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Better atomic force microscopy for nanoelectronics

It was not until long after 1977 that the name nanoelectronics came into use, but David Ferry was already actively engaged in developing some of the world's smallest transistors.

The field, called ultra-small devices at that time in the later part of the1970s, was in its infancy, and Dr Ferry's research team was one of only four select groups around the world aggressively researching the limits of small electronic devices.

Today, Ferry heads up the nanostructures research group at Arizona State University (ASU) in Tempe, a collection of faculty, staff and students working on research in the regimes of nanolithography, and the physics of nanostructures and ultra-small semiconductor devices.

The group is a part of the University's college of engineering, centre for solid state electronics research, whose alumni makes up a serious constituency throughout the nanoelectronics universe, in both industry and academia.

Their current interests lie in the area of quantum dots, quantum wires, and ultra-small semiconductor devices in a variety of materials. The group conducts a wide spectrum of theoretical studies of quantum transport in these very small devices. For example, they are doing a process called scanning gate microscopy at low temperatures.

This involves taking the equivalent of an atomic force microscope and putting bias on it, and studying the change in conductance of small semiconductor structures as they move this bias tip around on a surface.

Their system is mounted in a large cryogenic cooler, an enclosed container with a helium-3 cooling system, an isotope of a helium molecule - which is brought down to 300milli-Kelvin, about one-half a degree above absolute zero.

Arizona State University nanostructures group uses negative-stiffness vibration isolation to eliminate ultra-low frequencies and improve data in nanoelectronics AFM research, reports Jim McMahon

The cooler has a vacuum jacket around it so the heat can't transmit in, and it protects the cold from being mitigated by the ambient room temperature. The AFM tip is on a cantilever.

Normally, with the AFM, you just move this cantilever along the surface then note the change in position as it goes over topography on the surface. Ferry's group is utilizing a process called a piezo-electric sensor.

They metalicise the AFM cantilevered tip with a very thin layer of metal so they can apply a voltage to it. Then use that voltage to perturb the structure they are looking at. As the tip moves it creates a voltage across the plane, which is measured to determine certain mechanical property values. This is a technique that was developed at Harvard four to five years ago.

This type of experimentation is not uncommon, similar experiments are being done by a large number of universities. But what is not common is the system that the nanostructures research group is using for vibration isolation: negative-stiffness vibration isolation, developed by Minus K Technology - which provides a significantly greater and more stable attenuation of the critical lower vibration frequencies, and therefore more reliable accrued data sets.

When measuring a very few angstroms or nanometers of displacement, you have got to have an absolutely stable surface upon which to rest your instrument. If you do not, any of that vibration coupled into the mechanical structure of your instrument will cause vertical noise, and fundamentally an inability to measure these kinds of high resolution features.

'Any kind of vibration noise in the system makes that AFM cantilever tip move, and that gives you bad signals and incorrect data,' says Ferry. 'We actually went further than most university applications because we integrated a rather large magnet into our system, something that Harvard, for example, is just now putting into their operation.

'The magnet allows us to look at different types of transport. 'We can turn the magnet on and look at the magneto-transport of the semiconductors. 'It is a quite a different mode of transport altogether. 'The entire system had to be isolated, not just the cantilever,' continues Ferry.

'We required an extremely high level of vibration isolation given our research parameters. 'We are deriving modern electronic devices from our experiments. 'Future electronic devices are our interest. 'What we are doing is looking at the conductivity of materials and then seeing how quantum mechanics fits into this.

'We study basic physics which has a real application - engineering - and particularly in the semiconductor industry. 'Our research covers: (1) Electron beam lithography of quantum dots and quantum devices, with applications such as quantum ballistic transport at very low temperatures and high magnetic fields, as well as the quantum-classical transition, and the role of quantum effects in real devices at room temperature.

'(2) Magneto-transport studies used to probe the nature of electron dynamics in semiconductor quantum dots, which are quasi-zero-dimensional structures whose size is comparable to the Fermi wavelength of the electrons themselves.

'Magneto-transport studies may be used to probe these phenomena and to determine the factors which limit electron phase coherence within the structures. 'Current interest in these devices is motivated by their potential application in new areas of technology, such as quantum computing and ultra high frequency signal processing.

'(3) Surface chemical analysis performed with a scanning Auger microprobe. 'Under good conditions, a lateral resolution of about 25nm is achievable. 'And, (4) Professor Michael Kozicki, in the group, has examined chemically enhanced vapour etching (CEVE) patterning technique.

'He has used hydrocarbon contamination layers from laboratory air or vacuum chamber ambients and successfully demonstrated nanoscale pattern formation in silicon dioxide. 'He has also developed a nitrogen chamber coupled directly to a UHV STM/AFM facility for CEVE processing of silicon dioxide resists, and their use in semiconductor device fabrication.

