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SWAMP Research Group

Formation of Encapsulated Si Quantum Dots via Rapid Ge Diffusion during High Temperature Oxidation of Si/SiGe Pillars

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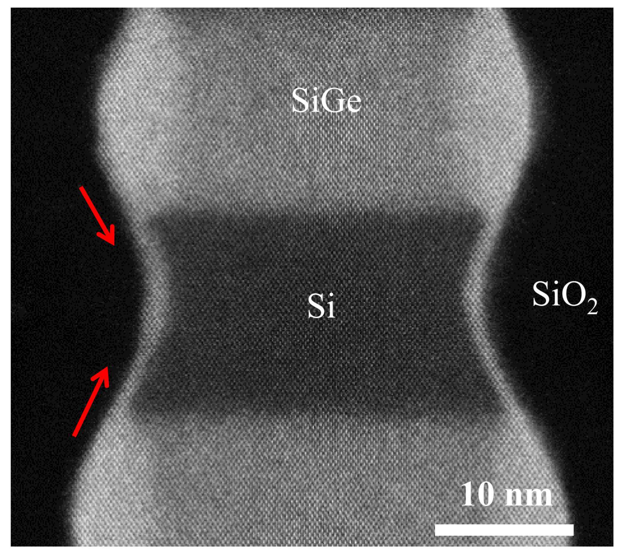
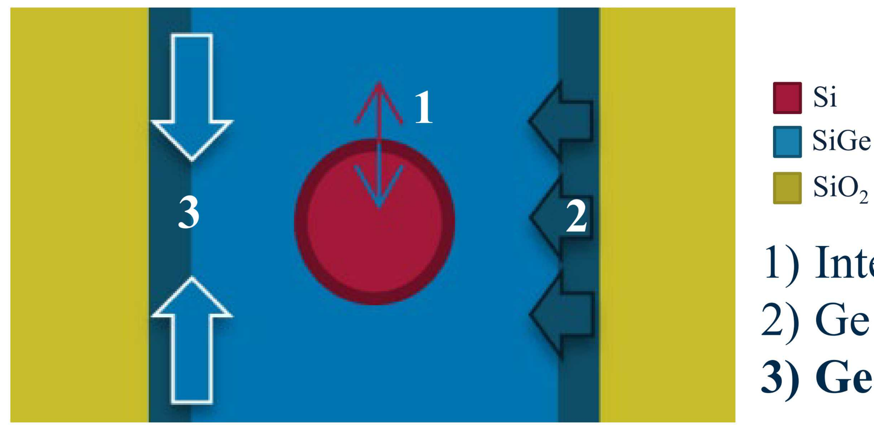
INTRODUCTION



HAADF STEM image of fin cross section after 5 min at 900˚C in dry O_2 with red arrows indicating unusual Ge diffusion along sidewall of fin [1].

The next generation of Si and SiGe are devices require scalable methods to manufacture quantum scale structures in the sub-10 nm regime. This work explores the use of a novel Ge diffusion process to form Si QDs encapsulated in SiGe. This Ge movement was first observed in fins, where Ge rapidly diffused along the sidewalls of oxidizing fins, encapsulating the Si layers and forming Si nanowires down to 2 nm in diameter [1]. The re are three key diffusion processes that must be well understood in order to control the final architecture of the nanostructures after oxidation: interdiffusion between SiGe and Si layers[2-4], Ge pileup in SiGe layers[5-7], and the rapid diffusion of Ge along the sidewalls of the oxidizing nanostructures.



1) Interdiffusion of Si and SiGe
2) Ge pileup as SiGe is oxidized
3) Ge diffusion along sidewalls of nanostructures

