Motivation and Goals
Emerging interest in the self-assembly of nanoscale semiconductor structures (quantum dots or nanowires) is prompted by the anticipation of reaching the fundamental limits of silicon-based device miniaturization via lithographic techniques within a decade.

The ability to control the positioning of self-assembled epitaxial Ge island on Si surface will enable many potential applications, including quantum cellular automata (QCA) and incorporation of internal light sources in the photonic structures.

Reliable placement of Ge islands on specified locations is achieved by performing subtle surface modification of Si surface by low-dose focused ion beam (FIB) patterning.

The goal of this study is an investigation of mechanisms influencing the registration fidelity of Ge islands with the encoded sites on relatively large patterns (hundreds of square microns) with nanoscale separation between individual islands.

References:

Quantum Cellular Automata
Groups of four islands with an extra charge (or spin) present in two of them:

- Clusters of QDs close enough for charge tunnelling
- Electrostatic communication with the next cell

QCA wire:
- Information transmission

QCA based logic:
- Signal inversion

Goals:
- Nanoscale QD placement precision combined with large area fidelity
- Ability to functionalize the islands (add electronic or magnetic dopants)

Experimental Approach
Ultra High Vacuum (UHV) Transmission Electron Microscope (TEM) at IBM with integrated Focused Ion Beam (FIB) chamber and Ge deposition capability

- CVD+ Chemical Vapor Deposition Chamber pressure ~2x10^-8 Torr
- Controlled Ge nucleation mechanism
- Annealing: recrystallization and emergence of nano-topography
- Ge exposure: selective Ge island growth
- Surface damage, recovery, and control of nucleation

Analysis and Conclusions
Model: nucleation exclusion zone

- Another island can form here but not there
- Assumptions:
  - An island is equally likely to nucleate anywhere within a circle of radius \( R \) (FIB-encoded sites)
  - Nucleation does not occur outside of the these areas
  - Once an island nucleates, another one cannot nucleate closer than a distance \( R \) from it

Sample Model Calculations
- Strong exclusion zone effect (\( R \)): growth conditions
- Weak pattern resolution effect (\( R \))

Conclusions:
- Competition between nucleation sites (related to the growth conditions and kinetics) dominates as the factor limiting the fidelity of directed assembly
- The role of FIB resolution and accuracy is less significant in this growth regime

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