a neighbor, such that the total energy is enough to break up one of the molecules. It is less of a problem in green- and red-emitting PHOLEDs because it takes lower energies to make these colors.

"That early work showed why the blue PHOLED lifetime is short, but it didn't provide a viable strategy for increasing the lifetime," said Yifan Zhang, a recent graduate from Forrest's group who is first author on a new study published in the September 24 issue of *Nature Communications* (DOI: 10.1038/ncomms6008). "We tried to use this understanding to design a new type of blue PHOLED," says Zhang.

The solution, which was demonstrated by Zhang and Jae Sang Lee, a current doctoral student in Forrest's group, spreads out the light-producing energy so that molecules are not as likely to experience the bad synergy that destroys them.

The blue PHOLED consisted of a thin film of light-emitting material sandwiched between two conductive layers—one for electrons and one for holes. Light is produced when electrons and holes meet on the light-emitting molecules.

If the light-emitting molecules are evenly distributed, the energetic electron–hole pairs tend to accumulate near the layer that conducts electrons, causing damaging energy transfers. Instead, the team arranged the molecules so that they were concentrated near the hole-conducting layer and sparser toward the electron conductor. This drew electrons further into the material, spreading out the energy.

The new distribution alone extended the lifetime of the blue PHOLED by three times. Then, the team split their design into two layers, halving the concentration of light-emitting molecules in each layer. This configuration increased the lifetime tenfold.

Nano Focus

Gradient microstructures alleviate pitfalls of nano-grained metals

While steel may be the benchmark for high-strength metals, materials science and engineering is now able to engineer materials that surpass this standard. Through processes such as grain refinement, metals that are typically thought of as much weaker take on unprecedented properties that rival those of traditional and even high-strength steels. This process of grain refinement strengthens metallic materials by reducing the average grain size to the nanoscale. While this may improve the strength of the material it is not without its drawbacks. Metals that are often very weak and ductile such as copper or aluminum experience a significant increase in strength when processed to have nanosized grains. However, they often become very brittle, which leads to cracking and premature failure. The origin of this brittleness, which is seen in tension, is attributed to localized strains occurring at the grain boundaries. This localization of strain in the nano-grains results in void formation and intergranular cracking.

One solution to this problem of tensile brittleness has been reported by K. Lu of Shenyang National Laboratory for Materials Science in Shenyang, China, in the September 19 issue of *Science* (DOI: 10.1126/science.1255940; p. 1455). Lu studied gradient microstructures in copper to resolve the problem of increased tensile brittleness that accompanies nano-grained metals. Gradient microstructures are categorized by a gradual increase in grain size, starting from nanoscale grains at the surface to a more coarse-grained microstructure near the center. The researchers were able to induce this unique type of microstructure by generating a strain gradient in a coarse-grained metal so as to cause increased deformation near the surface.

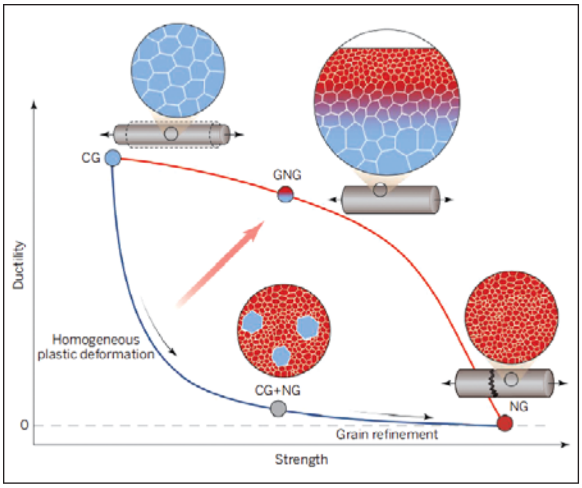

Illustration of the tradeoff between strength and ductility that typically accompanies the shift from a coarse-grained (CG) to nano-grained (NG) microstructure (lower curve). This is compared to the synergy achieved with gradient nano-grained (GNG) structures (upper curve). Credit: K. Lu.

This novel approach to microstructural engineering also leads to the enhancement of other mechanical properties. Microstructural plastic deformation under tension, which typically occurs prior to failure in these materials, occurs simultaneously throughout materials with a very narrow grain-size distribution. In materials with a grain-size gradient in contrast, plastic deformation begins first in the coarse-grained region before transmitting into areas of finer and finer grains as the applied load is increased. This gradient effect helps to relieve strain localization, which leads to an increased yield strength (the onset of irreversible deformation) without sacrificing ductility. The researchers also found that this exterior gradient of finer grains helps to improve fatigue resistance and suppress detrimental surface cracking. This work has helped to explore gradient grained materials that retain the ductility of metals with coarse microstructures, while still benefiting from the enhanced strength of nanoscale grains.

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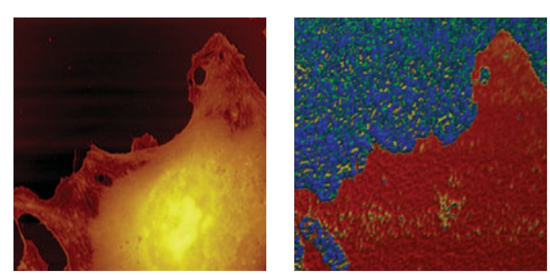

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