substrate

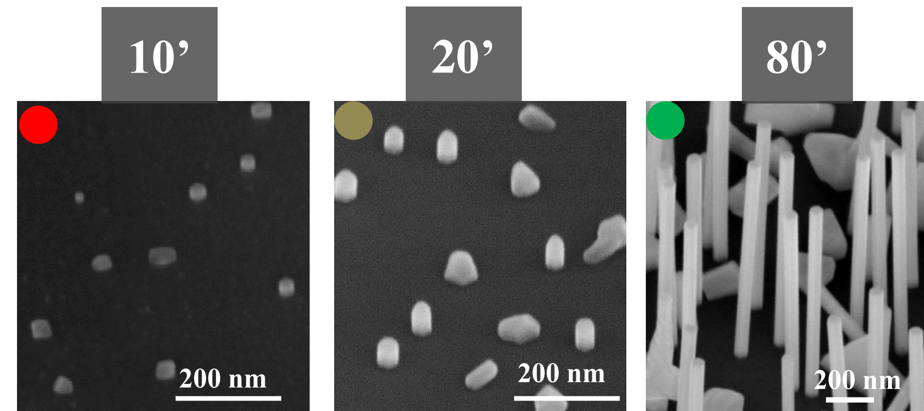
Growth protocol





- LT enhances nucleation but NWs grow only radially



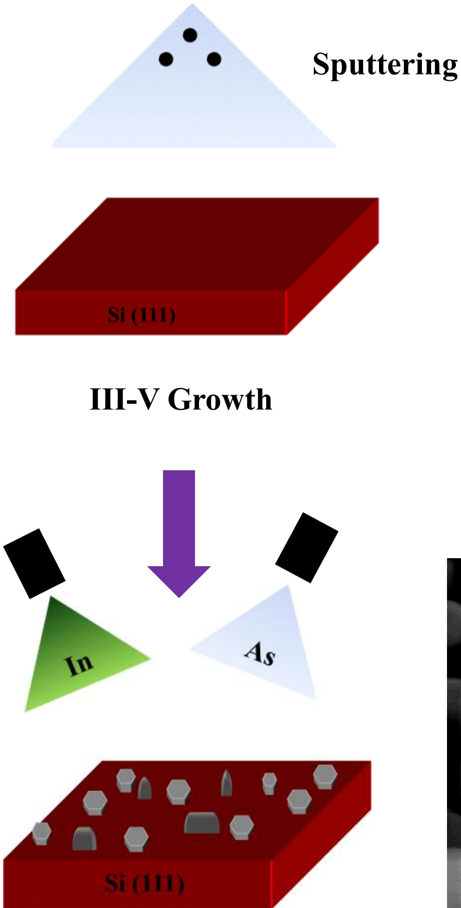


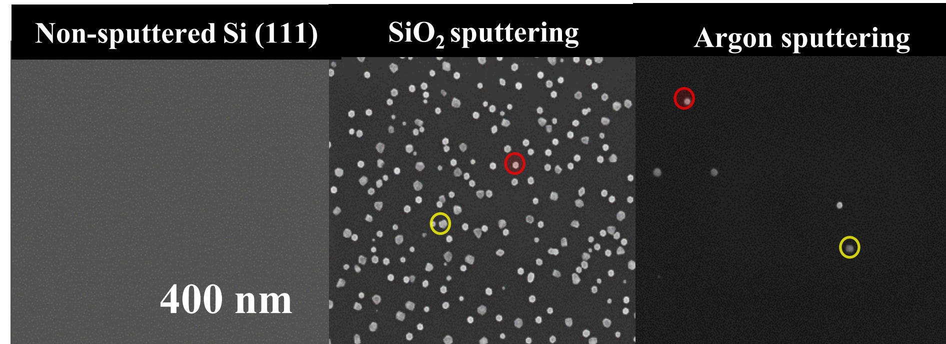
- Two-step temperature growth
- LT nucleation stage to control NW density
- HT stage to enhance anisotropic NW growth

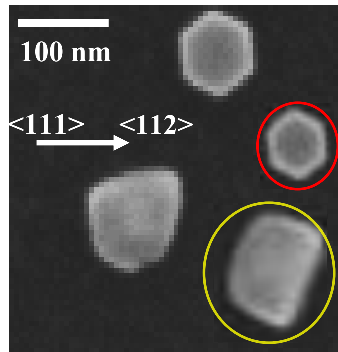
U. P. Gomes et al., Nanotechnology, 26, 415604 (2015)