'Within the nitrogen chamber there is a processing system for the actual CEVE development. But, the current work with the scanning probe system is really interesting, and made possible by the negative-stiffness isolators,' says Ferry.

The negative-stiffness isolator is a passive isolation approach, and has a key advantage in that it is not powered. It has no electricity going to it. So, in a site where heat buildup could be an issue, such as with enclosed cryogenic chambers, negative-stiffness becomes a highly efficient option.

Negative-stiffness isolators employ a unique - and completely mechanical - concept in low-frequency vibration isolation. Vertical-motion isolation is provided by a stiff spring that supports a weight load, combined with a negative-stiffness mechanism (NSM).

The net vertical stiffness is made very low without affecting the static load-supporting capability of the spring. Beam-columns connected in series with the vertical-motion isolator provide horizontal-motion isolation. The horizontal stiffness of the beam-columns is reduced by the beam-column effect. (A beam-column behaves as a spring combined with an NSM).

The result is a compact passive isolator capable of very low vertical and horizontal natural frequencies and very high internal structural frequencies. The isolators (adjusted to 1/2Hz) achieve 93% isolation efficiency at 2Hz, 99% at 5Hz, and 99.7% at 10Hz. Negative-stiffness isolators provide a capability quite unique to the field of nanotechnology - specifically, the transmissibility of the negative-stiffness isolator.

That is, the vibration that transmits through the isolator as measured as a function of floor vibrations - which is substantially improved over active isolation systems. Although active isolation systems have fundamentally no resonance, their transmissibility does not roll off as fast as negative-stiffness isolators.

So, at building and seismic frequencies the transmissibility of active isolators can be ten times greater than negative-stiffness isolators. This causes substantial adverse measurement and imaging artifacts in the data. Compared to other laboratory research instrumentation, the growth of AFM usage has been quite extensive over the past ten years.

AFM equipment placement has gone through a doubling phase pretty much every year during the last decade. Since its inception in 1988, it has continuously proven to be a key tool in moving nanotechnology research forward.

'More than half of the universities in the United States, and worldwide, are engaging in nanotechnology research,' says Dr Ferry. 'In the electronic area, the nanoelectronic side of it has been going since the late 1960s. 'This is driven by the fact that in the semiconductor industry all things are getting smaller and smaller.

'Today, the transistors have critical dimensions down around 25 nanometers. 'And the most critical dimension is the oxide thickness which is one nanometer. 'When you consider that you have to control one nanometer vertical thickness over 300 millimeters of lateral dimension, that is a difference of 10 to the 8th power. 'That defines what modern manufacturing technology produces.

'The need for effective vibration isolation has never been greater, and will continue to become more demanding as the nano-industry progresses'. David K Ferry is a Regents' Professor of electrical engineering; recipient of the Arizona State University Graduate Mentor Award, 2001; and recipient of the IEEE Cledo Brunetti Award, 1999 'for fundamental contributions to the theory and development of nanostructured devices'.

The IEEE Cledo Brunetti Award was established in 1975 through a bequest made by the late Cledo Brunetti, who was an executive of FMC.

The award is presented annually by the IEEE board of directors on the recommendation of the Technical Field Awards Council and the Awards Board, for outstanding contributions to miniaturisation in the electronics arts.

Ferry has authored and co-authored several books including, Electronic Materials and Devices (2001); Semiconductor Transport (2001); Transport in Nanostructures (1997); Quantum Transport in Ultrasmall Devices (1995); and Quantum Mechanics (1995, 2nd Edition 2000).

David Platus is the inventor of negative-stiffness mechanism vibration isolation systems, and president and founder of Minus K Technology. He earned a BS and a PhD in engineering from UCLA, and a diploma from the Oak Ridge School of (Nuclear) Reactor Technology.

Prior to founding Minus K Technology he worked in the nuclear, aerospace and defense industries conducting and directing analysis and design projects in structural-mechanical systems. He became an independent consultant in 1988. Platus holds over 20 patents related to shock and vibration isolation. Minus K Technology was founded in 1993 to develop, manufacture and market state-of-the-art vibration isolation products based on the company's patented negative-stiffness-mechanism technology. Minus K products, sold under the trade name Nano-K, are used in a broad spectrum of applications including nanotechnology, biological sciences, semiconductors, materials research, zero-g simulation of spacecraft, and high-end audio.

The company is an OEM supplier to leading manufacturers of scanning probe microscopes, micro-hardness testers and other vibration-sensitive instruments and equipment.

Minus K customers include private companies and more than 200 leading universities and government laboratories in 35 countries.