Posed on the perfect moment between wakefulness and sleep, an imminent slumberer does not know the exact moment that dreams commence. It is the conundrum of altered states: How, and where, do boundaries change so that a conscious mind is suddenly disabled, leaving the body immobile for hours, yet flooding the restless subconscious with vibrant image and sound?

Old Dominion University professor of electrical and computer engineering Hani Elsayed-Ali studies neither beds nor dreams. But he asks a related question: when is a solid no longer solid and instead something else? Or, more precisely, at the moment of transition from solid to liquid what happens to the topmost layer of atoms on a material’s surface?

Fascination with the ultrafast began for Elsayed-Ali in 1985, when repeated readings of advances in the field spurred his professional interest. He says ultrafast studies are of more than passing theoretical curiosity. Transitions in nature occur at very high speeds; such rapid changes are particularly germane to the making of modern-day microcomponents.

“The main thing is understanding the melting phase transition, the point at which a solid becomes a liquid,” he explains. “Especially when you deal with microelectronics manufacturing, it’s very important to understand that transition. The whole microprocessor manufacturing industry is based on layering. The cleaner you can make an interface — the better you understand what’s happening to atoms at the surface, which don’t have the same properties as those in the bulk — the more stable the devices you produce.”

Two years ago, Elsayed-Ali discovered a property known as “smoothing by superheating.” He irradiated the outermost layer of a metallic crystal for 90 trillionths of a second with laser light, producing a virtually defect-free, highly smooth surface. While the extreme temperature of the laser pushed the material’s surface to just above the melting point, its extraordinarily short duration didn’t induce melting, but rather a semi-molten state. A technique known as time-resolved electron diffraction revealed that although the material’s atoms were vibrating at an amplitude greater than that normally seen in solids, the material did not liquefy.

“This kind of superheating produces a kind of metastable state,” Elsayed-Ali says. “It’s somewhere between the molten and the solid states, although it remains to our probing technique as a solid. Obviously if you’re able to smooth the surface of microchip wafers like what we observed, such a technique will be very valuable.”

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**Surface Science Leading The Way To Mightier Microelectronics**

By James Schultz

“The main thing is to understand ... the point at which a solid becomes a liquid.”

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Old Dominion University’s QUEST 5
Continued breakthroughs in microelectronics may depend on advances in the branch of physics known as surface science, which concerns the behaviors of only the top few atomic layers of a given material. What holds at the top may not at the bottom: a fact of keen interest to producers of all devices that are microcomponent-dependent. The thinner the material — as in the case of electronics, where greater miniaturization requires finer construction and structure that has more in common with an onion than a brick — the more important becomes a thorough appreciation of crucial surface characteristics and how they differ even a few atoms deep.

Since his arrival at the university in 1992, and for the past 15 years, Elsayed-Ali has been studying ultrafast solid-state processes and how phase transitions on materials’ uppermost surfaces begin and propagate. Electrons act as either individual particles, or display the properties of waves; Elsayed-Ali uses electrons’ wave properties to analyze diffraction patterns in crystals and metals to analyze atomic structure. To do so, he employs a combination of sophisticated instrumentation, including a kind of laser that generates an electron pulse that interacts with the atoms under study.

Differences in the ways surface atoms are arranged can lead to intensified chemical activity and a differing array of chemical interactions. Depending on surface structure, materials can exhibit more than one electrical state; some surface areas can be more electrically conductive, for example, than the remaining bulk. While these differences are trivial in a macroscopic world, in the microscopic world they matter profoundly.

An enormous array of molecule-size marvels will affect everything from human health to space travel.
Molecule-Size Machines?

Engineers today are working with devices so small they cannot be seen except with the aid of powerful microscopes. In this emerging field of nanotechnology (from the word nano, or one-billionth of a part) machines and the parts that comprise them will be so minuscule that atomic properties will both limit and enable their performance. Although nanotechnology remains a speculative field, its promise is vast, holding out the prospect of an enormous array of molecule-size marvels that will affect everything from human health to space travel.

“Electricity still takes time to travel between electronics components. To achieve high speed, what you need to do is reduce the physical space between components,” Elsayed-Ali explains. “When you’re designing things that are very thin, the atoms at the surface don’t have the same properties as those in the bulk. They behave in a different way because they’re not bonded as tightly.”

How to harness these properties is a central and daunting research challenge. Another, and one that affects Elsayed-Ali directly, is designing and arranging the optimum amount and kind of laboratory equipment required for such sophisticated investigations. And that’s not to mention bringing on and retaining interested graduate students, who, to work successfully in surface science, must have a concatenation of talent.
“Things have become so interdisciplinary that boundaries between departments are disappearing. You need to know more than one specialty,” he says. “The physics involved is complicated — but so are the instruments. This is very instrumentation-intensive research that requires high-speed lasers and vacuum systems that are better than the vacuum of outer space.”

Elsayed-Ali has designed a new generation of high-speed, high-resolution microscopes to better examine phase transitions. He’s also involved in a series of national and international projects, including ones at the University of Michigan’s National Science Foundation-sponsored Center for Ultrafast Science and Technology, and in Russia at the General Physics Institute in Moscow.

“Techniques like ours usually aren’t characteristic of or developed in electrical engineering departments,” he says. “They’re normally found in applied physics. I’m fortunate to be able to integrate the two in this kind of work.”