



Asst. Prof. Xin Zhang and graduate student Shushen “Forest” Huang inspect arrays of tiny infrared sensors.

## Thinking Small

MANUFACTURING ENGINEER XIN ZHANG DEVELOPS TINY MACHINES WITH BIG POTENTIAL

By Ryan Olson

**I**ronically, Xin Zhang’s career continues to grow on the principle of one overarching theme: thinking small. A specialist in the field of micro-electrical mechanical systems, or MEMS, she helps design and build tiny sensors and machines, including a millimeter-length cryogenic pump used to cool delicate satellite instruments and microscopic arrays for detecting the minute physical forces exerted by cells. Between manufacturing, aerospace and mechanical engineering, she’s a fundamentalist in her approach, trying to increase our understanding of the basic principles associated with these tiny machines to make the next generation of MEMS devices even better.

An assistant professor of manufacturing engineering, Zhang came to Boston University in late 2001 from the Massachusetts Institute of Technology, where she spent several years working first as a postdoctoral researcher and then as a research scientist in the microsystems technology and gas turbine laboratories. In 2002 she founded BU’s Laboratory for Microsystems Technology, with the goal of creating a college-wide, student-centered MEMS research and education program.

From BU Medical School to engineering firms like Fraunhofer, which occupies space near her lab on St. Mary’s Street, across from the Photonics Center, Zhang’s background brings her diverse projects and

collaborators together. Her appreciation and strong desire for collaboration is resulting in the growth of a BU program striving to make important advances in the field.

### Power in a Small Package

With her experience constructing microscopic gas turbines and other machines with the potential to revolutionize the entire concept of battery technology, it is not surprising that Zhang's research into the enhancement of power MEMS has attracted the interest of the US Air Force. "Many people in this field share the belief that a revolution is underway," she says. As the desire for unmanned vehicles continues, so too does the need for small, reliable ways to provide these devices with power and cooling. From satellites to small space vehicles, power MEMS devices could be used in propulsion systems, batteries and fuel cells.

Working jointly with engineering firms Foster-Miller and Fraunhofer, Zhang has developed a tiny cryogenic pump designed to keep delicate, densely packed satellite instruments cool. A mere 25 millimeters square, these arrays of pumps can be used to push a coolant-like liquid nitrogen through a series of tiny tubes snaking through telescope optics. Early tests have gone well, but reliability is still a key issue when it comes to the success of these devices. Operating remotely, they must be able to run for years at a time without the need for repair.

Before the large-scale construction of the next generation of power MEMS devices like battery replacements, tiny blowers, compressors and heat pumps, the structures and materials used in their construction must undergo a significant amount of additional study. With

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so much power being created by such a tiny machine, the damaging effects of heat become more of a problem, leading to the need for thicker deposited layers as electrical insulation. But because of their small size, layering extra materials creates a second problem—stress. Thin film materials like silicon oxide, silicon nitride, and various metals are combined with one another, then

go through a complex construction process to form structures with specific properties and functions.

"Thin films have, in general, properties different from their bulk counterparts," Zhang says. By doing things like constructing different structures and taking constant measurements and modifications of stress levels during the construction process, she and her student Zhiqiang "Jay" Cao are thinking of new ways of depositing MEMS materials and ways to develop more stress-resistant designs.

### High Tech Imaging

Similar to her work with power MEMS because of the problems affecting the construction of many of the devices, infrared MEMS will provide the next generation of thermal imaging technology. One type of device uses arrays of tiny sensors called bolometers to detect infrared energy that can be used to create thermal images. Numerous medical and military applications exist for the technology, which Zhang estimates could reduce the cost of current equipment by a factor of 10, power consumption by a factor of 20 and size by anywhere from 10 to 100 times.

These microscopic sensors, which can be as small as a few dozen micrometers across, work because of their unique response to infrared energy. When struck by infrared light they bend, resulting in a corresponding change in resistive capacity. By measuring the total change in resistive capacity across arrays of these tiny devices, integrated electronics can interpret the signal as an image, whether for night vision goggles or a medical scanner. Using a unique design conceived by her Fraunhofer colleague

and former postdoctoral researcher Biao Li, two bolometers sit at the ends of cantilevers, arranged like a sandwich with a small space in between. When hit with energy they bend, just like a single-layered bolometer does, but in opposite directions from one another, resulting in a more pronounced change in conductance and a higher sensitivity. With low noise (interference)



Sensors arrayed on a wafer.

and an established manufacturing process, many of the difficulties associated with building these devices have already been overcome. But problems remain.

Stress, an obstacle in the construction of power MEMS, causes problems here as well. The layers of thin films used to create the microbolometers are also made of many different materials, and stress that accumulates during their construction causes the sensors to curve, making them useless. Zhang's team is investigating ways to reduce this curvature, using a machine built by Professor Thomas Bifano (MFG) to work on mirrors. In the technique, called ion beam machining, or IBM, a beam of ions blasts the surface of the bolometers, flattening them by creating an additional layer of material on the surface or removing some of it.

