Mixing it up with Metals

On the nano level, Evan Ma triggers structural changes to give copper and other metals exciting new twists in performance.

By Bob Cooke

In modern materials science, more exotic materials like carbon nanotubes and biomaterials may sometimes upstage metals. But En “Evan” Ma has been getting a lot of attention lately for his breakthrough work with nanostructured metals. In fact, the Whiting School of Engineering professor of Materials Science and Engineering was recently honored with ASM International’s 2004 Materials Science Research Silver Medal “for important experimental and theoretical contributions in the study of metastable and nanocrystalline materials.” Ma, who earned his PhD at Tsinghua University in China with thesis work at the California Institute of Technology, is also affiliated with the Whiting Schools Center for Advanced Metallic and Ceramic Systems.

Putting it in the simplest terms, Ma sees himself “working in an old metallurgy field in which we try to discover something new.” Since the Bronze Age, advances in the use of metal have profoundly influenced human civilization. Our ancestors sought ways to gain advantage or solve problems by altering the characteristics of the metals they extracted from nature. Whether forging a blade sharp enough to penetrate the enemy’s armor, setting off precious jewels, supporting tall buildings, or containing tiny explosions inside an engine, humans extracted, fired, quenched, mixed, shaped, and otherwise changed metals to create new possibilities.

The difference today is the depth of our understanding of what’s going on in the structure of metals as they undergo these man-made changes. “When the electron microscope was invented,” says Ma, “scientists began actually seeing metallurgical microstructures on nanometer scale.” Researchers could see how those structures were altered by treatments that were already in use or being developed, and this enabled them to conceive of ways to use both existing and new metallurgical techniques to achieve new levels of performance.

Materials scientists now understand that it’s all a matter of equilibrium, and the lack thereof. Most engineering materials in use are somewhat unstable. Given enough time and temperature, they would approach thermodynamic equilibrium and stability. But new and often valuable properties of metals arise in states far from equilibrium. So this is where Ma takes them.

In his earliest studies, Ma used ion beam mixing. He accelerated ions of atoms and shot them into a matrix to trigger structural changes. In later years, Ma investigated self-propagating reactions of elements in multilayered geometry (see cover image, repeated above), and employed severe plastic deformation to mechanically force the formation of highly nonequilibrium materials. He also has used a vapor quenching technique to alloy metals that wouldn’t otherwise mix. That process involves heating two metals until they vaporize, then condensing the mixed atoms into a solid on a cold substrate. In a recent review published in Progress in Materials Science, Ma describes the metastable nature of the alloys created between these immiscible elements. The structure of the new alloy can be further evolved with heat treatments, yielding different performance characteristics along the way. Currently, Ma’s group is working on creating different structures in an amorphous (structureless) alloy.

Obviously, new scientific advances have made possible some unusual processing techniques and novel alloys. However, in a recent project, Ma and his colleagues also showed that it is possible to use strictly traditional tools to make a well-known metal behave in an unprecedented way.

Customized Copper

Copper is known to be a very ductile metal, easily stretched and suitable for making electrical wire. But copper is normally quite soft. Knowing that conventional copper is almost in equilibrium and has a structure of relatively large microcrystals, Ma set out to introduce smaller nanocrystalline grains into the copper microstructure because they tend to enhance strength. “We wanted to tailor the metal to achieve a great combination of strength and ductility,” he says.
Ma’s research team succeeded by finding the right combination and sequence of fairly conventional treatments. First, a 1 inch cube of copper is cooled to -200º C. Then it is run through hard rollers that flatten it out into a 1mm-thick sheet. The sheet is then heated to 200ºC. By controlling the cooling and heating steps, the proportion of nanoscale crystalline grains in the copper is adjusted. With optimized level of these small grains, the copper exhibits significantly higher strength—about six times the normal level—without sacrificing its high ductility. Easy to produce and endowed with a nice combination of performance characteristics (strength and ductility), such a new form of metal is attractive for a range of applications. Similar customization of nanocrystalline metals makes it possible to customize metal parts for micro machines known as microelectromechanical systems, or MEMS.

Tailor-made Tungsten

Ma also is collaborating with his colleagues in Mechanical Engineering to develop anti-armor materials for use by the military. For years, armor-piercing projectiles have been made with depleted uranium. This high-density material exhibits a highly desirable self-sharpening capability. Rather than mushrooming on impact, it spirals and maintains a pointed shape that penetrates armor plating. However, the use of uranium is controversial, so the search is on for an alternative. Ma thinks he and his colleagues may have the answer.

Tungsten, like uranium, is a very strong, very dense material, and it has a high melting point. But it lacks the critical self-sharpening capability. However, by pushing the tungsten to extreme nonequilibrium and carefully controlling the resulting nanostructured grains, Ma’s team has already been able to achieve shear localization in the metal. The plastic flow concentrates in a localized shear zone, so the material shears off at a 45º angle—potentially useful as a self-sharpening penetrator material.

With the freshly minted tools of nanotechnology at their command, materials scientists like Evan Ma are truly the alchemists of the new millennium.

To learn more about Evan Ma’s research, visit www.jhu.edu/~matsci/people/faculty/ma/ma.html.
Next Gen Robotics: See Them Roar!