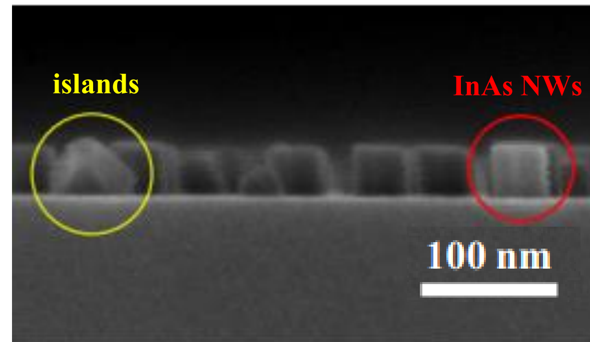
Catalyst-free growth of InAs NWs on silicon substrate

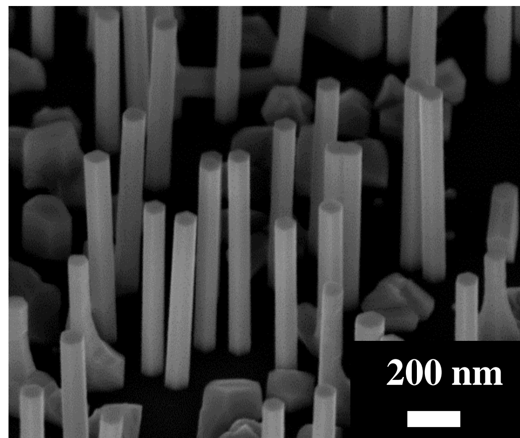
Morphological characterization

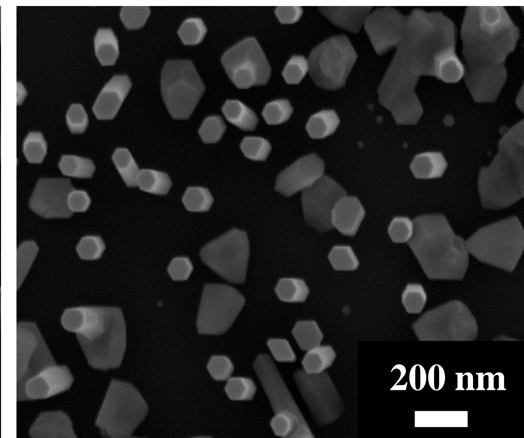












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U.P. Gomes et al. *Nanotechnology*, 2015, 26, 415604.

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Effect of sputtering parameters on crystal density and yield

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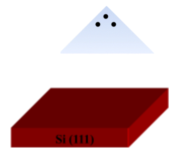
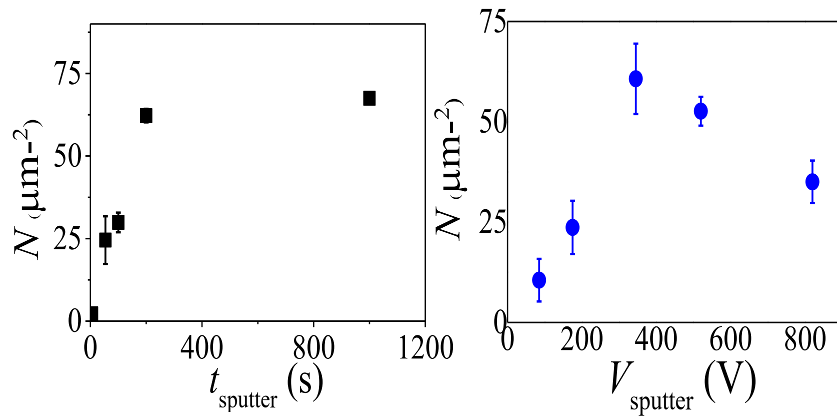
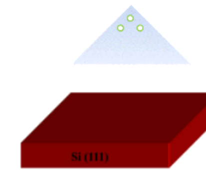
Crystal density (N) = (InAs NW + island) density
Yield = InAs NW density/total crystal density