"It's post processing — like a little surgery," Zhang says. "The whole chip can be modified or improved to make it better."

But extensive use of the ion beam can risk deteriorating, or delaminating, the sensors. Because it was designed to work with

mirrors, results aren't perfect, and IBM is often combined with another technique, called rapid thermal annealing, which uses a small oven to heat the structures to high temperatures, causing them to flatten. Funded by the US military and the Photonics Center, Zhang and her student Shusen "Forest" Huang are working on the best possible combination of these two techniques to optimize the reduction in the curvature of the bolometers.

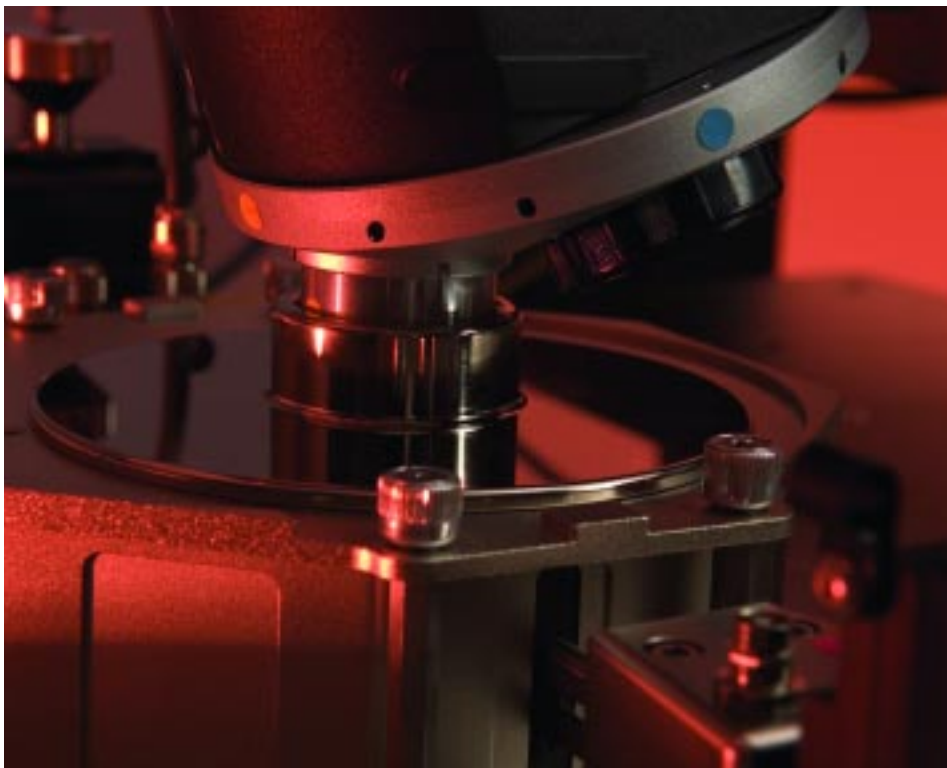
### The Future

For Zhang and her students and coworkers at the Laboratory for Microsystems Technology, there does not appear to be a shortage of available work. Between finding ways to reduce the stresses on the tiny machines and moving from micrometer- to nanometer-scale in projects studying cellular forces, she continues to find ways to increase our understanding of these devices, no matter how small. From systems integration, biology, biomedical engineering and her ongoing collaboration with researchers and departments across campus, she always seems to be up to something.

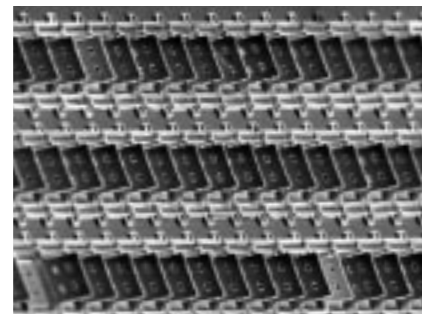
"My group has a lot of potential to grow and perform really competitive research," Zhang says. "I feel excited to get up in the morning and go to work to do something interesting. Students come to me with a high motivation. They feel it's worthwhile to spend a couple of years working in a competitive research field."



Graduate student Yi Zhao uses a microscope in the lab.



Prof. Zhang's team uses this Cascade probe station to characterize MEMS structures and devices.



Arrays of tiny infrared sensors, or bolometers, are used to detect thermal energy. When infrared energy hits their surface, they bend, causing a change in conductivity, which can then be interpreted by integrated electronics and used to create a thermal image. But construction problems resulting in bent, ineffective sensors must be overcome before the technology can be reliably commercialized.

