EXPANDING SHRINKING SCIENCE:

HARVARD'S NEW HOME ON THE NANOTECHNOLOGY FRONTIER

Bridges: Then and Now

As a bone-colored tile floor slopes suddenly downward to reveal a narrow, ill-lit nave flanked by offices, Robert L. Graham offers assurance, saying, "We are now walking over the Van Vleck Bridge to Cruft Hall." Graham, as Director of the Gordon McKay Laboratory and Assistant Director for the Nanoscale Science and Engineering Center (NSEC) and Materials Research Science and Engineering Center (MRSEC), has become the de facto tour guide for visiting groups exploring Harvard's expanding efforts in small-scale science.

To provide context, Graham offers some history. In the 1950s, John Hasbrouck Van Vleck, Nobel laureate and the first Dean of the Division of Engineering and Applied Physics (DEAS), created the bridge to literally and intellectually connect the applied sciences with physics at Harvard. In spirit and intent, this link from a half-century ago foreshadows the role that will be played by the Laboratory of Integrated Sciences and Engineering (LISE) rising nearby today.

Once completed in December 2007, LISE, a 135,000-square-foot structure, will serve as both a bridge and a stand-alone building. Above- and below-ground passages will link with eight other Harvard buildings housing the physical and engineering sciences. Laboratories will dominate that portion of LISE above ground. The three-level basement will house a shared clean room (dust-free environment), facilities for materials synthesis, and a microscopy suite—applications best situated far from outside light and vibrations. (See sidebar, page 26.)

Right: ??? at work in a clean room

LISE has been designated as the new home of the Center for Nanoscale Systems (CNS). CNS researchers now housed in other buildings will congregate here to strengthen Harvard's foothold in the shrinking science arena, studying phenomena on the scale of nanometers (a unit measuring one-billionth of a meter, or three to four atoms wide). Within the world of nanoscience, researchers move individual atoms around like Legos in realms where the rules of conventional physics no longer apply.

This tiny universe promises unlimited possibilities. Seeing phenomena at smaller and smaller scales empowers scientists and engineers with the capability to do more, including creating new classes of structures that are stronger than steel but lighter than graphite, using atoms and molecules to store and process information, and employing DNA to build motors.

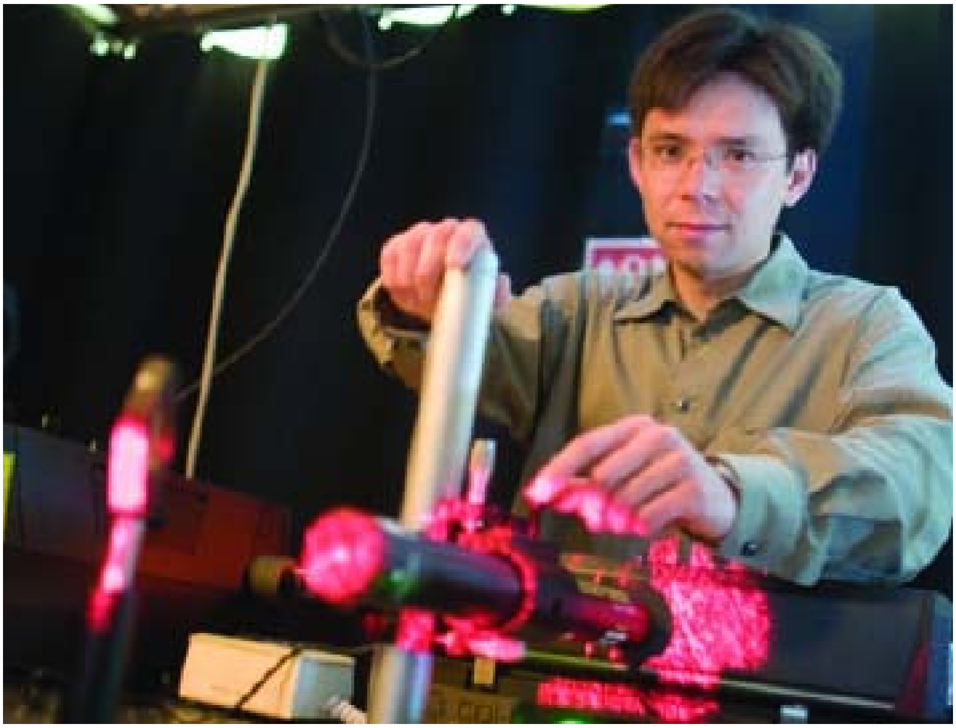
Nano is also the right scale for blending synthetic materials with biological ones. Even now, Harvard researchers are finding ways to make movies of a single virus particle inside a living cell and designing nano-"detectors" that can pinpoint the presence of a virus.

