Bio Focus

Bionic plants point toward leafy sensors and power sources

Plants are hardy organisms, built to withstand the elements. A new field, plant nanobionics, intends to tap into that power to not only create more robust plants, but also form more robust materials. As reported in the April issue of *Nature Materials* (DOI: 10.1038/nmat3890; p. 400), a research team from the Massachusetts Institute of Technology (MIT) has shown how the fusion of plants, carbon nanotubes, and ceria nanoparticles improves plant function, especially in the power-generating chloroplasts.

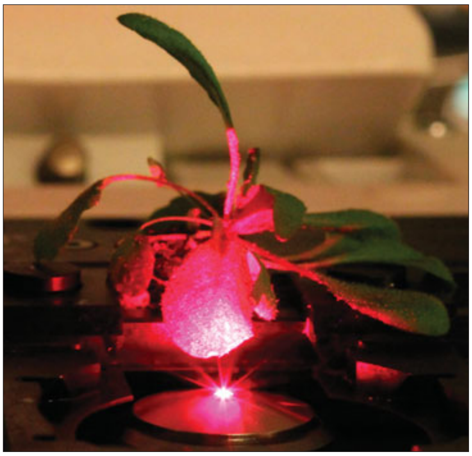
"Plants can do so much," said Michael Strano, a chemical engineer at MIT. "And humans [and other animals] have nothing that compares to the [tissue] repair cascade that plants can do. So we flipped our thinking. Why not see plants as technology?"

Together with plant biologist Juan Pablo Giraldo, Strano and his research team chose nanoparticles and solutions that had proven nontoxic in previous experiments with mice. Due to their special optical and electronic properties, single-walled carbon nanotubes (SWNTs) can enhance photosynthesis processes. The team was also particularly interested in ceria nanoparticles (nanoceria), which have been shown to boost healing properties in bioimplants by absorbing free radicals that can cause tissue damage.

But getting the nanoparticles into the plant was another matter. Going up the roots seemed the logical pathway, but plants have evolved safeguards to prevent foreign objects from entering that way, said Strano. Giraldo identified another possible pathway: through the leaves.

On the underside of leaves, pores allow carbon dioxide in and oxygen out. When a solution containing the nanoparticles was applied, a backflow effect occurred, with the carbon nanotubes getting absorbed into the leaf. Because the nanotubes were wrapped with polymers or materials that had an affinity for lipids in the chloroplast, they were drawn there, attaching and creating nano-enhanced plants.

Strano and Giraldo ran three experiments, testing the capabilities of the new bionic plants. First, the carbon nanotubes were tuned to respond as a sensor, dropping their near-infrared light emission in the presence of toxins such as pollutants. Second, since the nanotubes could be used to absorb light at wavelengths outside the normal photosynthesis range, extracted chloroplasts with the nanoparticles showed a 49% boost in light energy capture outside plants and 30% inside leaves of living plants. And third, with the help of the nanoceria combined with nanotubes, the chloroplasts were even more robust outside of the plant, rendering them capable of capturing light energy for several hours more than nontreated chloroplasts.



The *Arabidopsis* plant, with carbon nanotubes absorbed inside its leaves, has augmented light energy capture and may act as a photonic biochemical detector. Image credit: Juan Pablo Giraldo.

"This is unlike anything we've seen before," said Giraldo. "But we need to do more work to understand how the carbon nanotubes" aid in boosting the plants' abilities.

While these are proof-of-concept ideas right now, Strano foresees many possible applications, not the least of which is materials that have a self-healing property. Imagine, his team said, a cell-phone case that fixes itself after a drop. In addition, there is also the hope of a plant-powered solar cell that could have a negative carbon footprint; it would actually use carbon dioxide to produce clean, environmentally friendly energy.

