

Maryland NIRT Highlight:

Nanostructures are Dynamic

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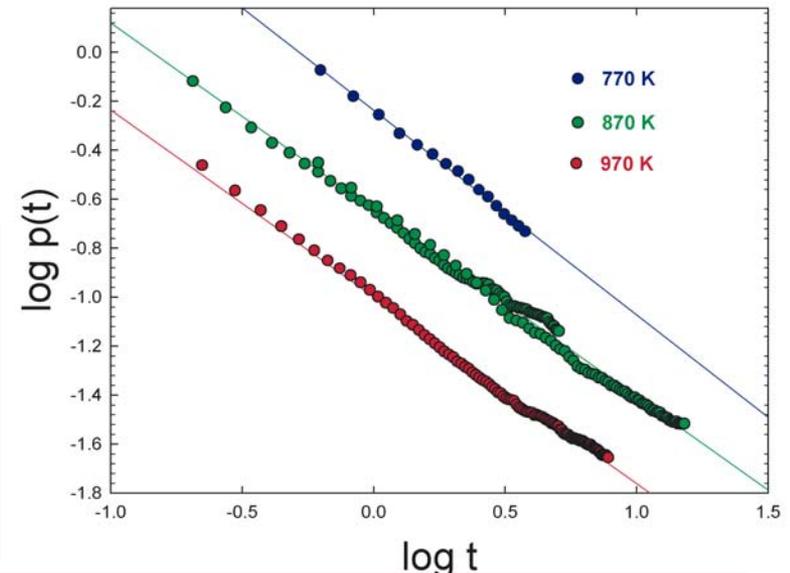
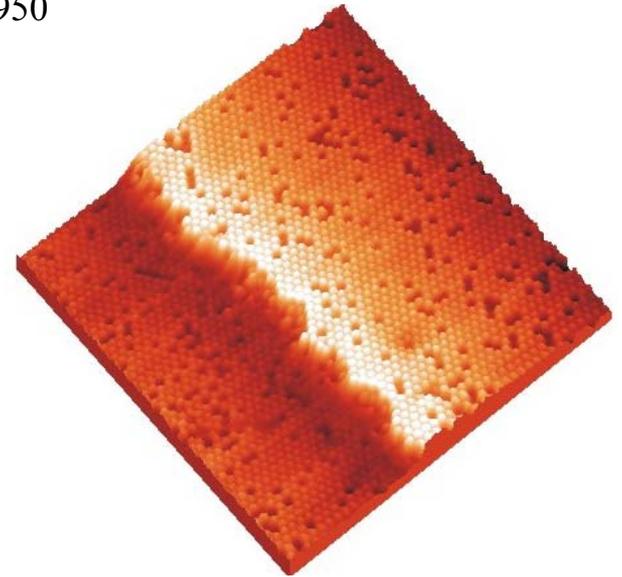
Thermal energy not only causes lattice vibrations, it can also cause atoms to diffuse (move around randomly). On nanostructures, when even one atom moves, it can change all the properties of the nanostructure. Is this good or bad? Well that's a new question peculiar to nanostructures, so we have start from the beginning and figure it out.

Amazingly, we can directly observe the thermal diffusion effects at the surface of a nanostructure using scanned probe microscopy. In a time-freeze image we can see that a thermal motion keeps the nanoscale edge from being straight. If we then observe the structure dynamically, measuring over and over again at different times), the edges move around due to diffusion, and we can measure the time dependence.

How Random?

Top right: Time-freeze image of a nanoscale edge. The random wandering at the edge results from thermal diffusion.

Bottom right: Although the atomic scale edge of a nanostructure follows the random processes of diffusion - some aspects of its behavior are predictable. The probability that the edge reaches a particular place in a time interval t follows a well defined law.



We are interested in atoms moving around on the surface because electronic transport processes are affected by electronic reflections at the surface and at interfaces. For nano electronic structures this may become a significant contributor to the overall behavior (e.g. when the surface to bulk ratio is high). This may represent a fundamental limit to nanoelectronic behavior, with thermal motion just creating noise. Alternatively, one can imagine using this behavior to create novel properties. One possible idea is to trigger changes in thermal motion by a chemical or electrical step function that will abruptly change the diffusional behavior and thus the transport behavior. (most extreme would be to induce the merger of two adjacent conductors, or induce a breaking of a conducting wire, thus have a true one-way switch) Of course in real life we don't want our electronic devices depending on an apparently random process like diffusion, we want control and predictability. So understanding at what level we could predict the evolution of electronic behavior (as governed by diffusional behavior) in nanostructures is quite an interesting question. The answer is rather surprising - the random walk behavior contains more predictability than we would have expected. So if we consider a single step edge fluctuation - we can predict the probability that it will take a certain time for it to fluctuate to a chosen new position (a "cliff," which might be the edge of another structure to which it will make contact). The specific prediction for a single step is that the probability $p(t)$ of NOT returning to the chosen point in time t goes as $p(t) \sim t^{-(\theta)}$. θ is 0.75 in the illustration above.

Ongoing work is two-fold. 1) measure electron transport at the same time as measuring structure fluctuations 2) learn how to extend the "predictability" calculation to structures composed of groups of steps (the edges of all crystalline nanostructures can appropriately be defined this way).

References:

1. D.B. Dougherty, O. Bondarchuk, M. Degawa, and E.D. Williams, *Persistence Exponents for Step Edge Diffusion*, Surface Science **527** L213-8, 2003.
2. O. Bondarchuk, D.B. Dougherty, M. Degawa, M. Constantin, C. Dasgupta, and S. Das Sarma, *Correlation Time for Step Structural Fluctuations*, submitted, 2004.
3. E.D. Williams, *Nanoscale Structures: Lability, Length Scales, and Fluctuations*, Materials Research Society Bulletin in press, 2004.
4. D.B. Dougherty, O. Bondarchuk, W.C. Cullen, M. Constantin, C. Dasgupta, and S. Das Sarma, *Sampling Time Effects for Persistence and Survival in Step Structural Fluctuations*, in preparation, 2004

Maryland NIRT Education and Outreach Activities

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Educational activities:

To date 1 undergraduate, 6 grad students, and 2 post-docs have received training an interdisciplinary nanoscience including chemistry, physics, and materials science. Undergraduates and graduate students participate in a weekly journal club, and graduate students present their ongoing research to their peers once a semester.



One of the co-PI's (left) supervises a competition at a home-schooling enrichment lesson on electricity. Pre-teen girls are seeing who can light the most bulbs using a bicycle generator.



Graduate student Tosh Degawa shows a scanned probe cantilever to a Northwestern High School team researching nanotechnology for a school newspaper article. This activity is part of a popular science writing class sponsored by the UMD-NSF MRSEC.

Outreach activities:

Our NIRT graduate students are also involved in public outreach activities, which are designed to provide them with life skills in communicating the excitement of scientific research to the general public. Each student participates in 20 hours per year of activities that involve one-on-one contact with K-12 students from the local school systems. The activities are coordinated by the staff of the UMD NSF-MRSEC, who also provide the students with training in effective outreach skills.