René Vidal develops the techniques that will enable computers to tell a tiger from a tree—and learn from what they see.

By Dave Beaudouin

Browse along the shelves of your local movie rental shop, and you're sure to find them. From the 1926 classic Metropolis down to the present-day Star Wars, sci-fi films for decades have cast robots in leading roles, capturing the public's imagination along the way. However, for René Vidal, the possibility of creating a fully autonomous robot may not be as far off as it seems. "I think it's hard but feasible," he says, "maybe within the next 20 to 40 years. It's a matter of putting perception, action, and learning together."

While robotics researchers are engaged with studies ranging from neural networks to voice recognition, Vidal focuses on the science of seeing, specifically at the intersection of computer vision, machine learning, robotics, and control. The Whiting School of Engineering professor has joint appointments with Biomedical Engineering, Computer Science, and Mechanical Engineering. As he puts it, "The main motivation of my research is to gain an integrated understanding of a class of vision, robotics, and control problems that I believe will enable the development of the next generation of intelligent machines."

Vidal, a native of Chile, began his academic career in electrical engineering; however, the robotics bug bit him early on. While completing his PhD in electrical engineering and computer science at the University of California, Berkeley, he began investigating the issues involved in vision and control. "My first project was to have a helicopter fly autonomously and land on a moving platform," he recalls. "So we developed the necessary vision algorithms so that the helicopter, using its onboard camera, could 'figure out' its position and orientation relative to the landing target. This work made me realize that vision is a lot more challenging than I thought."

Taking up the challenge, Vidal pursued those studies, which led him to his appointment at the Whiting School in January 2004, and placement as a member of its highly regarded Center for Imaging Science (CIS) in Clark Hall. Affiliated with the Whitaker Biomedical Engineering Institute, CIS brings together a diverse group of Hopkins researchers engaged in a broad spectrum of imaging studies, including computer vision, medical imaging and computational anatomy, and target and statistical pattern recognition. Within this interdisciplinary environment, Vidal is taking a fresh look at various problems in dynamic vision, and by extension recognition, perception, and action.

How to Encode a Predator

As with all research, Vidal's study starts with a question: How can a computer visually isolate and recognize a single target or action within a complex and dynamically changing environment? Take, for example, a photograph of a tiger walking through a jungle. Despite the constant shifts in motion, shadow, and light, not to mention the presence of other objects like bushes and branches, the human eye, trained by years of experience, can instantly pick out the animal. However, a computer, which must be programmed in minute detail to complete even the simplest task, cannot distinguish the tiger from its surroundings. "A computer doesn't know what a tiger is to begin with—it can only relate to defined colors, textures, motions, and shapes," says Vidal. "So how do you encode these visual cues mathematically and use them to recognize objects and actions? That is significantly more difficult."

To answer this question, Vidal is developing a mathematically based machine learning technique he calls Generalized Principal Component Analysis, or GPCA. Through an advanced series of
mathematical techniques, GPCA can extract a compact representation of visual information automatically (in this case, the tiger) from a larger set of data (the jungle). What’s more, if several representations are extracted, then the computer has a basis for distinguishing one from the others—in short, a platform for autonomous recognition.

**Wheeled Robots on the Hunt**

Another area of Vidal’s current vision research involves coordinating the actions of multiple agents through the perception and estimation of motion. This involves robotic devices plotting their positions and orientation relative to what they “see,” using both onboard cameras and GPS. In one study, two teams of small wheeled robots actually play a game of “fox and hounds.” The pursuers track the evaders with the help of a small hovering helicopter that is observing the action below. Eventually, Vidal hopes to make the visual interaction of these robots fully automatic, using cameras only. That scenario, he admits, is “very challenging.”

As he explains, “To do that, you need the ability to recognize and track these multiple objects that are in motion, which involves developing algorithms that are provably correct. That is what I have been working on for the last year and a half.”

By integrating these three research areas—recognition, perception, and action—into a single framework with GPCA, Vidal feels that he is on his way to developing machines that can learn from what they see.

**Imaging Solutions for Remote Surgery**

Beyond robotics and machine learning, Vidal also is exploring additional applications in the field of biomedical engineering. “These same techniques can be applied to the recognition of normal versus abnormal in scanning the human body,” he notes. Such scans could instantly detect physiological abnormalities well in advance of an actual incident, such as a heart attack or other organ failure.

To detect such abnormalities, Vidal and his research team also are conducting studies in spinal cord and heart motion analysis. With the latter, he hopes to produce an imaging solution that will allow a surgeon to operate remotely on a living human heart.

“To conduct a remote surgery precisely with a robot, the surgeon would need a video image that looks static, even though the heart is beating,” he says. “By estimating the motion of the heart and compensating for it, we want to present a static image of the tissue being examined.”

For Vidal, our capability as humans to avoid collisions with objects as we walk around is in itself an amazing feat. “We can recognize and interact with the world around us in a remarkably natural fashion,” he says with a smile. “However, all of these things that are simple and automatic to us are actually very difficult to do arithmetically on a computer.”

Discover more about René Vidal’s work at [www.cis.jhu.edu/~rvidal/](http://www.cis.jhu.edu/~rvidal/).