"Bottom-up" meets "top-down": Self-assembly to direct manipulation of nanostructures on length scales from atoms to microns

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

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Problem

State-of-the-art instrumentation is needed for fabrication and characterization of engineered nanostructures on surfaces.

Combining low-energy electron microscopy (LEEM) and scanning tunneling microscopy (STM) allows direct imaging of surface features on length scales from atoms to microns.

- Find templates for 3D nanostructures
- Investigate "bottom-up" generation of surface nanostructures

Novel nano-manipulator inside of a scanning electron microscope (SEM) provides "top-down" construction & characterization of unique nanostructures.

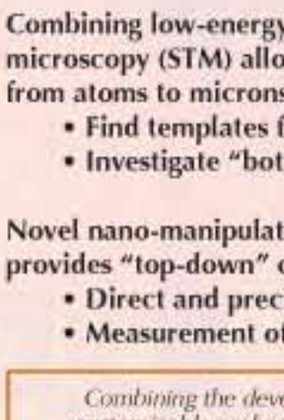
- Direct and precise control over placement of individual nanostructures
- Measurement of nanostructure electronic properties

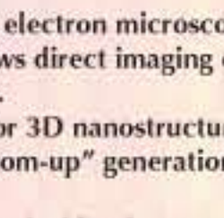
Combining the development of a nanomanipulation framework with an expertise in customizable probes, in an environment where new nanostructures and materials are constantly being discovered, allows us an exciting opportunity for impact.

Results

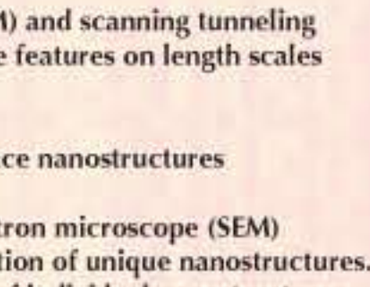
Si adatoms on Au/Si(111) surface diffuse by a new defect-mediated process.

Si atoms atop the Au/Si(111) surface diffuse along the 1D surface rows.

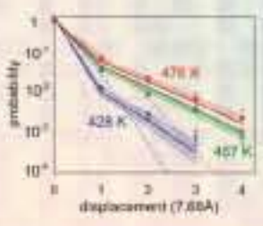


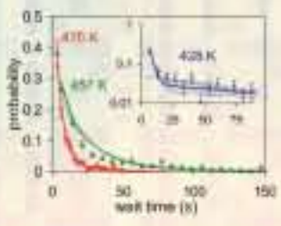


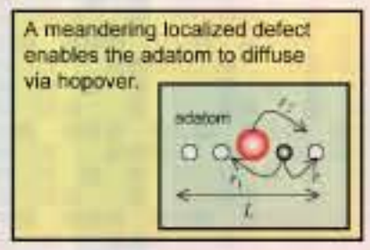
Distinctive features of the statistics of motion – a non-binomial jump distribution, a nonexponential wait-time distribution, and direction and time correlations — imply 1D hopover diffusion.



Temperature dependence yields the activation barrier.

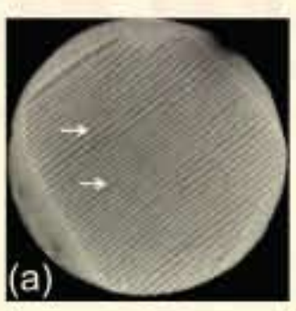






Approach

"Self-assembly" and "directed-assembly" is used to form two-dimensional nanostructure patterns.



5μm LEEM image of self-assembled stripe pattern on heavily B-doped Si(001)

