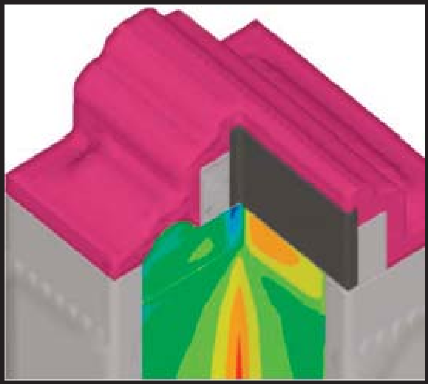
Nanoscale Strain Metrology

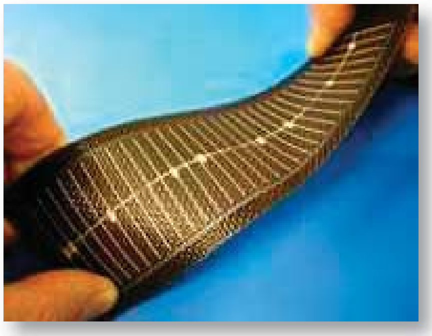
Objective

Our goal is to enable the manufacture of active nanodevices by developing novel methods to measure and model strain with nanoscale resolution. Strain is a pervasive issue for nanodevices due to their relatively large interface-to volume ratios. In addition, local strain is intentionally introduced in many nanodevices to enhance performance, pushing these structures near the brink of failure. Product optimization hinges on accurate prediction and measurement of strain at unprecedented length scales.



Impact and Customers

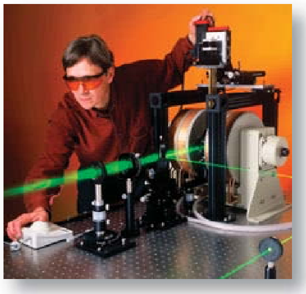
- Semiconductor products represent a global market of more than $250 billion per year. To enable future IC performance improvements, manufacturers will increasingly rely on strain engineering, because of the fundamental limits of conventional geometric scaling. It is predicted that all future-generation CMOS devices will be strain-engineered.



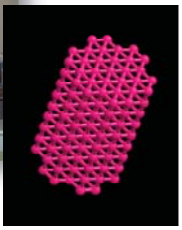
- Accurate and CPU-efficient models that estimate nanoscale strain distributions will be essential for future device development. Validated multiscale models will enable intelligent design and reduce the need for iterative empirical tests.

- Strain is one of the most important factors affecting device performance, but it is also the most difficult to measure (International Technology Roadmap for Semiconductors, 2007). Novel tools for measuring strain will enable more efficient process development, more reliable devices, and improved inspection during manufacture.

Approach



We are developing a suite of complementary tools for mapping strain at the nanoscale. These include high-resolution transmission electron microscopy (HRTEM), electron back-scatter diffraction (EBSD), tip-enhanced Raman spectroscopy (TERS), and surface-enhanced Brillouin light scattering (BLS). Each technique has advantages in terms of achievable resolution, ease and extent of specimen preparation, and depth sensitivity. For example, BLS has the potential to provide unique nanoscale information as a function of depth, but has low lateral spatial resolution. Conversely, EBSD and TERS offer nanoscale lateral resolution, but only probe material near the surface.



When coupled with our multiscale Green's function modeling approach for predicting strain fields, these methods will collectively enable the design and characterization of nanoscale devices with high performance and reliability. We are demonstrating our methods on a variety of strained systems, including Ge/Si, AlGaAs/GaAs, and InGaN/GaN.

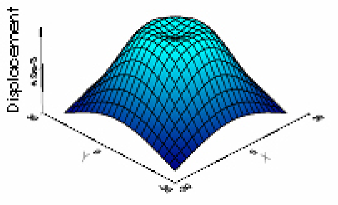
Accomplishments

This project is in its first year and has already produced results supporting our integrated approach that couples experimental methods with theory.

Multiscale Modeling

Modeling of three-dimensional atomic positions and lattice distortions over micrometer-scale volumes can be a difficult task with conventional approaches, due to impractical computation times. We have developed multiscale Green's function (MSGF) methods to attack this problem. To properly treat nonlinear elastic effects in severely distorted material, a method has been developed for iteratively linking MSGF calculations to molecular dynamics calculations in highly distorted regions of nanostructures.

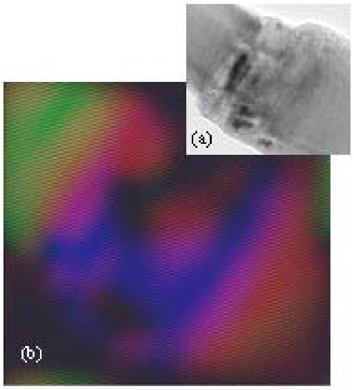
The figure below shows an example of a calculation of surface displacements arising from a buried 7 nm diameter Ge quantum dot in a Si lattice.



Surface displacements in silicon.

Electron Microscopy

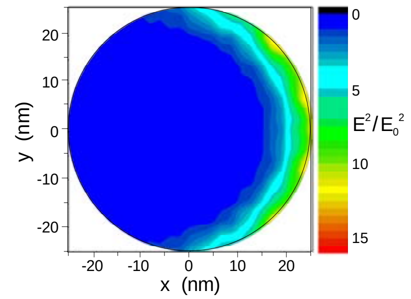
High-resolution transmission electron microscopy (HRTEM) will serve as a reference for validating the MSGF models, EBSD, and the optical measurement techniques in this project. We have demonstrated a new HRTEM method for mapping lattice strains. The figure below shows a pair of images from a nanowire composed of GaN with an $In_xGa_{1-x}N$ quantum well. The grayscale image in (a) shows a high-resolution lattice image of the structure. A fast-Fourier-transform (FFT) analysis was performed, and selected sections of the resulting reciprocal space were used to reconstruct the image in (b), where red denotes a 0.266 nm lattice spacing, green denotes 0.258 nm, and blue denotes 0.272 nm. This mapping method reveals distinct variations in strain as one traverses the $In_xGa_{1-x}N$ quantum well.



Lattice spacing map in a nanowire.

Brillouin Light Scattering

Brillouin light scattering (BLS) offers the potential for determining variations in strain and stiffness versus depth in blanket films, such as strained-layer pads incorporated into IC wafers. However, the range of detectable phonon wavenumbers in BLS must be increased by an order of magnitude to enable the nanoscale depth resolution needed to characterize buried interfaces. To achieve this, we are implementing a surface-plasmon enhancement method that involves bringing an array of gold nanodisks in contact with the specimen. The figure below shows a calculation of enhanced electric fields associated with such an array. The nanoscale variations in electric field that appear in this figure will lead to inelastic (Brillouin) scattering from phonons with correspondingly high wavenumbers, boosting the output signal. During the past year, we demonstrated enhanced BLS peak heights using nanopatterned structures to promote surface plasmon coupling. This work provides the first experimental evidence that BLS output can be sufficiently enhanced to enable detection of sub-surface strains.



Electric field intensities on a nanodisk.

Learn More

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Publications

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