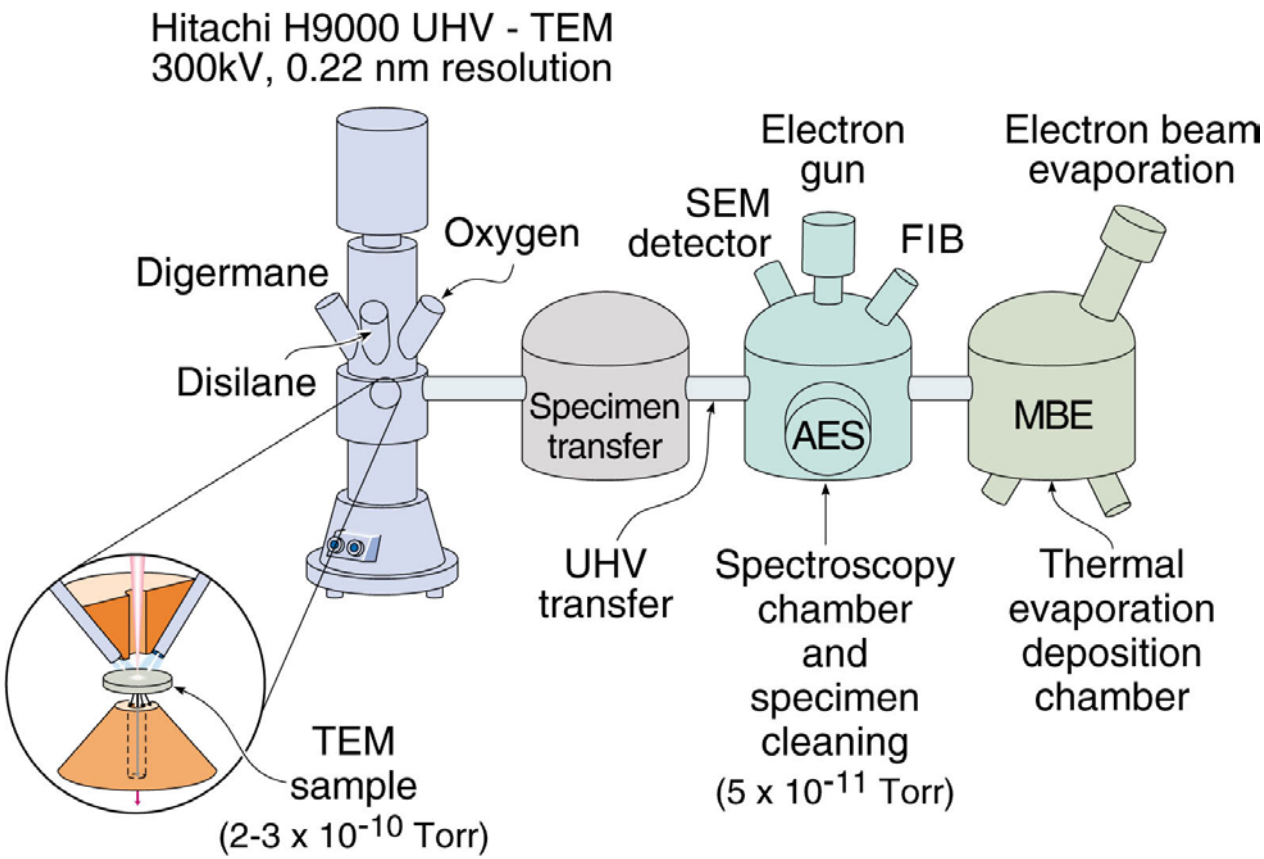
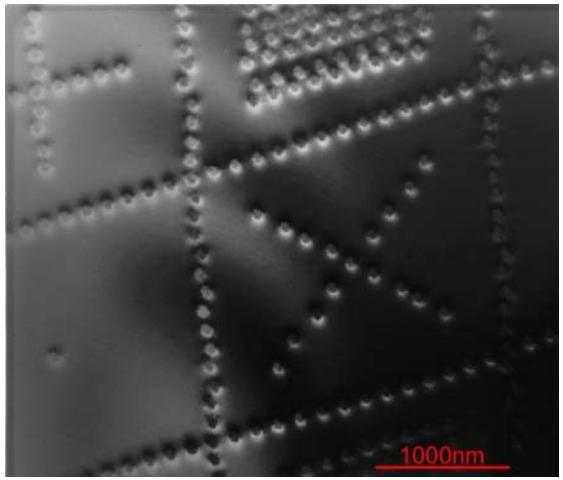
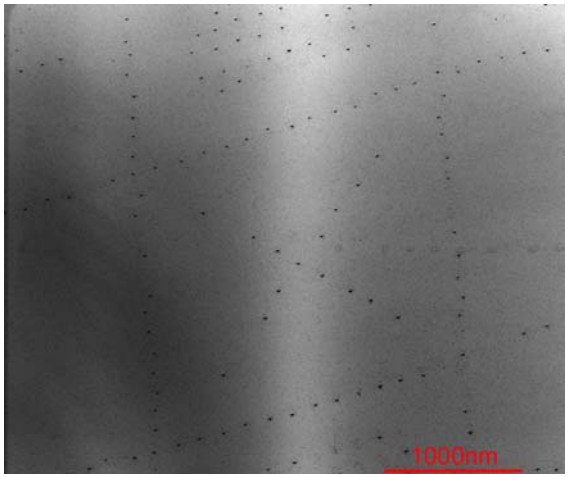
Nanoscale Assembly of Semiconductor Quantum-Scaled Heterostructures: Templating with Focused Ion Beams





