Heterogeneous nucleation of CBE grown catalyst-free InAs nanowires on silicon

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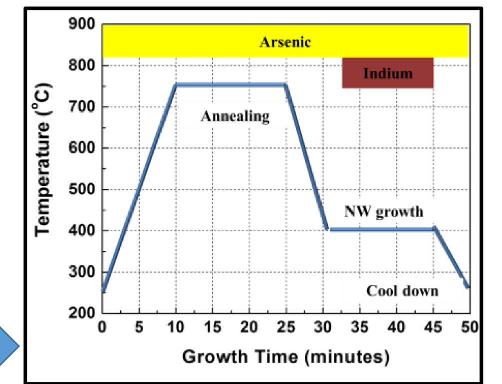
Motivation

- Au-free growth of NWs is fundamental for:
  - optical applications, to avoid the effect of Au impurities in the semiconductor
  - Si CMOS integration, incompatible with Au
- InAs NWs:
  - high electron mobility
  - low bandgap and possible band engineering with compatible barrier materials (InP, GaAs, GaSb)
  - easy fabrication of high performance leads

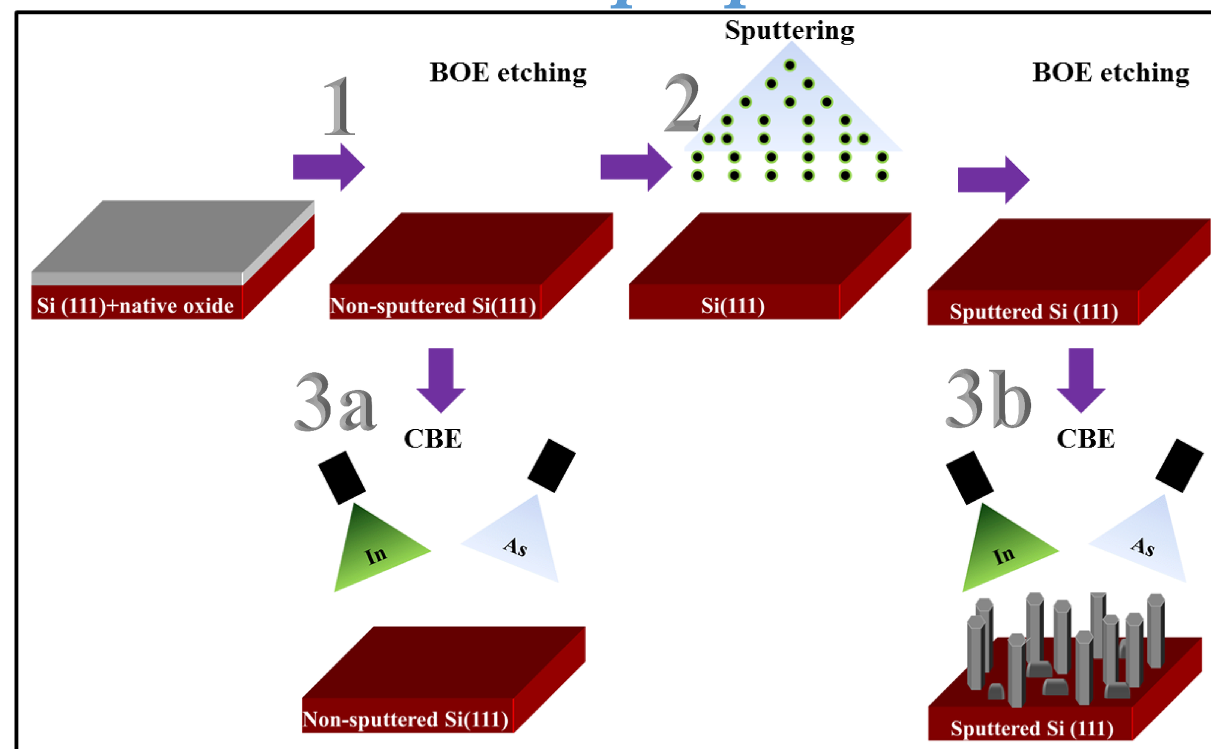
Growth technique (CBE)

