a powerful way to think about designing metamaterials by exploiting electronic disorder at the appropriate length scale."

Like other metamaterials that have been touted for their ability to hide or camouflage an object, it is possible that this VO_2/sapphire structure could be used as a coating on a tank, for example, to make it blend in with the landscape surrounding it. A tank that would normally show up easily in an IR camera because it is hotter than its surroundings might be made to blend in by using a little bit of heat to drastically change its IR emissivity and make the vehicle look colder in an IR camera. Kats has also proposed the possibility of making a rewritable IR "blackboard" held at a temperature within the IMT range. A laser beam or soldering iron could be used to write a message on the blackboard by changing the local emissivity; the message could only be seen by thermal imaging, and would be invisible to the naked eye. Temperature control of satellites in space, where the only way an object can heat up or cool down is by absorbing or emitting radiation, is another possible application down the road.

Kats talks about future plans to modify the VO_2 or change the substrate to produce a whole family of structures that could be effective in different circumstances. "We need to be able to do this either over a larger temperature range or at lower temperatures," he said. "If you want to put this on a person for temperature regulation or for camouflage, you need to do it not at 75°C but 35°C. A lot of this is going to depend on how we can control the system to change the transition temperature."

According to Richard Haglund, Professor of Physics at Vanderbilt University who was not involved in this research, "This paper suggests a broad applications potential for tunable thermo-optical systems based on the complementary properties of a phase-changing film and an appropriately selected or designed substrate. Given the potential of the VO_2-sapphire system for infrared tagging, camouflage and identification schemes, and the range of possibilities for designer film-substrate systems with specific thermo-optical properties, this paper may well turn out to be Reference Number 1 in many papers yet to come."

"I think that one of the most clever things about this work is that this team saw that the transition region, instead of being a necessary bridge from insulator to metal, could be a region with a wealth of really interesting physics," said Dan Wasserman, an assistant professor in Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign. "The idea of a naturally occurring, and dynamic, disordered metamaterial is fascinating, and they've utilized this transition region to show some really interesting macroscopic features of the material. I look forward to seeing what happens as they continue to explore this material system, in particular at the nanoscale."

Tim Palucka

Nano Focus

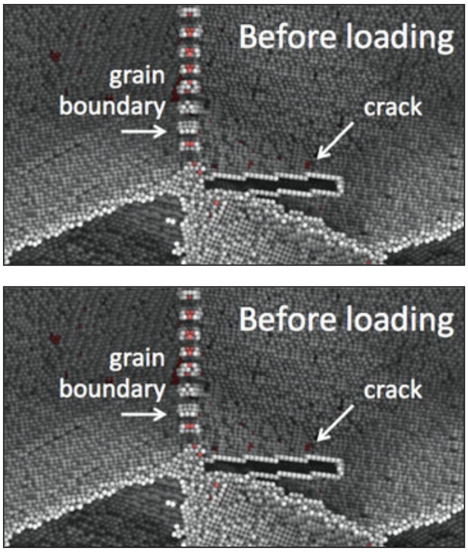
New mechanism heals nanocracks in metal under tensile stress

When a crack forms in a material, typically it is downhill from there onwards. Any further tension makes the crack spread and only increases the damage. At least, that is what intuition and conventional fracture mechanics indicate. Now, the opposite effect has been observed. Under certain circumstances, applying tension or other loading to cracks can actually trigger these fissures to close.

"This really turns our understanding of what is possible in fracture mechanics on its head," said Michael Demkowicz, an assistant professor of Materials Science and Engineering at the Massachusetts Institute of Technology and co-author with graduate student Guoqiang Xu, of an article published in the October 4 issue of *Physical Review Letters* (DOI: 10.1103/PhysRevLett.111.145501; 145501). "It's not surprising if a crack closes under compression, but if you pull on the crack and see it close, that's very unexpected."

Demkowicz and Xu stumbled across this discovery by accident. While studying hydrogen embrittlement in nickel-based superalloys as part of a project on deep-sea oil well applications, they noticed that one of their simulations was behaving in a counterintuitive way. Rather than spreading, the nanocracks they observed seemed to be healing. The researchers assumed there was a mistake with the program or in their parameters, so they combed over the setup for any possible glitches. "We went back and eliminated all of those options," Demkowicz said. "Eventually, we convinced ourselves that it was really happening."

The challenge, then, was to figure out why this was happening. Xu and Demkowicz created detailed computer models simulating how the microstructure of nickel behaved under a number of conditions. Disclinations—a somewhat exotic class of string-like, one-dimensional defects that form in metal but have a much stronger internal stress field than the more common dislocations—turned out to be responsible, based upon quantitative measurements of the strength of the stress field. The stress field intensity causes the



Molecular dynamics simulation of nanocrystalline Pd, where a grain boundary migrates under shear stress and heals a crack. Pure shear loading would neither close nor open the crack in the absence of grain-boundary migration. Credit: Guoqiang Xu.

material to pull together rather than separate apart under an applied force. Depending on the kind of microstructure evolution occurring, external loads ranging from hundreds of MPa to GPa triggered the crack closure.