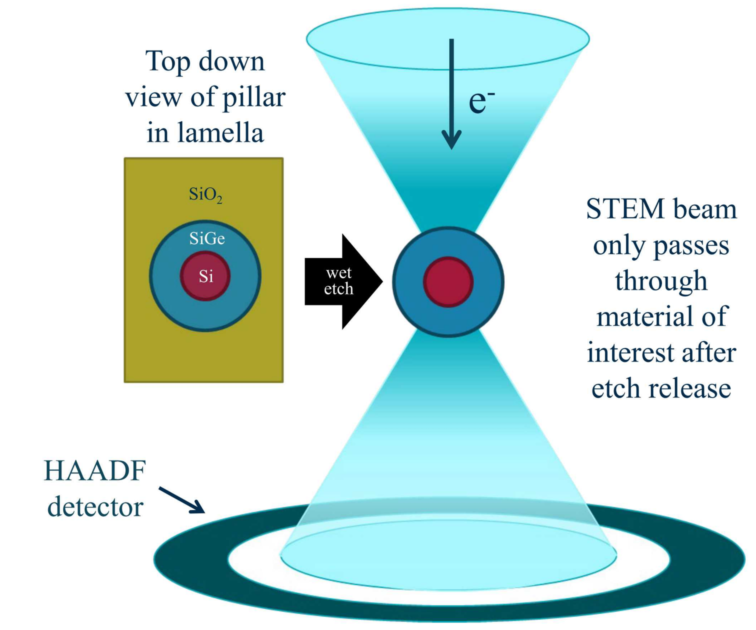
EXPERIMENTAL METHODS

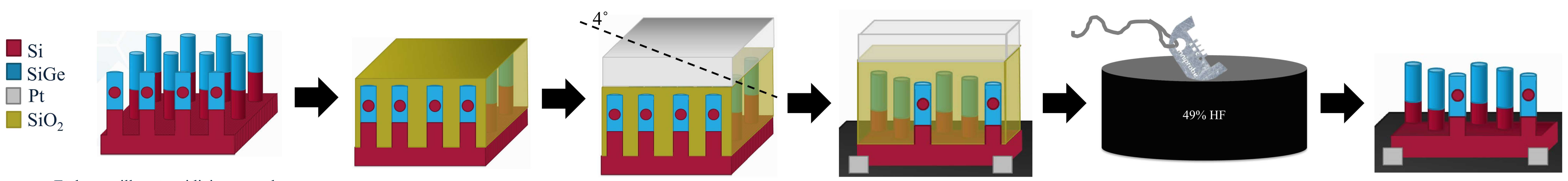
Fabrication of Si/SiGe Nanostructures

- Alternating layers of 15 nm thick Si and $Si_{0.7}Ge_{0.3}$ were grown on (100) Si wafers
- Arrays of Si/SiGe pillars were defined using e-beam lithography and plasma etching
- Pillars were then oxidized for a range of times at 900˚C in a conventional tube furnace with a dry O_2 ambient
- Cross sectional HAADF STEM and EDS were used to characterize pillars

S/TEM Specimen Preparation

- Challenges in viewing on-chip 3-D features with dimensions <100 nm
- Novel wet-etch method developed to facilitate clear imaging of 3-D nanostructures





Etch out pillars + oxidizing anneal
- RIE continuous Bosch etch
- Tube furnace flowing O_2 at 900 ˚C

Deposit additional ~200 nm of SiO_2

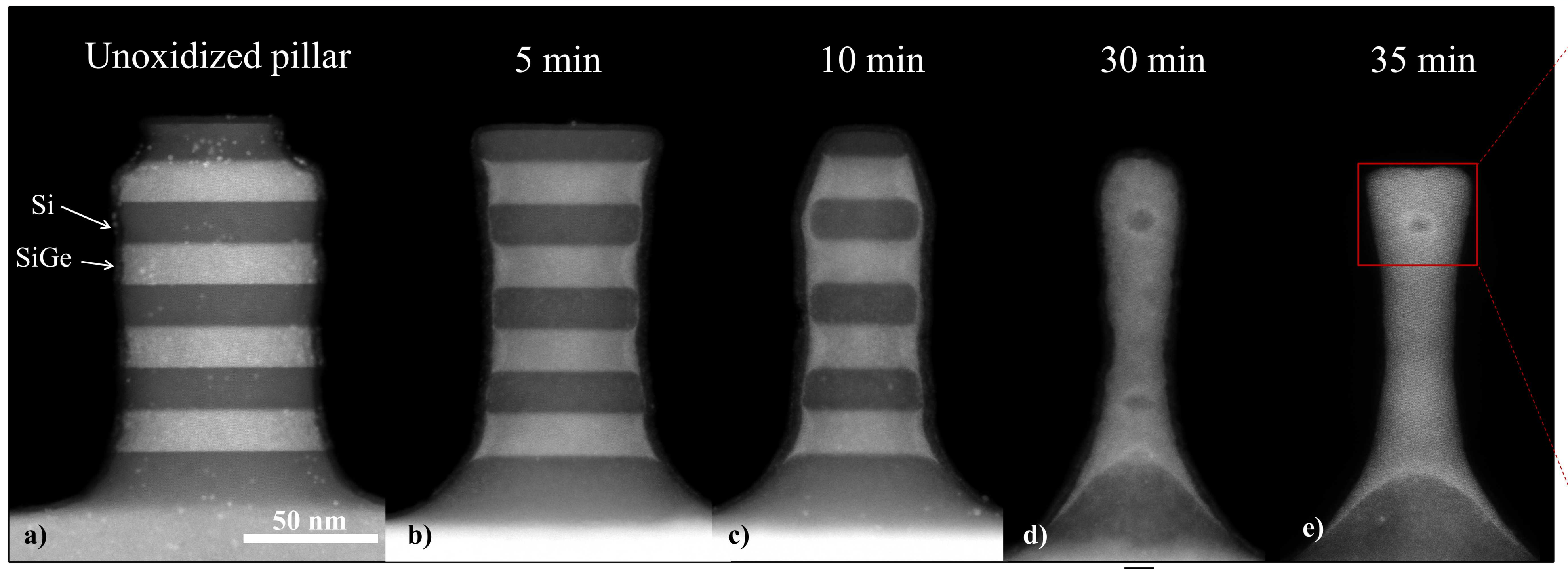
Deposit protective Pt strap in FIB, cut cross section at angle