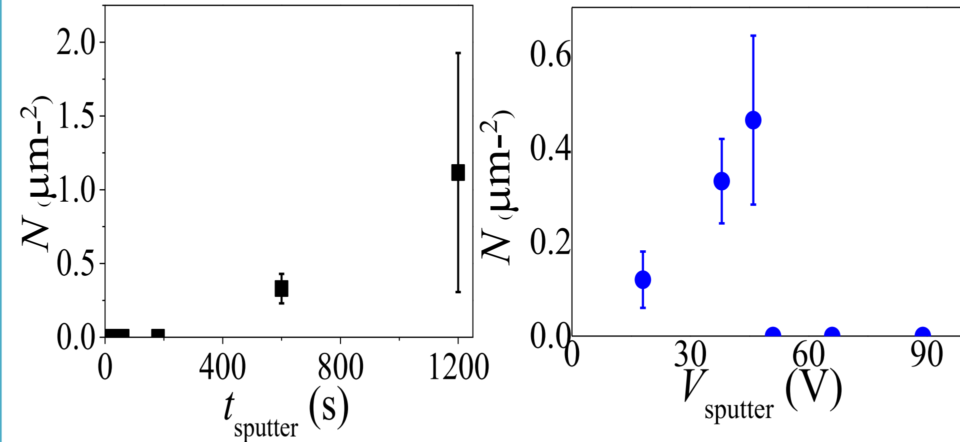
RF magnetron SiO_2 sputtering





ICP Argon sputtering





❖ **Crystal density increases with $t_{sputter}$ and $V_{sputter}$ (as long as no etching /amorphization occurs)**

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Effect of sputtering parameters on NW Yield

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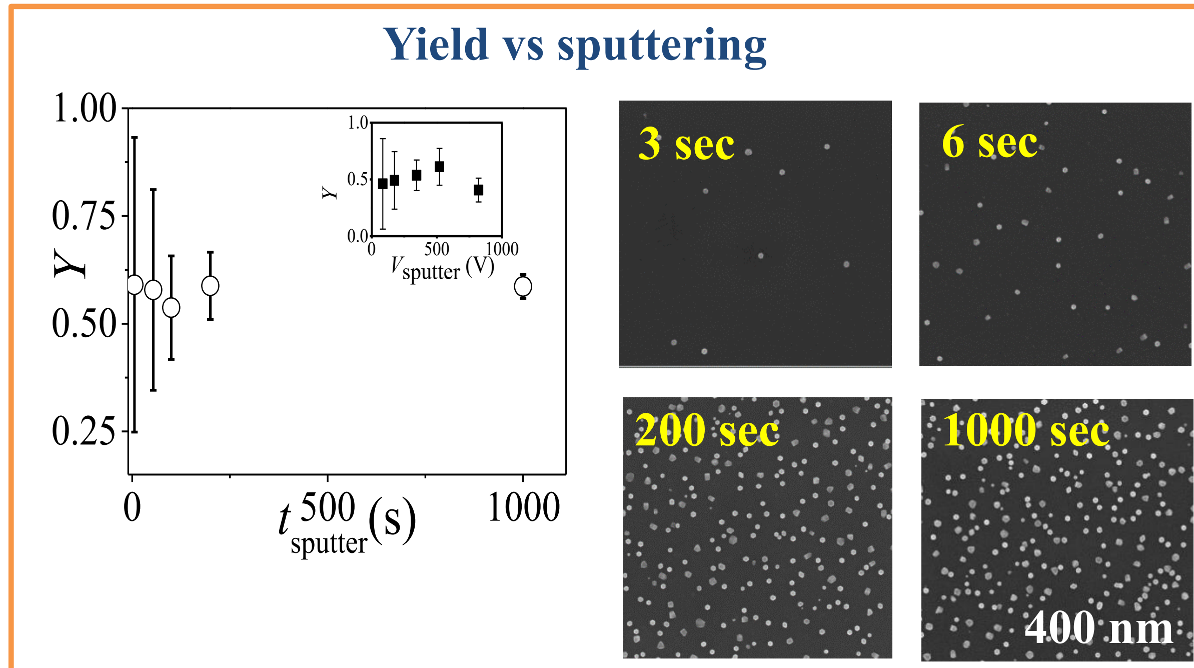
Yield vs sputtering