- UHV epitaxial growth (base pressure = 10^{-10} Torr)
- Load lock and intermediate buffer chamber to avoid contaminants
- Heated sample holder (up to ~800°C)
- Gas-phase metalorganic precursor (TBAs, TMIn) flow regulated through line pressure (P_{TBAs} and P_{TMIn}) control
- TBAs pre-cracked in high temperature (1000°C) injector
- Two stage growth protocol: HT annealing step under As flux and NW growth



Si substrate preparation and InAs NW growth

Si substrate preparation



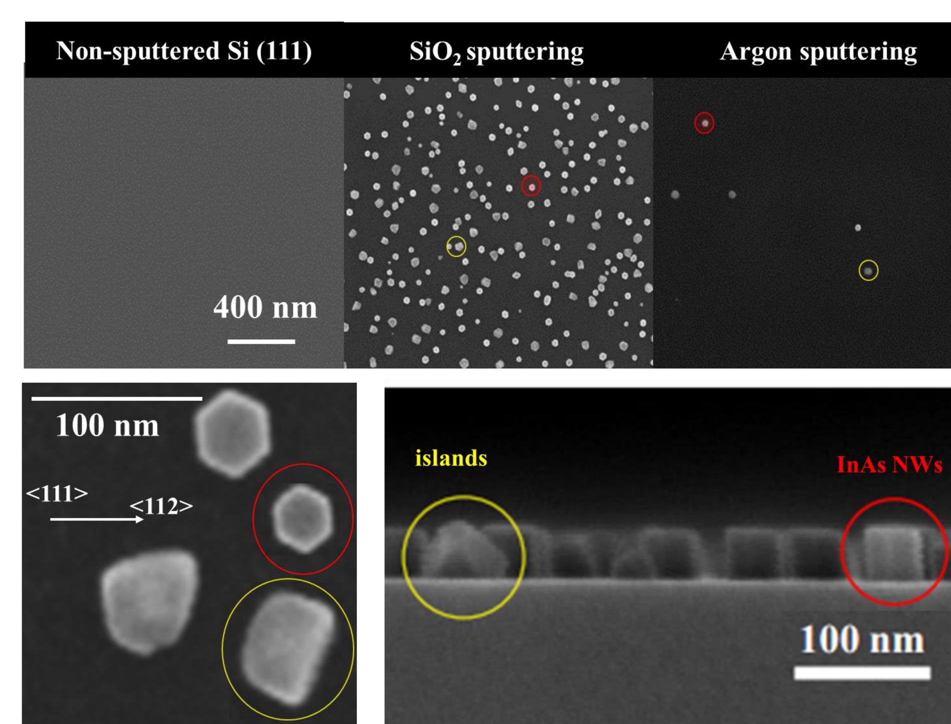
Step 1 → Commercial Si 111 wafers buffered HF etch (2') for native oxide removal

Step 2 → Sputter coat with few (1-20) nm SiO_2 + Buffered HF etch (2') for sputtered oxide removal or Ar^+ sputter with DC gun or with AC plasma

Step 3 → InAs NWs growth by CBE on: a) non sputtered and b) sputtered Si (111) substrates