FIB patterns written into Si substrate



Digermane Deposition at 650 C
20 nm Quantum Dots!

UHV-CVD-TEM-FIB

M. Kammler, R. Hull, UVA; F. Ross, R. Tromp, IBM

University of Virginia - MRSEC

Explanation

UHV-CVD-TEM-FIB = Ultra High Vacuum – Chemical Vapor Deposition – Transmission Electron Microscope with Focused Ion Beam

As part of MRSEC collaboration, IBM provides cost free access to system. UVa postdoc Martin Kammler based essentially full time at IBM Yorktown Heights. FIB attachment funded by MRSEC.

FIB patterning, annealing of ion implantation damage and CVD (digermane) deposition all in-situ in a unique ultra high vacuum TEM at IBM

Possible ways FIB patterning might affect nucleation of Ge QDs: strain, chemistry(implanted Ga acting as surfactant?), topography (sputtering), crystallography (beam induced damage

FIB writes pattern seeding sites at doses corresponding to removal of less than one monolayer of substrate (beam current 10 pA, dwell time 100 us / feature, so doses of about 6000 Ga ions into each 100 nm diameter feature)

Ge QDs form on the patterned sites! For these low doses, possible mechanisms are strain or surfactant effects from implanted Ga. We have also looked at higher does where topography does develop and patterning still occurs but with different mechanisms / features.

Undergraduate Research and Education within the Center for Nanoscopic Materials Design

The MRSEC Center for Nanoscopic Materials Design has hosted a total of 17 undergraduates during its first two summers of existence. These students have been involved in a wide range of nanotechnology-related research and education developments within the center.

University of Virginia - MRSEC

The Cast

a) Brandi Tregre, Xavier University of Louisiana: Multimedia Educational Materials on the Focused Ion Beam

b) Nadine Gergel, University of Virginia: E-BRITE Deposition for Fuel Cell Interconnects Using Directed Vapor Deposition

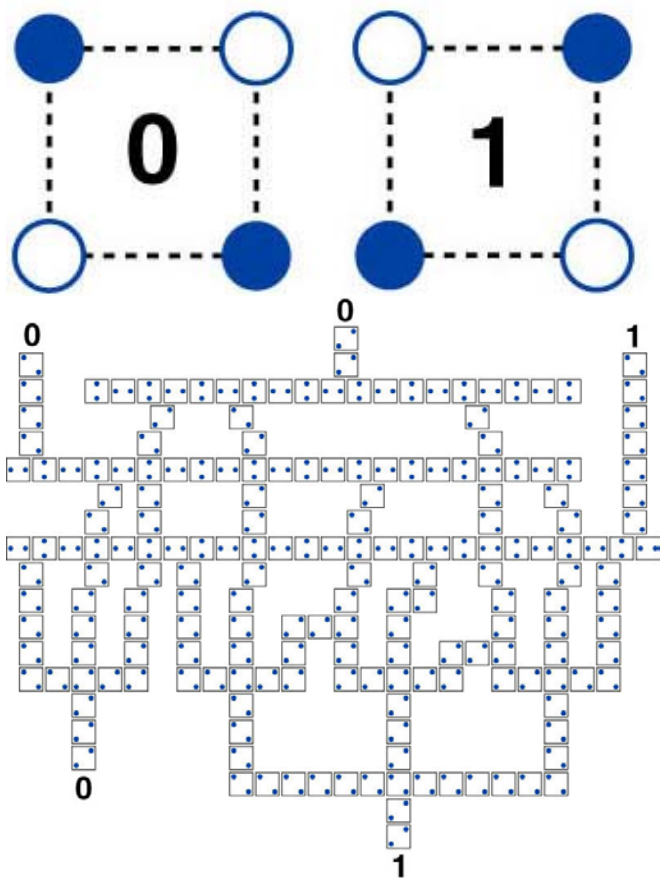
c) Carlos Caro, Columbia University: The Microstructural Evolution of a Binary Two-Phase System, Spinodal Decomposition