Meg Marquardt

Nano Focus

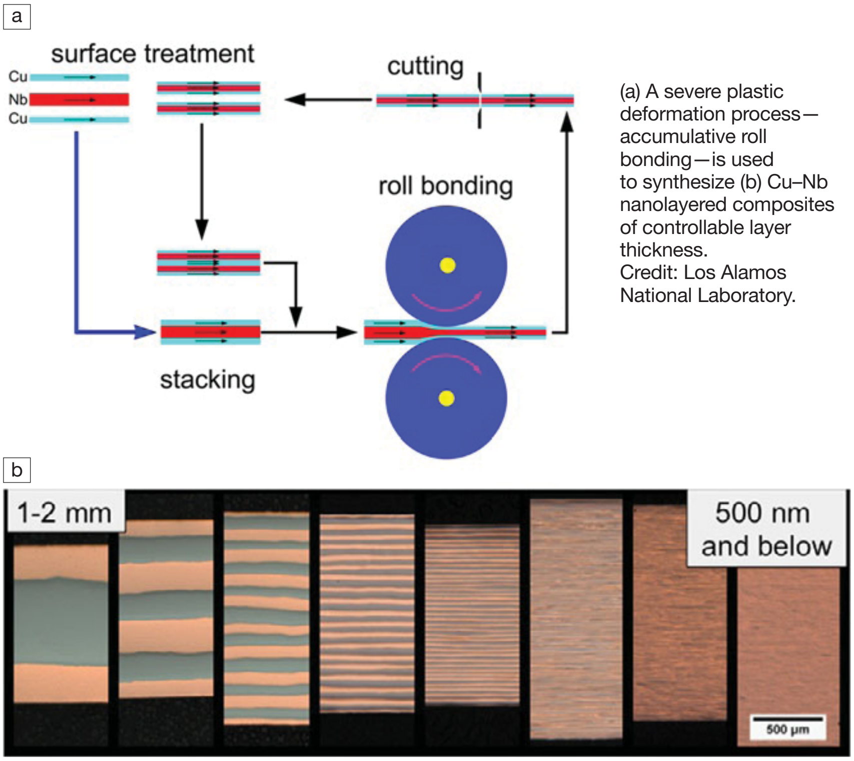
Stable bimetallic interfaces achieved in extreme plastic deformation

Generating uniformly ordered interfaces in bulk nanostructured metals is a challenge in designing materials that are stable under extreme environment conditions, such as next-generation, highly energy-efficient systems. Irene J. Beyerlein, Amit Misra, and their colleagues at Los Alamos National Laboratory have shown that by imposing an extreme amount of plastic strain in a Cu–Nb nanolayered crystal system, low-energy, well-ordered bimetal interfaces evolve.

According to Beyerlein, the project lead in this work, the research team has been studying interfaces in bimetallic nanocomposites in order to understand this phenomenon at the microscopic and atomic-scale level. She said that under extreme conditions defects, voids, or damage in a material is expected. However in this case, "what was surprising is that the interface that emerged was ordered, similar to the interfaces found in epitaxially grown films," she said. Most remarkably, experimental evidence showed that this preferred interface occurs ubiquitously throughout the volume (>cm^3) of the nanocomposite. This interface was also stable with respect to further straining, high-temperature exposure, and irradiation, giving the nanomaterial extraordinary tolerances in other extreme environments.

As reported in the March 25 issue of *PNAS* (DOI: 10.1073/pnas.

1319436111; p. 4386), the researchers fabricated Cu–Nb nanolayered materials in bulk form (>cm^3) and imposed extreme strains. To identify the stability conditions that govern the emergence of a preferred interface at extreme strain, they combined theory, atomic-scale modeling, and experimental characterization. They used accumulative roll bonding (ARB), a severe plastic deformation (SPD) process often proposed for the production of ultrafine grain metals. The figure shows that ARB is characterized by rolling a stack of metal sheets; the stack is repeatedly rolled to a severe reduction ratio, sectioned into two halves, piled again and rolled. The researchers used an alternating stack of sheets of these two dissimilar, immiscible metals, Cu and Nb, to carry out the ARB process. Unlike conventional rolling, ARB strains the sample through a cycle of rolling, cutting, and restacking, and maintains the original sample dimensions.



(a) A severe plastic deformation process—accumulative roll bonding—is used to synthesize (b) Cu–Nb nanolayered composites of controllable layer thickness.
Credit: Los Alamos National Laboratory.

In this work, the researchers imposed extreme strains, decreasing the height by 5–6 orders of magnitude, from 2 mm to 20 nm. This is equivalent to stretching a nickel coin to 2.2 km in length (or strains exceeding 12).

Beyerlein said that the ARB technique can make nanostructured composites in large quantities sufficient for structural applications. “This work paves a way to looking at different materials structures that go beyond the Cu–Nb systems,” she said.

Additionally, to understand this phenomenon, the team applied atomic-scale and crystal-plasticity simulation. The results revealed that the preferred interface is one of few interfaces under extreme straining that can remain plastically stable while forming interfaces corresponding to a minimum in formation energy.

This finding has the exciting potential of eliminating the aforementioned tradeoff and permitting the creation of materials with pristine interfaces in stable nanocomposites of unlimited quantities. Most significantly, it points to other interfaces that could also emerge in extreme straining and exhibit similar stability properties. This work introduces an innovative way toward manipulating interfaces through severe plastic deformation for target material properties.

Jean L. Njoroge