Thermal Engineering of Electronic Micro and Nanostructures

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Abstract

Heat transfer influences the performance and reliability of a variety of electronic micro and nanostructures, ranging from nanopillar transistors and high-density thermomechanical data storage devices to microchannel cooling modules for VLSI. This seminar provides an overview of related research activities at Stanford with a focus on new physical modeling and measurements:

Nanoscale Heat & Mass Transport in Polymer Data Storage at 1 Terabit in^{-2}: Heat and mass transport govern the writing and reading capabilities of thermomechanical data storage, which forms and detects sub-30 nm doformations in an organic layer using AFM technology (1). Figure 1 illustrates the writing and read-back processes. Modeling and 1D grating relaxation measurements illustrate size effects on the polymer effective viscosity. Modeling of sub-continuum conduction and deformation processes for the cantilever and the polymer film relate the bit size and time required for bit writing to the applied electrical current pulse and the force.

Phonon Transport in Semiconductor Devices: Electron-phonon scattering within sub-100-nm regions in silicon transistors induces an extreme departure from equilibrium within the phonon system and impedes heat removal (2). The thermal impedance is measured and simulated using multiple approaches including the phonon Boltzmann transport equation, a coupled Monte Carlo electron-phonon transport simulation, and a compact thermal resistance model (3). Studies of phonon transport in silicon films (4,5) provide details of phonon interactions with boundaries and impurities, as indicated in Fig. 2. The new model is integrated with device simulators for electrothermal reliability engineering, and indicates a dramatic increase in device temperature as transistor channel lengths scale towards the 50 nm node.

Near-Field IR Imaging with a Microfabricated Solid Immersion Lens: This study achieves high-throughput sub-micrometer IR imaging with a microfabricated solid immersion lens (6). The integrated lens and cantilever are fabricated from single-crystal silicon and scanned in contact with a sample to obtain an image. The system achieves a focused spot size of $\lambda/5$ and an effective numerical aperture of 2.5 with $\lambda=9.3$ µm light. The device is promising for high-resolution optical thermometry, for biomolecule spectroscopy, and for laser processing.

Bubble Nucleation, Stability, and Growth in Sub-100 μm Microchannel Boiling: On the border between micro- and nanoscale engineering is the study of nucleation and two-phase flow in silicon channels with hydraulic diameter below 50 micrometers (7,8). Wall temperature measurements using integrated thermistors and microscopy (see Fig. 3) investigate the coupling between heat transfer coefficient, surface-tension induced pressure drop, and channel wall thermal capacitance in fluctuations of the liquid-vapor interface. These channels are targeted for application in 2D and 3D cooling modules for VLSI circuits, as well as for integration within 3D circuits, which combine digital, RF, and photonic functionality, containing integrated cooling channels.

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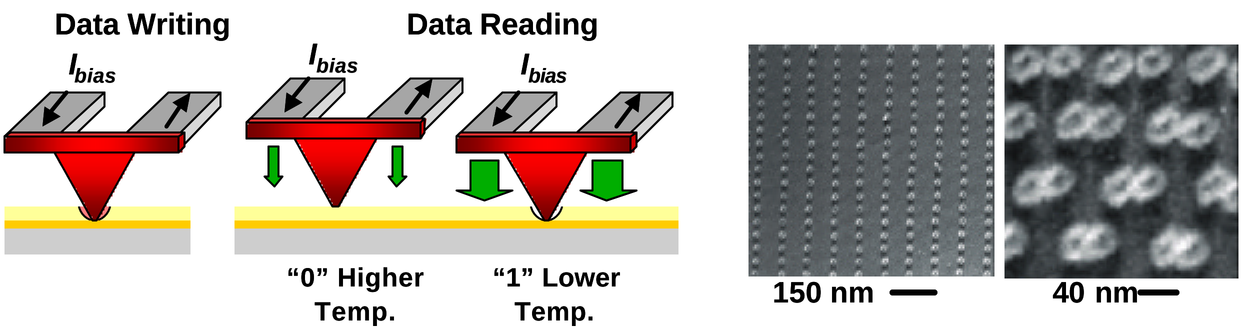

Fig. 1. Schematic of the thermomechanical data storage process and images of the resulting data bits (1).

Fig. 2 Phonon scattering mechanisms in thin-film silicon transistors (2).

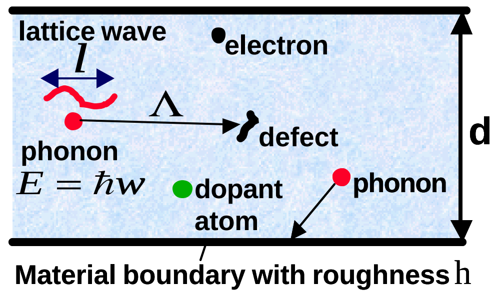

Fig. 3. Optical images of vapor and liquid domains for boiling convection in channels (7,8).