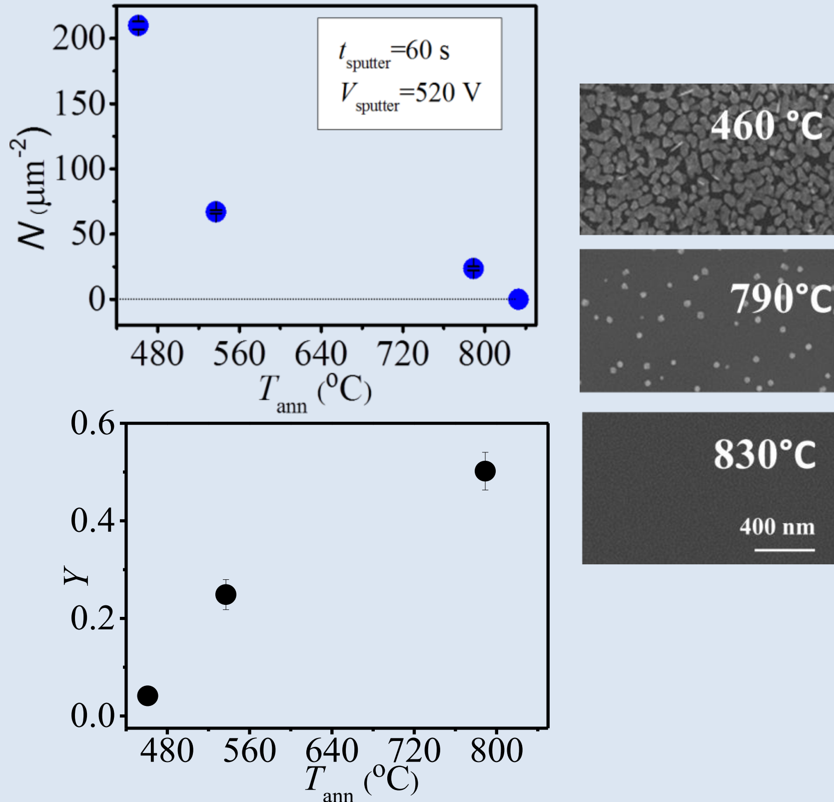
❖ **Yield independent of sputtering parameters (~ 50 %)**

Catalyst-free and growth of InAs NWs on silicon substrate

Effect of growth parameters on crystal density and yield

$T_{annealing}$

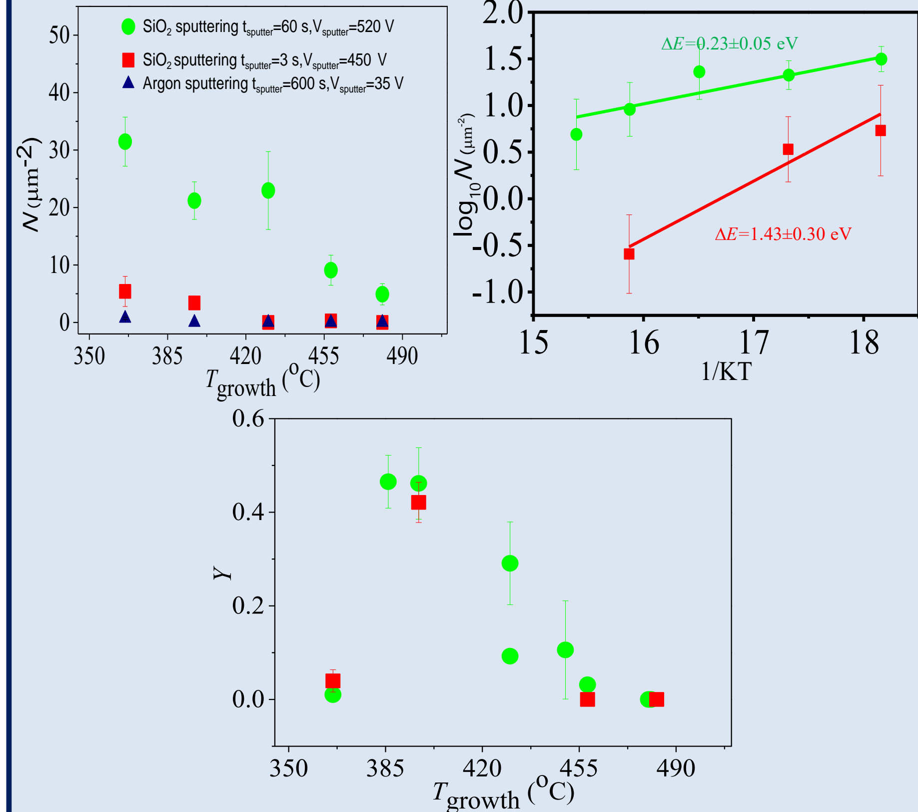
T_{growth}=400°C, t_{growth}=15 mins



- Annealing reorders the Si (111) surface
- Defect density decreases and crystal density decreases
- Yield increases with annealing temperature
- Highest yield of NWs at 790°C

T_{growth}

T_{ann}=790°C, t_{growth}=15 mins



- InAs crystal density decreases with T_{growth}
- High $V_{sputter}$ and $t_{sputter}$: low ΔE (Arrhenius plot)
- Maximum yield at 400°C
- NW density in the range of 1-30 NWs/μm^2