d) Esin Alice Isin, Technical University of Yildiz (Turkey): Characterization of Silicon and Germanium Nanoparticles

e) Elizabeth Logsdon, University of Virginia: Smooth Muscle Cell Differentiation and Response to Mechanical Stress

f) Edmer Martinez, University of Virginia: Multimedia Educational Visualization of Scanning Electron Microscopy

Quantum Cellular Automata



G. Snider, X. Luo, Notre Dame; R. Hull, S. Atha, UVa

- Exploration of new nanoelectronic architectures – electronics beyond the MOSFET?
- Collaborations between industry and academia: broader perspectives for graduate students
- Extrapolation of basic research to potential technological applications
- Multi-disciplinary research

Top: QCA bistable logic – filled circles represent quantum dots with extra electrons

Bottom: QCA adder circuit

The QCA concept is based upon two bistable states (arising from Coulomb repulsion) of extra electronic charges in a quantum dot quadruplet. These individual cells can also be aligned into more complex patterns where a change of state in one cell will trigger a change in the next, to allow digital logic functions to be implemented (the circuit shown on the slide is a full adder circuit). The potential advantages of such states are high packing densities (defined by the dot size and spacing in individual cells), the lack of need for multiple level interconnects (as signal lines can propagate through each other), and much lower power-delay products ($< 10^{-21}$ J) compared to conventional MOSFET microelectronics. However, the fabrication constraints stretch the capability of conventional techniques: state-of-the-art fabrication using electron beam lithography of Al/Al_2O_3 QCA structures has yielded only very simple structures of a few cells that operate at a maximum temperature (essentially defined by the difference in energy levels between the bistable states) of a few hundred millikelvin. If we can create structures of much smaller dimensions in semiconductor materials, much higher operating temperatures and practical nanoelectronic architectures become conceivable. We are exploring the opportunities for making prototype QCA devices with our collaborators at Notre Dame (Greg Snider), using combined electron beam and focused ion beam lithography contacting techniques onto Ge quantum dot cells.

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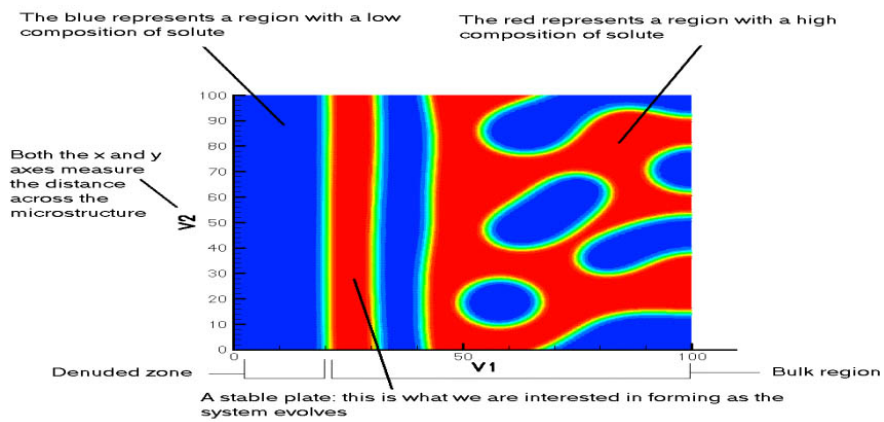
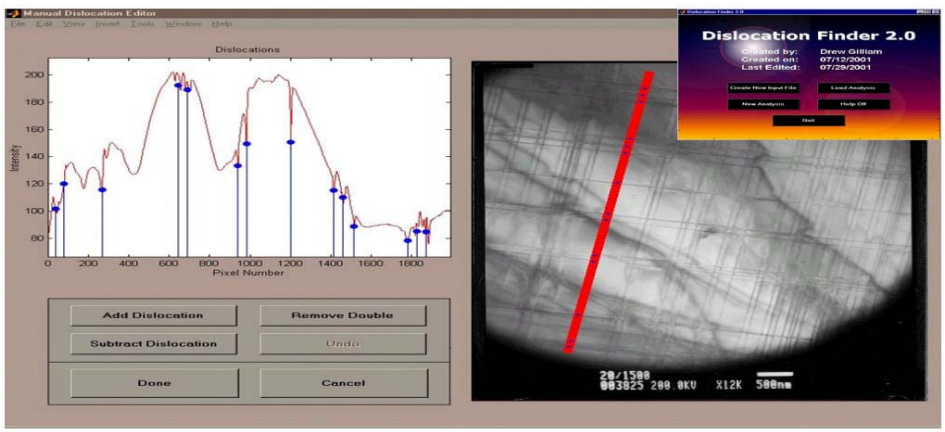
Diversity in Science