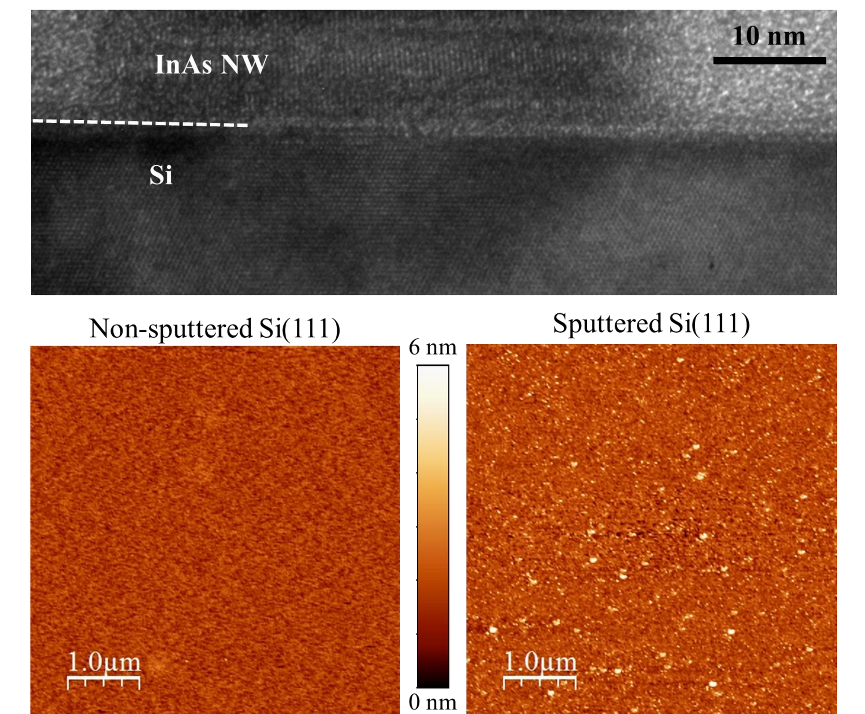
SEM characterization

NW growth



- Controlled sputtering of the Si(111) surface enhances the nucleation of InAs crystals (NWs and islands), while no nucleation occurs on non-sputtered Si(111) surfaces under identical growth conditions.
- The yield (Y) of NWs, determined as NW density/total crystal (NWs +islands density) is ~0.5 for both SiO_2 and Ar sputtered samples