From across the disciplines, Harvard faculty and students will convene and collaborate within LISE to advance our understanding of this previously unknown world. Most significantly, Harvard scientists and engineers will increasingly be able to control what was once beyond our reach: matter itself. LISE will enhance these pioneering efforts on the frontiers of nanotechnology, as they expand the world's knowledge of the many sides of small.

In this feature, we will meet some of the CNS researchers whose work will be enhanced by a move to LISE.

Silicon Wafers and New Waves

Kenneth B. Crozier, Assistant Professor of Electrical Engineering on the Gordon McKay Endowment, is one of a dozen new engineering and applied sciences arrivals in just the past three years. A nanophotonics expert whose laboratory is currently located in the Maxwell Dworkin building, Crozier develops improved imaging techniques, such as optical microscopes for observations



Kenneth B. Crozier caption here

FUNCTION AND FORM

LISE's façade of treated multilayer glass changes color depending on the amount of sun it receives, resulting in a shimmering, clean structure. Designed by Rafael Moneo, the Josep Lluis Sert Professor of Architecture at the Graduate School of Design, the modern building simultaneously stands out from its Oxford Street setting, and still blends with the surrounding nineteenth-century brick architecture. Similarly, LISE's 120-foot height and its vast interior emerge from a diminutive footprint—three elegant supports form an open and welcoming pedestrian walkway.

The building is ideally suited for nanotechnological collaborations from across the disciplines. "Rafael Moneo has taken opposing ideas, either where scientific requirements are contrasted with aesthetic issues or where code and law seem to belie practicality, and come up with the optimal solution for all concerned," Charles M. Marcus, Professor of Physics and Scientific Director of the Center for Nanoscale Systems (CNS), says. Referring to the many state-of-the-art spaces that the architect has created, Marcus sums up, "Moneo has put function above form. He's most proud of the underground areas that you will not see. He has created a building where everything works, and everything is perfectly aligned."

at the nanoscale. "If you can make something smaller than the wavelength of light, then you can control the flow of light," Crozier explains. He also builds new devices based on photonics crystals, materials used to control and manipulate the spread of light, in such consumer products as flat-screen televisions.

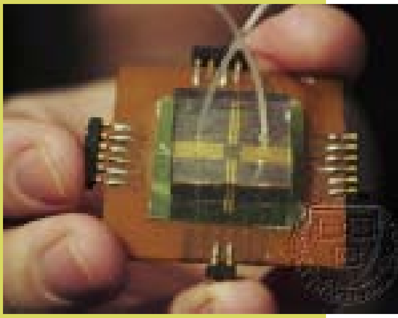
"The CNS facilities in the LISE building will offer a wider range of techniques used in IC [integrated circuit] fabrication," Crozier says. This means that when I teach a course like 'Phototonic and Electronic Device Laboratory,' where students fabricate transistors on silicon wafers, these undergraduates will have a wider range of applications and practical experiences."

Such microfabrication techniques provide future researchers with a firm foundation both during and following their time at Harvard. Donhee Ham, Associate Professor of Electrical Engineering, who, like Crozier will relocate his lab to LISE, has seen the results firsthand. Last spring, Ham's team, including graduate student David Ricketts, used CNS-based facilities to embed Harvard's prototype soliton oscillator, a device that produces the electrical equivalent of light pulses, onto a circuit.

The journal *Nature* has suggested that such an advance may make solitons the new "darlings of communications engineers" and help usher in a new wave of electronics. "Once further developed," says Ham, "the oscillator will open the door for ultra-fast electronic measurement now only possible in expensive lasers." Ham expects that LISE's expanded facilities will allow other new waves to surface.

MEDICINE GOES NANO

The tiny world of nanoscience has captured the imagination of the consumer, from the fast-selling iPod Nano to L.L. Bean's "Nano-Care" chinos. Farther from the public eye, Harvard researchers are able to film a single influenza virus particle as it travels within a living cell, opening the door to innovative ways of blocking viral infection. Nanoscience has begun to alter the practice of modern medicine, from diagnostics through treatment.



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Charles Lieber, who is Mark Hyman, Jr. Professor of Chemistry, and his colleagues have developed silicon nanowires that can detect the presence of cancer in the body long before the disease takes hold. This medical device could enable doctors to prick a patient's finger and scan the drop instantaneously, detecting with exceptional accuracy the exact type of cancer.