During its two summers of existence, the undergraduate program of the Center for Nanoscopic Materials Design has engaged six women and five underrepresented minorities, increasing participation of these groups in cutting edge science and technology.



a)



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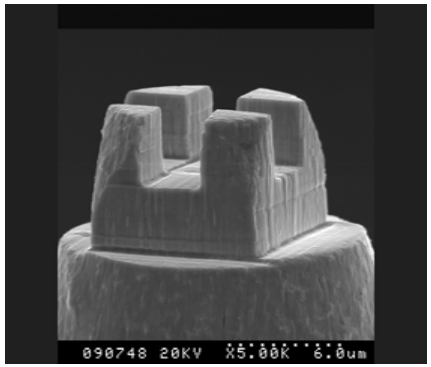
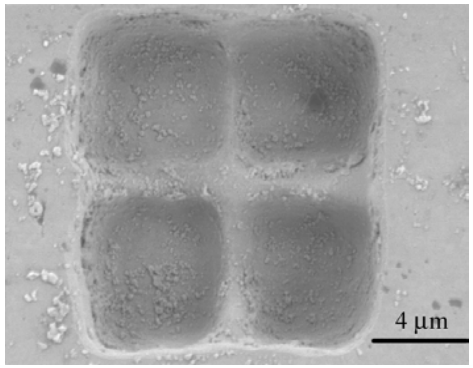
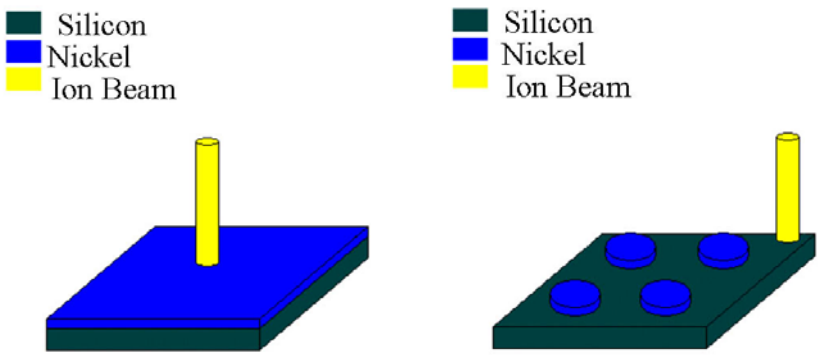




c)



d)

a) Study of the microstructural evolution of a binary two-phase system, spinodal decomposition, using time-dependent Cahn-Hilliard and phase-field evolution equations (Carlos Caro, UVA MRSEC undergraduate program, summer 2001)

b) Quantification of dislocation regularity in epitaxial GeSi layers on Si substrates (Andrew Gilliam, UVA MRSEC undergraduate program, summer 2001)

c) Electrochemical micromachining using shaped tungsten tips and ten nanosecond electrical pulses (Lan Nguyen, UVA MRSEC undergraduate program, summer 2002)

d) A focused ion beam can be utilized to etch away nickel from a silicon surface, leaving nanomagnetic regions that can be investigated as elements in a magnetic quantum cellular automata array (Justin Thorpe, UVA MRSEC undergraduate program, summer 2002).