Self-Growth Mechanisms for Silicon and Germanium Nanostructures

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Nanostructures are proposed for many applications, from quantum computing to photonics. For their potential applications to be realized, building these structures must be done quickly or cheaply enough. In the case of silicon and germanium, "top-down" methods, such as lithography, have been proposed. But most forms of lithography are too coarse and too slow to be an ideal method in producing these structures, which can sometimes be as small as 2nm wide, and often well below 100nm. Thus, "bottom-up" methods seem to be more favorable due to their relative speed and resolution. Using molecular beam epitaxy, nanostructures in the sub-ten to hundred nanometer range can be built at a much higher efficiency. However, self-growth methods are comparatively more random in terms of the structure formation, and can have less size uniformity. This poster seeks to explore a couple of the nanostructure growth methods being researched today and the potential resolves offered in terms of growth uniformity.

Self-Assembly Mechanisms for Silicon and Germanium Nanostructures

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Abstract
In the case of silicon and germanium, "bottom-up" methods in growing nanostructures have been proposed. Using **molecular beam epitaxy**, nanostructures in the sub-ten to hundred nanometer range can be built.

Motivation
Nanostructures are proposed for many applications, from quantum computing to photonics. For their potential applications to be realized, building these structures must be done quickly or cheaply enough. In the case of silicon and germanium, "**top-down**" methods, such as **lithography**, have been proposed. But most forms of lithography are too **coarse** and too **slow** to be an ideal method in producing these structures, which can sometimes be as small as 2nm wide, and often well below 100nm. Thus, "**bottom-up**" methods seem to be more favorable due to their relative **speed** and **resolution**. However, self-growth methods are comparatively more **random** in terms of the structure formation, and can have less size uniformity. This poster seeks to explore a couple of the nanostructure growth methods being researched today and a potential resolve offered in terms of growth uniformity.

Concept
•3D shapes with Ge/Si Deposit on Si.
•Structure shape controlled by deposit amount, substrate temperature, deposit rate, shape of substrate.

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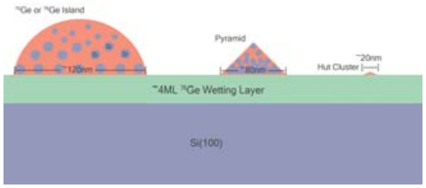
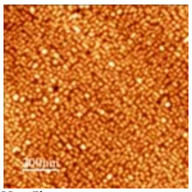
Ge Growth on Si(001)
•**Stranski-Krastanow** growth mode: 4ML ^{76}Ge wetting layer on Si(001).

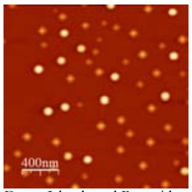
Germanium Structures Grown via S-K Method





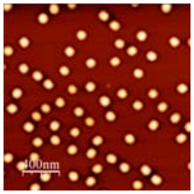
Hut Clusters

^{70}Ge/540° C/6.0ML



Dome Islands and Pyramids

^{70}Ge/680° C/4.0ML



Dome Islands
^{76}Ge/680° C/10.5ML

•Ge deposition through MBE at heater temp. = 1160° C and surface temp. = 500-800° C .
•Three shapes can be formed:
1. Hut clusters: oriented along [110] directions, high density.
2. Pyramids: caused by further deposition of Ge or higher temperature. Pyramid dots and dome dots can coexist.
3. Octagonal, Dome-Shaped Islands: further deposition of Ge or higher temperature.

•Bigger shapes have slower growth rates. This limits size of islands.
•Heated atoms move to islands with lower chemical potential (chemical potential = change in E of an island/change in # of particles).
•Chemical potential is lower for larger shapes → increasing temperature coarsens large shapes and diminishes smaller shapes.
•Increasing temperature → larger average size, less size distribution.
•Strain caused by the different lattice constants of the deposited material and the substrate. Strain affects chemical potential, and therefore affects shape of island.
•Temperature affects Si concentration. High temperatures cause diffusion from the Si substrate. At 600° C, top of Ge island is ~100% Ge, base is ~50%. At 700° C, top is ~80% Ge and bottom is ~40%.
•Concentration of Si depends on shape. Pyramid dots have more Si (~50% on the top, ~100% on the bottom). Decrease in Si from bottom to top is more linear than island.
•Deposition rate affects the size and density of deposits. Faster rates allow for more nucleations and form more, smaller dots. Slower rates form fewer, larger dots.
•Deposition amount influences island size and size uniformity. Greater deposition amounts increase average dot size and size distribution.
•Capping islands with Si helps preserve shape but increases Si diffusion.