Notch mount lamella to TEM grid and thin to 150-200 nm

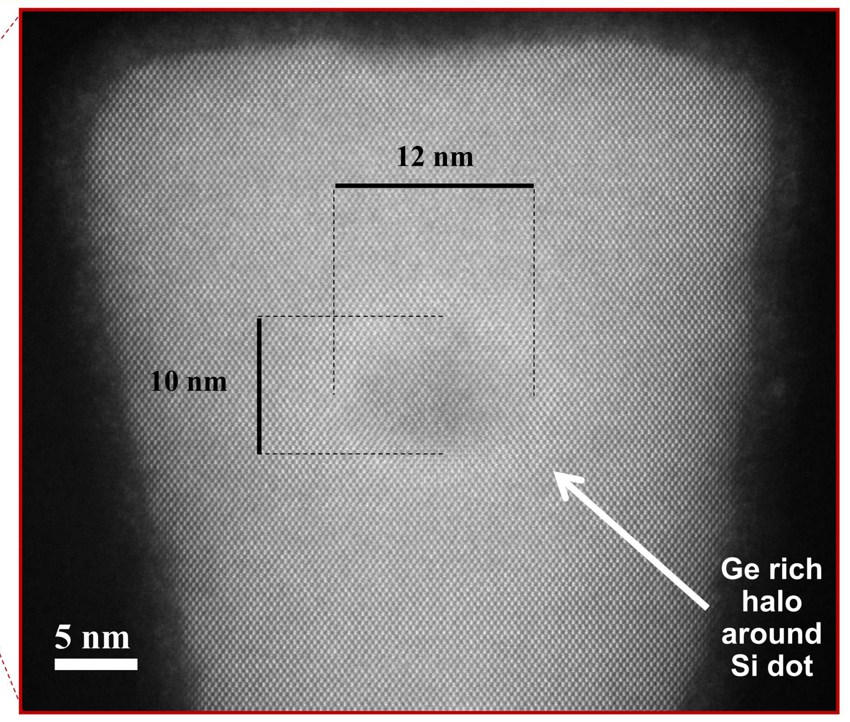
Dip TEM grid into BHF for 45 s
- Use teflon tape threaded through "O" to hold onto grid

Pillars are now freed of all surrounding material!

RESULTS AND ANALYSIS

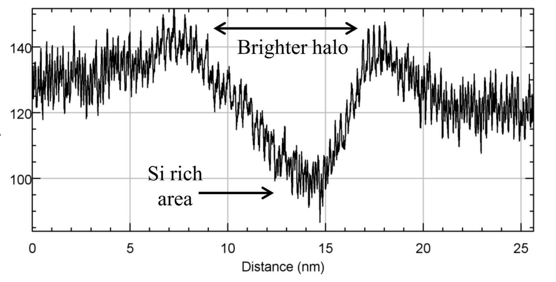


Ab-corrected HAADF STEM images of the Si/SiGe pillars after a) 0 minute oxidation b) 5 minute oxidation c) 10 minute oxidation d) 30 minute oxidation and e) 35 minute oxidation at 900 ˚C under dry O_2. Brighter grey corresponds to SiGe and darker grey corresponds to Si.