"A lot of work has already been done on self-healing of soft matter such as polymers and biomaterials, which are generally weak in comparison to metals or ceramics," Demkowicz said. "Our finding is interesting because it's a mechanism that allows for self-healing in much stronger materials."

Demkowicz and Xu are only in the very early stages of investigating this phenomenon, but they can already imagine several possible applications the finding may open in the future. One is to try to design materials with microstructures that use the mechanism to heal internal damage. If typical wear-and-tear could be prevented or arrested, fatigue—one of the most common forms of failure in metal components—may be reduced. The mechanism may also help prevent surface cracks from forming in harsh environments, such as in the deep-sea oil wells that Xu and Demkowicz were originally investigating. Thinking even further down the line, the energy stored within disclinations may even be harnessed to help modify other material properties, such as strain hardening, they said.

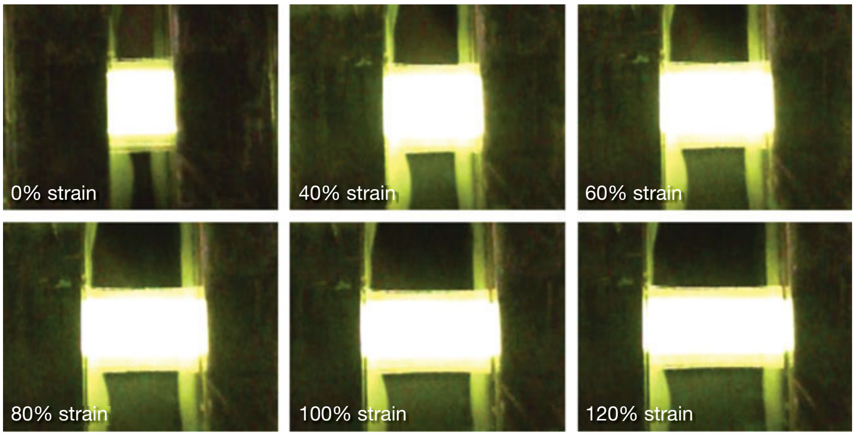
Demkowicz looks forward to further exploring the newly discovered mechanism. These efforts will include *in situ* experiments, developing design tools to create microstructures best suited to self-healing and, eventually, figuring out how to undertake cheap and efficient large-scale processing. "Here we have a truly new mechanism, something previously not known, that goes against conventional wisdom of fracture mechanics," he said. "To me it's extremely exciting because it opens up opportunities that previously did not exist."

Rachel Nuwer

New OLED overcomes elasticity obstacles

Stretchable electronics and displays represent a rapidly expanding technology. While difficult to fabricate due to the challenge of combining elastic components with rigid and brittle inorganic light-emitting diodes and organic light-emitting diodes (OLEDs), these devices offer remarkable advances in the development of expandable and foldable screens, wearable electronics, and biocompatible light sources for *in vivo* or epidermal medical devices.

In the October issue of *Nature Photonics* (DOI: 10.1038/nphoton.2013.242; p. 817), J. Liang and co-workers from the University of California–Los Angeles report the fabrication of an elastomeric polymer light-emitting device (EPLED) comprised of an electroluminescent polymer layer sandwiched between a pair of transparent composite electrodes. The group of scientists, led by Qibing Pei, prepared the rubbery composite electrodes by casting a thin silver nanowire (AgNW) network on the surface of a poly(urethane acrylate) (PUA) matrix. The electroluminescent polymer layer is a blend of commercially available products such as SuperYellow, a yellow light-emitting polymer, ethoxylated trimethylolpropanetriacrylate (ETPTA), poly(ethylene oxide) (PEO), and lithium trifluromethane sulfonate (LiTf). The resulting EPLEDs exhibit high transparency, emit from both surfaces with uniform high efficiency, and are collapsible at room temperature. Light emission continues even when the device is exposed to strains as large as 120%, and they can be stretched repeatedly up to 1000 times at 30% strain.



Device characterization of a stretchable polymer light-emitting electrochemical cell. Reproduced with permission from *Nat. Photonics*. **7** (2013), DOI: 10.1038/nphoton.2013.242; p. 817. © 2013 Macmillan Publishers Ltd.

In another experiment, the researchers showed that the device can be bent and folded without mechanical or electrical damage and without compromising its light-emitting properties. With these promising results, the researchers anticipate that fully stretchable OLED displays for high-resolution display of information will be achieved in the near future.

Dominica H.C. Wong

Addendum

In the October 2013 issue of *MRS Bulletin*, the authors (Oliver and Welander, p. 816) would like to acknowledge their colleagues at Berberian & Company, IARPA, Lincoln Laboratory, MIT, NEC, and the University of Tokyo with whom they have had numerous fruitful discussions and interactions related to the topics presented in their review article. The work at Lincoln Laboratory was sponsored in part by the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), through the Army Research Office; and by the Assistant Secretary of Defense for Research & Engineering under Air Force Contract Number FA8721-05-C-0002. All statements of fact, opinion, or conclusions contained herein are those of the authors and should not be construed as representing the official views or policies of IARPA, the ODNI, or the US Government.