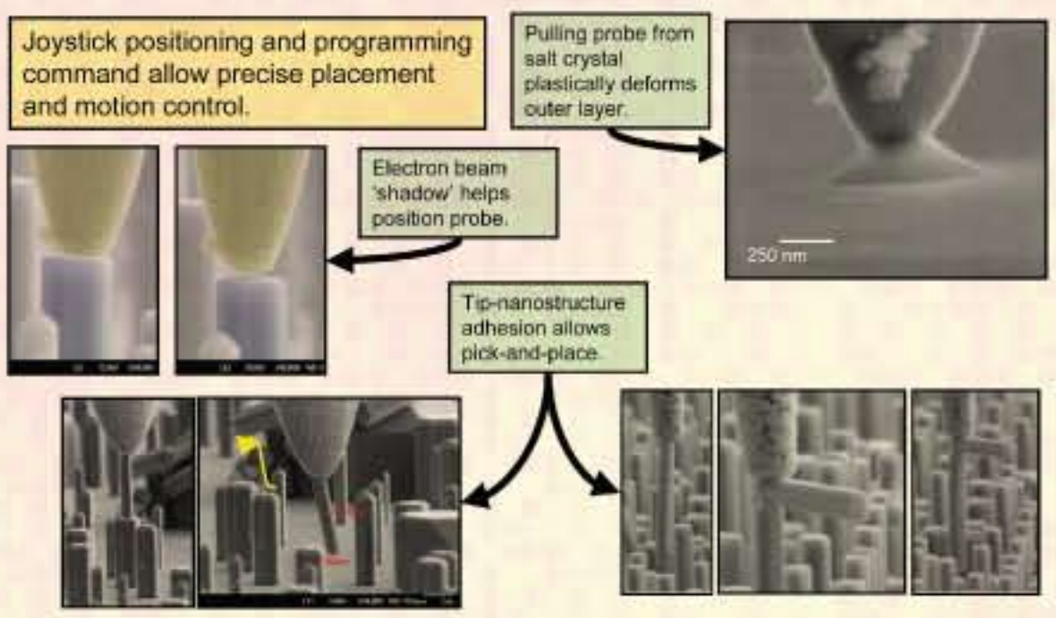
- Stripe patterns self-assemble on the Si(001) surface due to the presence of boron.
- Patterns form over very large distances (tens of microns).
- Patterns can be stabilized to room temperature to serve as templates for nanowire structures.

- Pit formation using focused-ion beam (FIB) allows directed-assembly of InAs quantum dots.
- Ion irradiation reduces the critical thickness for the formation of quantum dots.
- Pits are preferential nucleation sites for quantum dots.

AFM image of InAs quantum dots

Approach

Nanomanipulator in an SEM allows electrical characterization and direct manipulation of nanostructures



Advantage: complete flexibility in hardware, software, and data acquisition

Impact

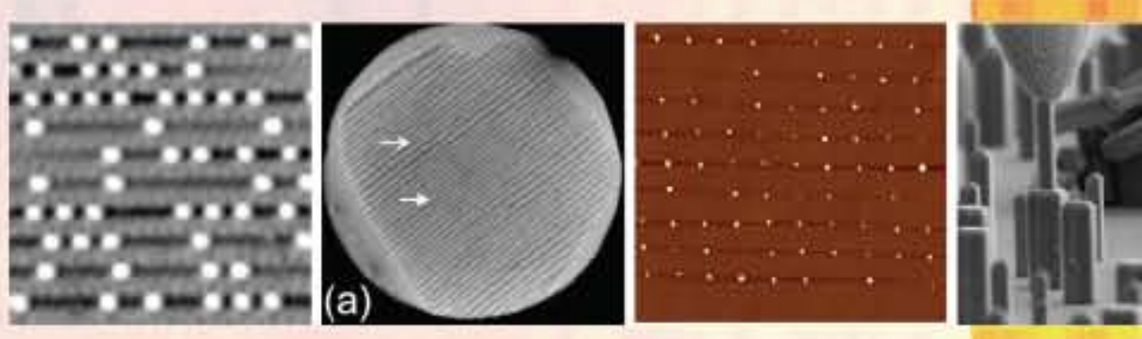
A successful program in nanoscience…

… relies on the innovative discovery of novel nanostructures and their characterization.

- Discover and understand surface self-assembly processes using LEEM and STM.
- Use the nanomanipulator to integrate small nanostructures with larger lithographically defined electronic or MEMS systems via direct manipulation for the creation of new functionality.
- Provide the necessary means to measure nanostructure properties.

… impacts the broader community.

- The inclusion of our instruments in the CINT portfolio greatly broadens the scope for collaborative impact.
- We offer new educational opportunities for students through UW-Madison, the University of Michigan, and the summer NINE program.



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