Using nanotechnology to treat disease, Gordon McKay Professor of the Practice of Biomedical Engineering David Edwards generated a way of delivering drugs through inhalation, and 1,000 diabetics are currently taking inhaled insulin in clinical trials as a result. With a grant from the Bill and Melinda Gates Foundation, Edwards and his colleagues are now developing oral vaccines for infectious diseases like tuberculosis and diphtheria.

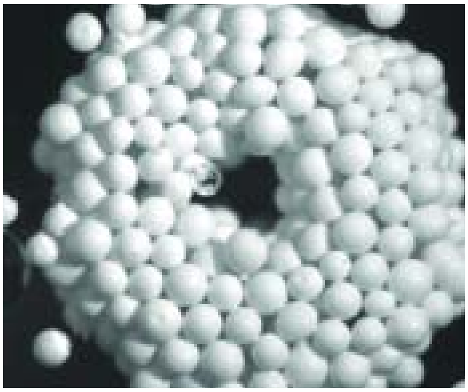
Through his ongoing investigation into the physics behind the self-assembly of living chemical structures, Assistant Professor of Physics and Chemical Engineering Vinothan Manoharan probes one of the greatest mysteries of biology: how do things self-assemble?

"For example," he says, "with proteins, our bodies synthesize long chains of amino acids and then those chains fold into three-dimensional structures that catalyze a reaction." Diseases like Alzheimer's and mad cow occur as a consequence of misfolded proteins. "I would like to know the rules we should follow to design the building blocks that will assemble by themselves. It's one of the most important questions around."

Tiny Bubbles

Within the Division of Engineering and Applied Sciences, nanotechnology researchers are also bridging the natural and synthetic worlds. On a typical day in Pierce, the building that houses the Van Vleck Bridge, Lakshminarayanan Mahadevan, Lola England Professor of Applied Mathematics, contemplates how an unfolding leaf may reveal techniques for the self-assembly of nanoscale devices. In another Pierce lab, recent Harvard College graduate William Adams '06 develops his microelectrode array, a "data collector" for experimenting on the electrophysiology of the heart.

Anand Bala Subramaniam '06 is a former biological sciences concentrator in the College and current research fellow in engineering with a lab in Pierce. He found his way to nanotechnology courtesy of tiny bubbles. Working in collaboration with other CNS members, including Howard Stone, Vicky Joseph Professor of Engineering and Applied Mathematics and Associate Dean for Academic Programs in DEAS,



Subramaniam created peapod-, doughnut-, and sausage-shaped bubbles by coating ordinary gas bubbles with a tightly packed layer of tiny particles and then fusing them.

"The ability to alter the shapes of bubbles and liquid drops may provide a means for altering the consistency or texture of certain products," he says. Someday these odd bubbles may be used as carriers for delivering drugs, vitamins, or even flavors.

Stone, whose own work spans topics from the origins of vertigo to how *E. coli* bacteria swim, wants to attract more broad-thinking investigators, especially as small-scale science points engineering into increasingly interesting directions. When CNS is fully integrated into LISE, Stone says, "One will be able to wander from questions in computer science to those in environmental engineering, atmospheric chemistry, bioengineering, biomedical, mechanical, and chemical engineering, applied math, and materials science." Bio-bubbles, in other words, represent just the beginning.

Elizabeth Smythe, Research Assistant in the Division of Applied Sciences, and Federico Capasso, Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering, hope to develop new lasers and artificial materials.

Electric Flow

Physics, like engineering, has become a fluid discipline. Advances increasingly occur in realms far from everyday experience—at minute scales, in the wires behind the walls, or within a fifth dimension. Advanced tools, often operated in unprecedented environments, enable researchers to explore these realms.

To study organic superconductors—materials that permit the flow of electric current without the loss of energy at temperatures near absolute zero—Assistant Professor of Physics Jenny Hoffman relies on a scanning tunneling microscope. The device, which manipulates a material atom by atom, is not only a custom job, but requires a custom room.

"LISE is definitely one of the main reasons that I decided to come here as a professor," says Hoffman. "The building promises very low-vibration space for imaging in the subbasement." This matters because, when imaging at the nanoscale level, the slightest tremor may result in a blurred picture. Hoffman's work would remain in the dark without LISE's sophisticated vibration dampening.

A Broad-Ranging Tool Kit

Federico Capasso, Robert Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering, is well-known for his work in quantum design and new materials. His cascade laser, considered one of the most significant devices developed in laser physics during the last decade, has applications in many settings, including health care. In particular, breath analysis, a noninvasive process whereby small quantities of organic compounds can be detected in human breath, possesses the potential to dramatically improve diagnostics.