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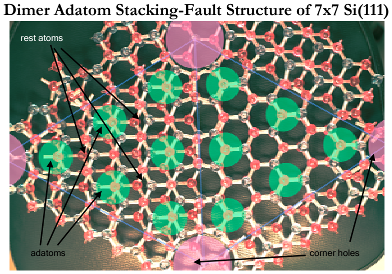
Ge and Si growth on Si(111)7x7 Surface

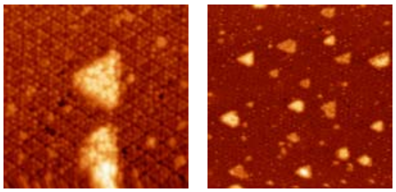
Dimer Adatom Stacking-Fault Structure of 7x7 Si(111)



•Si(111)7x7 reconstructed surface (DAS structure)
•dangling bonds(49→19)
•F half & U half

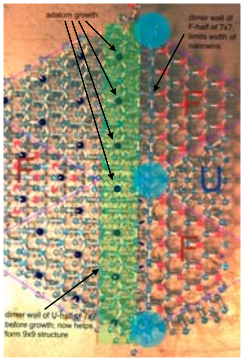
Ge on Si(111)flat surace

Flat Si(111) / ^{76}Ge @ 900° C, Sub @ RT, 90 min. 7/54BL / Post Annealed 10 min. @ 400° C

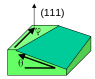


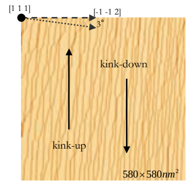
•Triangle islands surrounded by F halves. Magic sizes: 4, 9, 16, 25... half-unit-cells.

Si(111) 7x7 Surface Step Edge

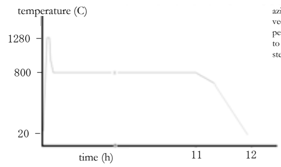


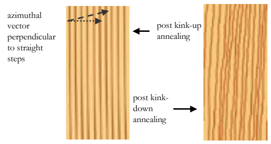
•If the surface has steps, deposited material tends to form at step edge.
•We can make long, kink-free steps.
•Step Lengthening:
1. ^{nat}Si (111) is polished and given a miscut (θ) of ~ 1° towards the [-1, -1, 2] direction and an azimuthal miscut (φ) of 3-4° . Azimuthal miscut determines surface kink formation.
2. Surface is flash cleaned up to 1280° C.
3. Surface is annealed at 800° C for 10 hours. Current in kink-up direction to bunch up the kinks.
4. Slow cool-down (~40min.) to room temperature to reduce defects.





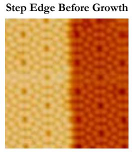
Rough graphical representation:



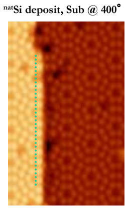


•After growth, single adatom row can form along step. Adatoms are spaced every 0.77nm. Wire is 0.67nm wide.
•Nanoclusters may form on upper step.
•Surface temperature during deposition determines the shapes formed. For Si;
300° C: nanowire and 2nm wide nanoclusters spaced every 2.7nm along upper step edges on the U halves.
400° C: nanowire row and incomplete 7x7 structures on edge.
~700° C: complete 7x7 structure extends edge.
•For Ge;
250° C: nanowire, nanoclusters on upper steps, and nanoclusters on terraces.
400° C: nanowire and incomplete 7x7 structures on edge.
~700° C: complete 7x7 structure extends edge.

Step Edge Before Growth

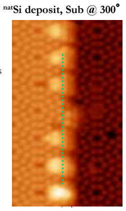


^{nat}Si deposit, Sub @ 400° C



Green line indicates position of U-half dimers at the step before deposition.

^{nat}Si deposit, Sub @ 300° C



^{76}Ge Deposit, Sub @ 300° C