Catalyst-free and growth of InAs NWs on silicon substrate

Nucleation mechanism vs growth time

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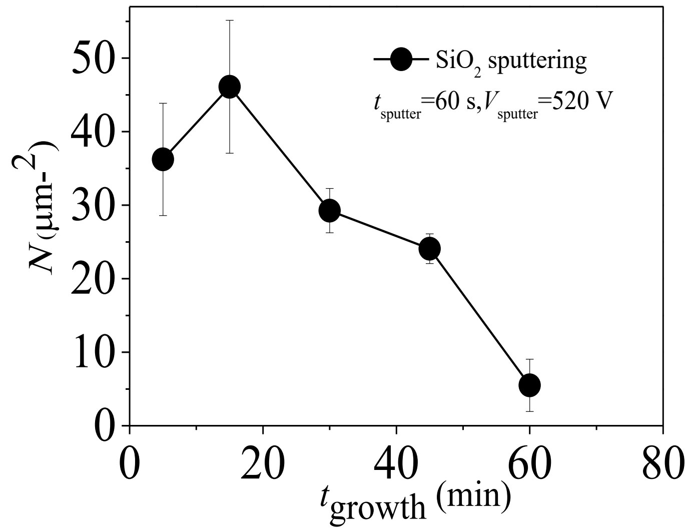

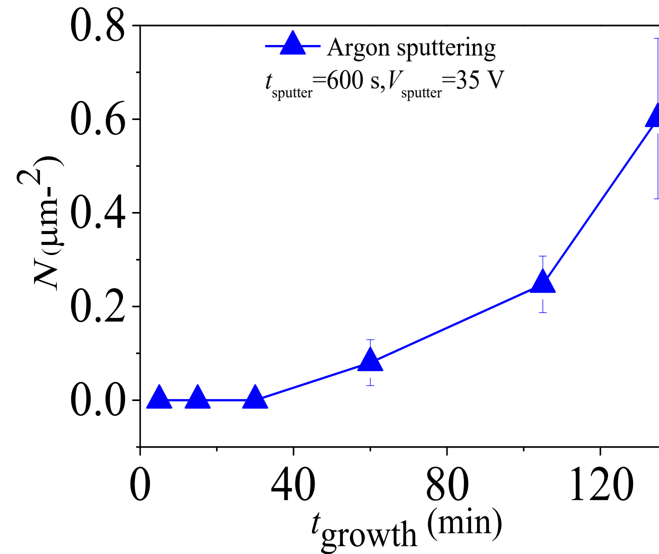

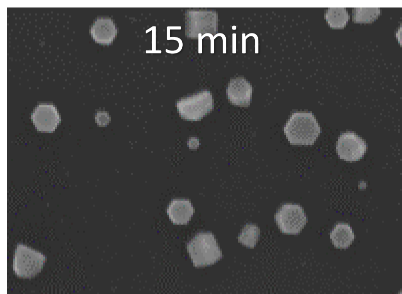

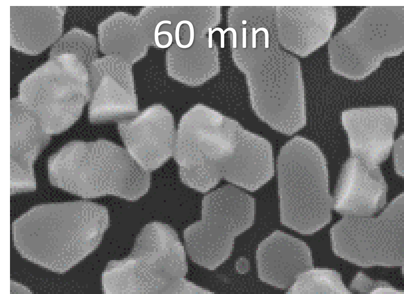

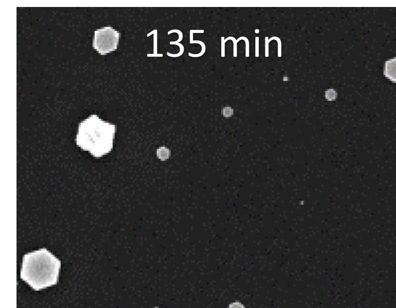

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Conclusions

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- ✓ InAs nanowires have been synthesized by Chemical Beam Epitaxy technique using catalyst-free approach.
- ✓ We assessed the role of substrate preparation, showing that InAs crystals nucleate on sputtered Si(111) surfaces while no nucleation occurs on non-sputtered Si(111) surfaces.
- ✓ We showed that the silicon surface can be obtained by modifying in situ growth and ex situ sputtering parameters, allowing us to achieve a good control of the InAs NWs density.
- ✓ Although the nucleation of parasitic islands could not be completely inhibited, the yield of NWs could be increased to about 0.5 by proper choice of growth and annealing temperatures.

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Thank you for your attention!

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