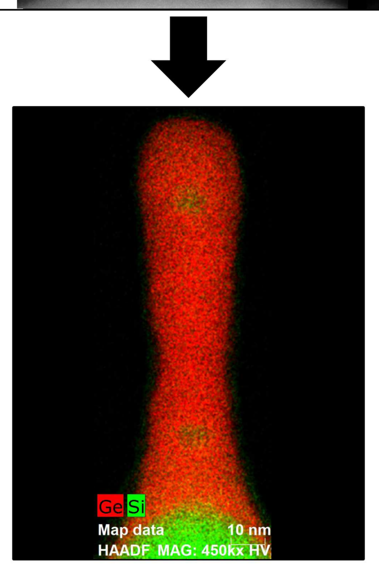
Formation of Ge Shell around Si QDs

- HAADF STEM reveals bright Ge righ halo surrounding Si QD
- Vertical gray value linescan shows peaks surrounding Si QD



Ge Diffusion along Sidewalls and Si Quantum Dot Formation

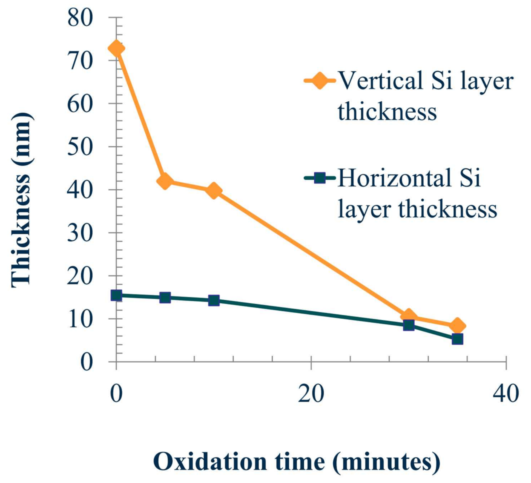
- The Si/SiGe pillars were oxidized for a range of times at 900˚C under dry O_2.
  - Enhanced Ge diffusion along sidewalls of pillars observed, eventually encapsulating Si layers to form Si discs during oxidation.
  - Continued oxidation of pillars forms Si dots surrounded by single crystal SiGe.
- EDS confirms Si rich dots encapsulated in SiGe

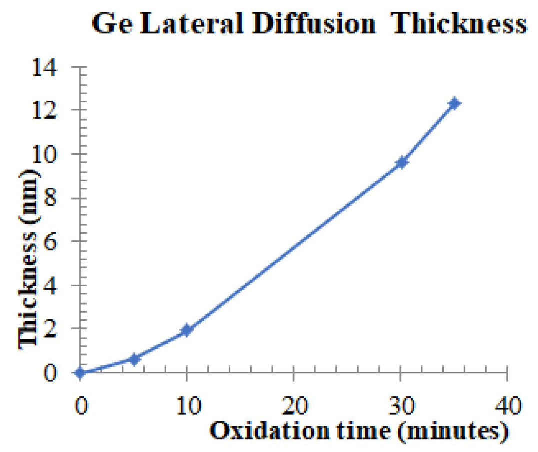


EDS of 35 minute oxidation, with Si shown in light green and Ge shown in red. Map confirms two green Si rich regions corresponding to dark regions in STEM.

Evolution of top Si QD

- Plotting the thickness of the top encapsulated Si layer reveals a steady decrease in size
- Plotting the Ge pileup alongside the Si layer shows steady increase in thickness





CONCLUSIONS

- This work extended the recently observed Ge diffusion in Si/SiGe fins to Si/SiGe pillars, succesfully encapsulating Si layers
- Demonstrated the formation of Si QDs with oxidation time controlled size surrounded by single crystal SiGe
- Unexpected Ge rich halo formation observed around the Si QDs at extended oxidation times
- This work enables the extension of the Ge diffusion process as a method to control architecture to other novel shapes such as toroids, rings, etc.

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