What the nanotechnology revolution requires, Capasso maintains, is a unified point of view: the ability to dig more and more deeply into materials, down to the level of atoms. "Every field participating in this interdisciplinary effort has to bring its own tools, so the range of the combined tool kit is far greater than before," he says. Centralizing the means and the perspectives makes practical and research sense.

This belief may explain why Capasso seems unperturbed that his current neon-orange–colored lab in the Cruft building will be sacrificed to make way for a new bridge extending from LISE.

"New tools are bringing together fields, especially in physics and engineering," Capasso says. "Working on the small scale means working together—and seeing the bigger picture."

"An Absolutely Open Facility"

Decked out in snow-white bunny suits, the astronaut-like gear necessary for working in a clean room here, teachers and students from Greater New Bedford Regional Vocational-Technical High School fabricated six plastic "membrane stretchers." The devices will help Kevin Kit Parker, Assistant Professor of Bioengineering on the Gordon McKay Endowment, investigate why certain athletes fall victim to commotio cordis—immediate death by heart attack when hit by a projectile like a puck or baseball in the chest. Parker, who hosted the group this past summer, happily reports that two of the students have been offered jobs at CNS.

Today, such fabrication labs often seem inaccessible, even to fellow scientists willing to dress the part. CNS Scientific Director

Charlie Marcus aims to change that perception: the facilities inside LISE will be widely shared. "LISE doesn't belong solely to physics, chemistry, engineering, or any other field," he says.

In fact, CNS already connects Harvard to the larger scientific community. Since its inception, the endeavor has welcomed researchers from around the world intrigued by the tools and expertise found here. According to Marcus, the advent of LISE will enhance major new avenues to and through the center. "This is absolutely an open facility!" he declares. "Everyone will be here because advanced science and technology all focus on materials synthesis, microscopy, or nanofabrication, which is what we will do."

Marcus is excited, even inspired, by the potential for contribution. "I cannot think of a nobler or more beautiful calling in life than to make a tiny contribution to our understanding of how the world works," he says. For those still unconvinced, he offers another, less philosophical solution. LISE will feature a glass-enclosed ground level café that opens out onto a wi-fi-equipped outdoor seating area. "I want to go on record that there is no better square-foot-investment in science than the new café. You'll be able to count the Nobel Prizes fifty years from now that grew out of little conversations there."

Making Other Connections

Several stories underground, the least visible link from LISE will be with the Science Center. Above ground, the architectural landmark will continue to serve as an academic mall for undergraduates and graduate students, replete with food courts, museums, computing centers, and auditoriums.

Below ground, a physical network from LISE that was created primarily as a "road" to move gases and other chemicals among buildings will ultimately join the burgeoning north end of campus with the Old Yard. Someday, perhaps, this innovative passage will symbolize a new dialogue among the natural sciences, social sciences, and humanities at Harvard.

The Van Vleck Legacy

Like other Harvard scientists, Richard Wilson, Mallinckrodt Professor of Physics, Emeritus, believes that the legacy of the Van Vleck Bridge has much to teach the University about interdisciplinary learning. He has long wanted to place plaques at the entries to the Van Vleck Bridge to recognize the pragmatic and symbolic achievement of this modest structure. "Van Vleck not only made this physical bridge between physics and engineering but was constantly building intellectual bridges across the University," Wilson says.

With LISE, the bridge-building promises to continue. ■

TRAINING FUTURE NANOTECHNOLOGISTS

Charles Marcus, Professor of Physics and Scientific Director of the Center for Nanoscale Systems (CNS), enjoys knowing that nanoscience enables undergraduates to jump in and perform their own experiments—often with extraordinary results. "I have undergraduates in my lab right now," Marcus says. "I just had a meeting with one of them, two postdocs, and an MIT professor who came over to look at the student's data."

As part of the Research Experience for Undergraduates (REU) summer program, Jennifer Harlow '07 of Tahoe City, California, a physics and math concentrator, worked in the Marcus group on a project that could lead to new quantum-based memory systems for computers.

In graduate education, the traditional approach that required students to spend five or six years working in isolation on one problem has given way to a new collaborative training environment providing the freedom to pursue several different problems across disciplines. The result? More mature graduates, says Marcus, because they start and finish three or four projects during the PhD process. "They see some projects fail and some succeed. They write up the successful ones and defend them, not simply as a thesis, but in public at conferences with other scholars breathing down their necks. The process really trains them to be scientists."

The opportunity to cross disciplines easily and the encouragement to tackle the big questions may also explain why, in 2005–2006, 80 percent of accepted graduate applicants with interests in applied physics decided to attend Harvard.