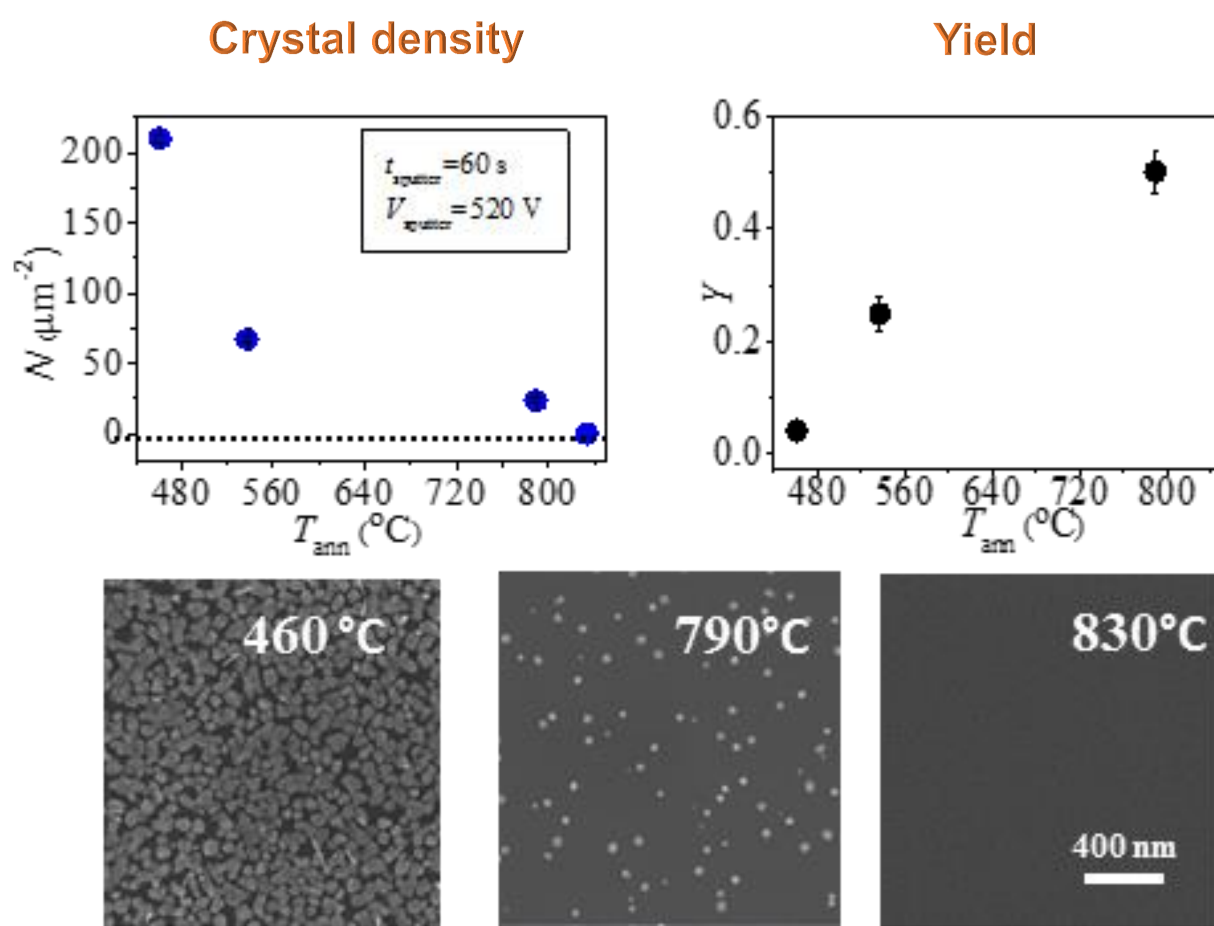
Nature of nucleation sites



- HRTEM analysis shows defect-free crystalline order of the sputtered Silicon substrates after growth.
- AFM scans show comparable surface roughness.
- Amorphization and roughness are unlikely to be the source of nucleation sites, which may be instead surface defects associated with the sputtering process that serve as preferential physical nucleation sites.