## Pillars of science

Zhang's self-described career project is in the field of Bio MEMS. With help from her student and PhD candidate Yi Zhao and a relationship with colleagues at BU Medical School, she is trying to understand the fundamentals of cellular mechanics through the measurement of the physical forces taking place inside and between cells. Important in vital processes like cell division, migration, growth and death, a more complete understanding of these forces might lead to technology able to predict larger-scale changes in the body. But finding answers to questions as simple as what happens when we consume chemical stimulants like caffeine, or more complex ones like understanding the intricacies of heart attacks, means finding unique ways to measure these tiny forces.

Historically, the cells used in cellular mechanics studies haven't had it very easy. Researchers have used invasive, labor-intensive techniques, from the relatively gentle optical tweezers (intense, focused beams of light on either side of the cell prevent it from moving but risk cell damage) to micro force transducers, which attach carbon fibers or glass pipettes to the ends of cells and pull on them. Even the relatively benign atomic force microscope affixes a cell to the end of a tiny cantilever, lowers it until the cell attaches to a surface and then pulls the two apart while measuring the amount of force necessary to do so.

Zhang's approach for measuring cellular forces is dramatically different. Using the strongest muscle cells available to them—heart muscle cells, or cardiac myocytes from rats, she and Zhao place individual cells atop arrays of tiny pillars made of special polymers and observe how the cells affect the pillars.

Using a technique called deep reactive ion etching, the researchers carve out an array of micrometer-width holes in the surface of a piece of silicon to make a master mold. Inverting the mold and placing it on top of a polymer substrate, they then use the pressure differential caused by a vacuum to draw the substrate up into the holes. After heating the polymer and solidifying it, the mold is removed, leaving a platform covered with tiny pillars (see photo). A single mold may be used to make pillars with a variety of flexibilities that are able to detect a wide range of cellular forces. Individual myocytes are placed on top of these pillars while bathed in a solution mimicking cellular fluid. By minimizing harmful outside influences and simulating the most realistic conditions possible, the team is able to obtain more realistic results while studying cells for longer periods of time. Using an environmental scanning electron microscope capable of scanning liquids and living materials, the two are able to directly observe how cells affect these tiny pillars.

By observing the deformation of pillars moved by the cell (see photo), the researchers can determine the total strength of the forces exerted by the cell. Variations in the ingredients used to make the polymers and the curing times give the researchers the ability to create arrays with different flexibilities and corresponding sensitivities. This allows the study of forces of different strengths and, in the future, different types of cells. By designing

and building arrays with multiple chambers for individual cells that include structures to ensure their proper alignment, many cells can be studied at the same time.

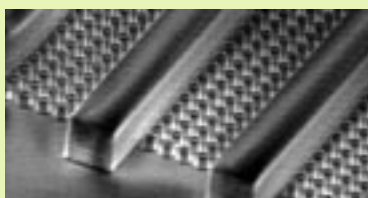
"You can talk about nanotechnologies for days, but finding a specific application is important," she says. "We are doing research [with] practical applications. It's delightful because we're not just picking up cells and doing superficial measurements; we're working with doctors and studying real problems."

### The Future is Moiré

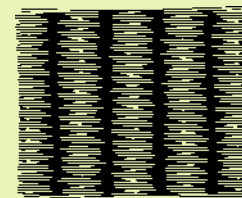
For Zhang and her students, the next step in the study of cellular forces means going even smaller — to nanometers. Because myocytes are the largest and strongest muscle cells in the body, studying other, smaller cells will require more sensitive equipment. Because the movement of pillars that are mere nanometers across is impossible to observe optically, Zhang is using a different technique to detect the changes across the array of pillars. Called Moiré interference, the approach refers to the pattern caused when two identical grids cross one another at an angle.

"This project is a very interesting combination of nanotechnology and biology," Zhang says. Cells are placed above a reference grid and below a second, identical grid and viewed from above; cellular forces affecting the tiny pillars obscure the bottom grid and cause a moiré pattern visible from the top. Fringes of alternating bright and dark bands emerge, at which point a computer is used to analyze the differences between these two images. With this technique it is possible to determine how the pillars on the polymer substrate have moved, even when individually they are too small to reliably see with a microscope.

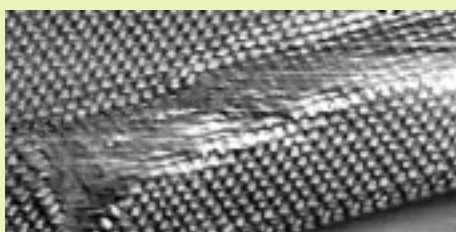
—R.O.



Zhang and Zhao create arrays of tiny pillars sensitive enough to respond to the minute physical forces caused by heart muscle cells.



A reference grating is visible under a moiré pattern generated by polymer nanostructures.



A heart muscle appears as a smudge on a pillar array. Because they know the amount of force needed to move a single pillar, making pillars with appropriate aspect ratios lets researchers more accurately determine the total amount of force the muscle can exert.