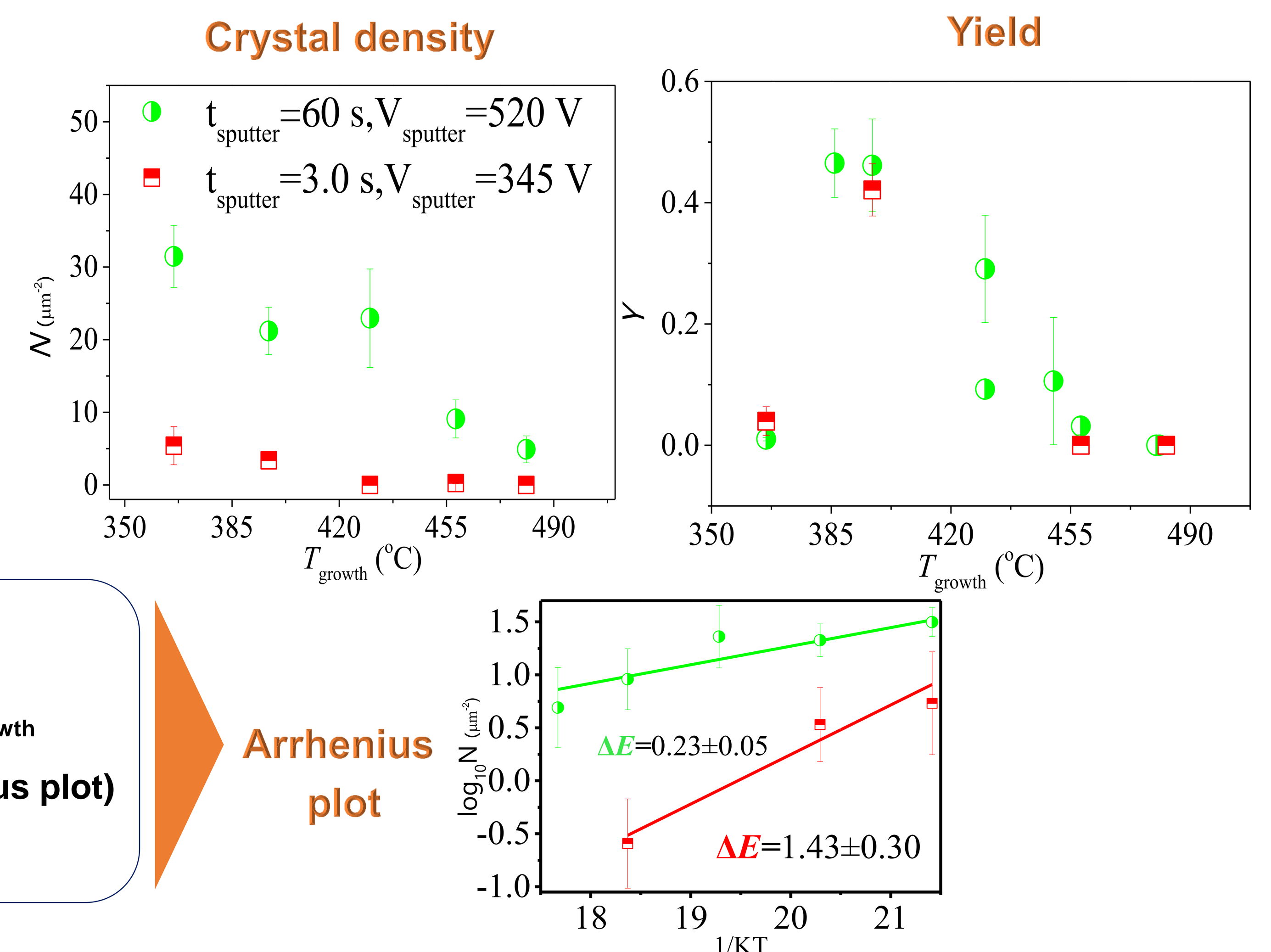
Impact of growth parameters

Annealing temperature



- 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

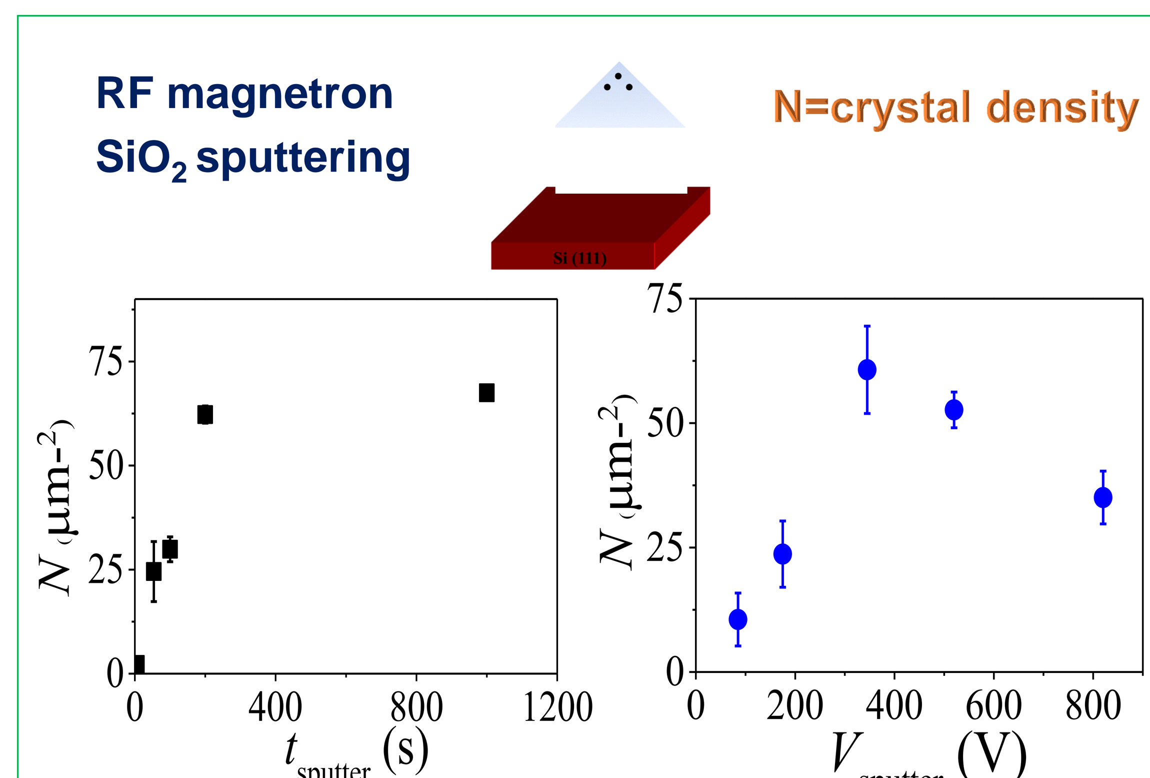
Growth temperature

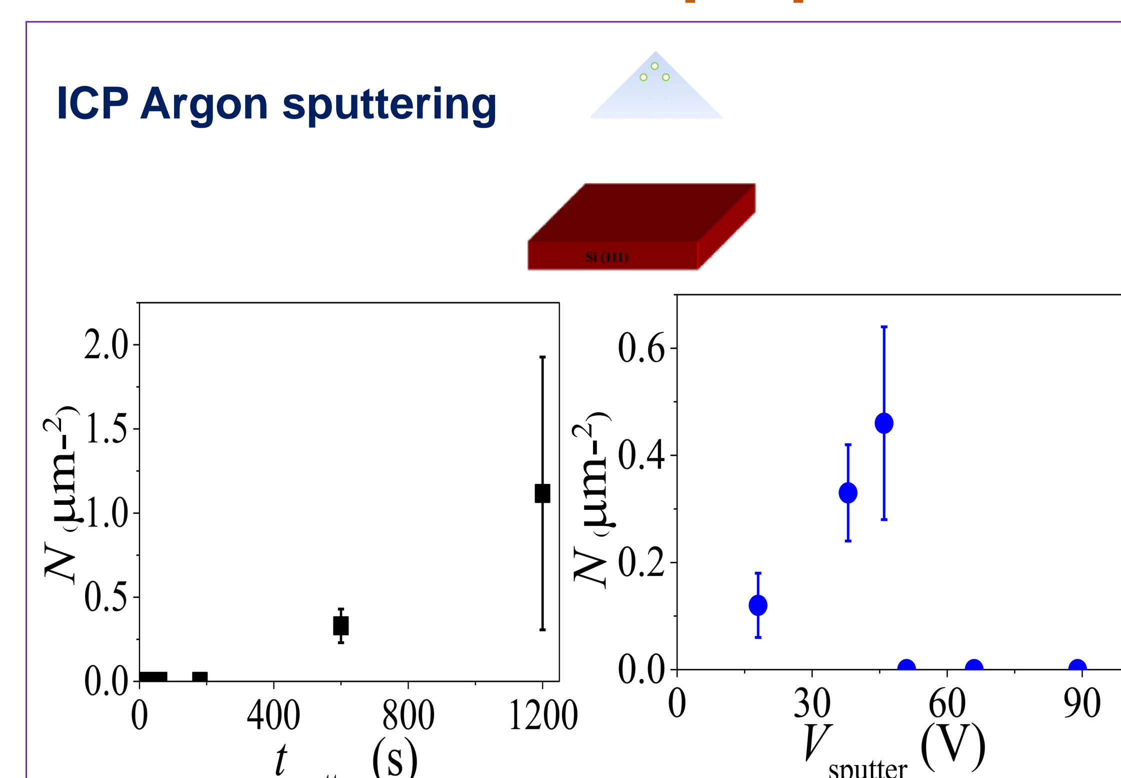


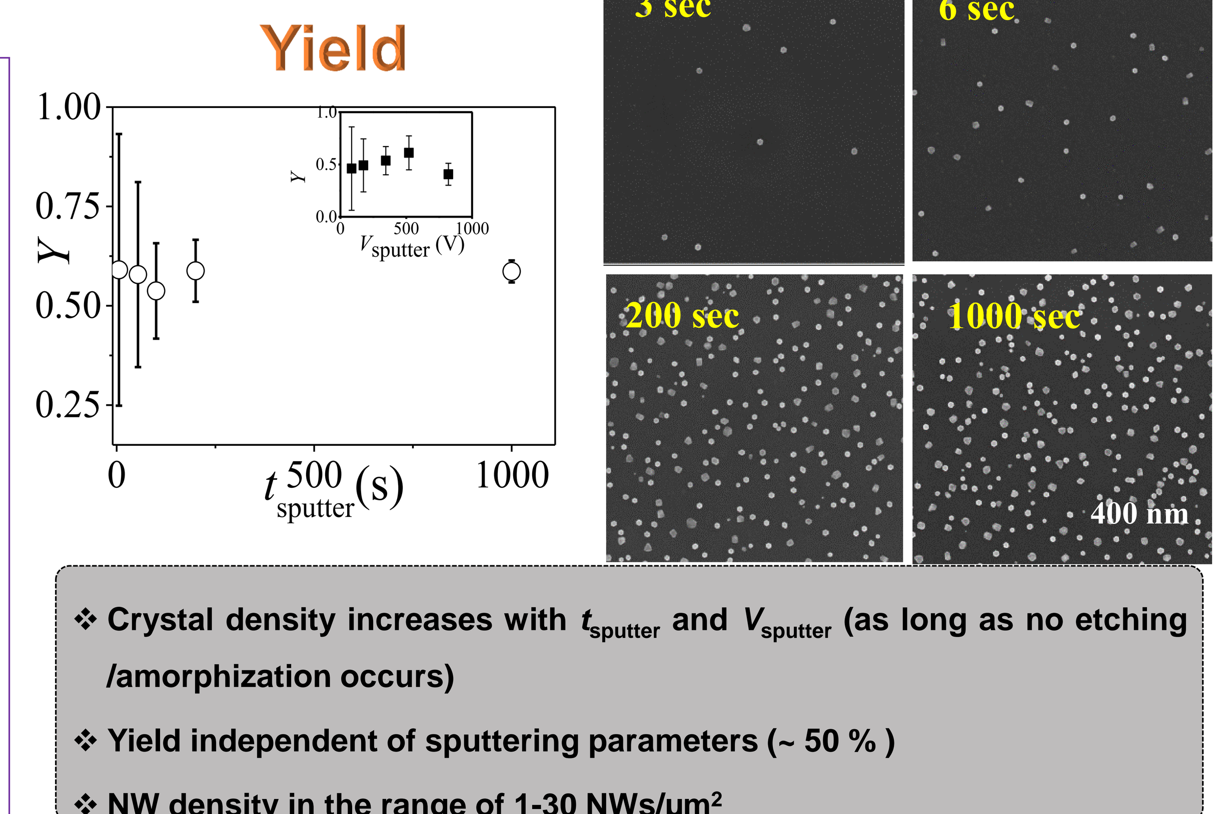
T_{ann}=790°C, t_{growth}=15 mins

- InAs crystal density decreases with T_{growth}
- High $V_{sputter}$ and $t_{sputter}$: low ΔE (Arrhenius plot)
- NW yield maximum (~0.5) at 400 °C

Role of substrate preparation







- Crystal density increases with $t_{sputter}$ and $V_{sputter}$ (as long as no etching /amorphization occurs)
- Yield independent of sputtering parameters (~ 50 %)
- NW density in the range of 1-30 NWs/µm²

Conclusions

- ✓ InAs crystals nucleate on sputtered Si(111) surfaces while no nucleation occurs on nonsputtered Si(111) surfaces.
- ✓ The InAs crystals nucleating on the sputtered silicon surfaces consist of InAs NWs and parasitic islands. 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.
- ✓ We assess the role of substrate preparation, showing that a range of InAs NW densities can be obtained by modifying in situ growth and ex situ sputtering parameters.

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 (2017). DOI: 10.1088/1361-6528/aa5252

U. P. Gomes, D. Ercolani, N. V. Sibirev, M. Gemmi, V. G. Dubrovskii, F. Beltram and L. Sorba, *Nanotechnology* **26**, 415604 (2015). DOI: 10.1088/0957-4484/26/41/415604

19th European Workshop on Molecular Beam Epitaxy
Korobitsyno, St. Petersburg, Russia
March 19 - 22, 2017