Bio Focus

Soft microrobots propelled by structured light

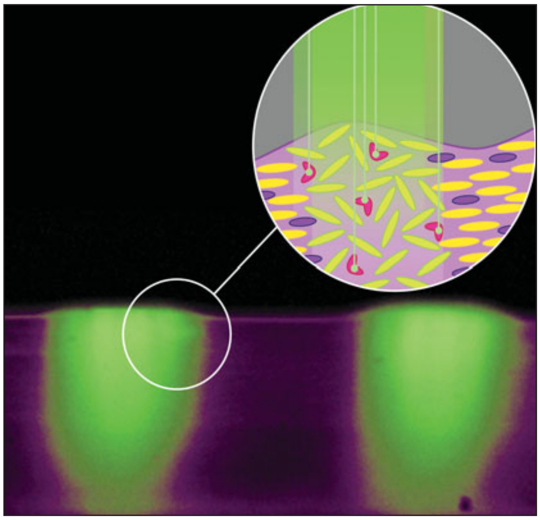
Miniature robots or microbots now have a new way to move—using only light. In an article published in a recent issue of *Nature Materials* (doi:10.1038/NMAT4569), a group of European researchers, led by Peer Fischer and first authored by Stefano Palagi, both from the Max Planck Institute for Intelligent Systems in Germany, explain how a soft microbot can be made to swim in a viscous medium just using patterned light.

Researchers have repeatedly turned to nature for inspiration in designing small-scale robots. Worms move by sending waves of muscle contractions down their body in a process termed peristalsis, similar to how food moves through the digestive tract in humans. Centipedes move their numerous legs sequentially creating what is called metachronal motion. However, implementing these designs in a small machine has not been easy or efficient.

The microbot developed in the present study is a liquid-crystal elastomer (LCE) cylinder, the largest being 170 µm in diameter and a millimeter in length. When appropriately excited using light, the LCE contracts lengthwise and expands radially. Alternating light and dark patterns over the cylinder causes the microbot to deform its body in a periodic way, creating wave-like propulsive motion. Thus the robot can be made to swim in a liquid using only light-powered body-shape changes.

By constructing the microrobot from a continuously addressable, soft active material and taking the onus of coordination of movement away from the microbot and putting it in the hands of an external light field that can be structured easily, the researchers have inverted the concept of microbot actuation.

"It's the first time I've seen people make an analogue of a microscopic swimmer. Since it's actuated by structured light, there are no external forces or torques acting on the device, so it is a true swimmer," says Thomas Powers, a professor at Brown University not associated with the study.



Cross section of a liquid-crystal elastomer microrobot (false color image) whose movement, powered by light, mimics that of a ciliate protozoa. The green illuminated sections show where radial expansion—or deformation—occurs versus the relaxed state. The schematic further depicts this localized phase transition—from the nematic to the isotropic phase. Credit: Stefano Palagi, MPI-IS.

The speed with which a microrobot moves depends on the medium, the wavelength of the light pattern, and structural parameters such as its length. Using a light pattern that is swept at 2 Hz across the microbot causes it to move a distance of 100 µm with speeds of 2–3 µm/sec. The study suggests that this performance can be improved through the use of faster responding materials.

The researchers also developed a detailed theoretical model to analyze their results. An interesting observation is that the microbot exhibits two modes of motion, termed *positive* and *negative*. The motion is led by radial expansion at small wavelengths, whereas longitudinal contraction becomes important at large wavelengths (relative to body length). This causes the microbot to swim in opposite directions depending on the deformation wavelength. These distinct modes are also seen in microscopic protozoa called ciliates.

Peter Palffy-Muhoray, a professor at Kent State University and also not connected with the work, told MRS, "The authors have succeeded both in producing microrobots capable of swimming and locomotion, and in showcasing the tremendous versatility of soft photoresponsive materials. Capable of large, rapid and continuous shape changes, liquid-crystal elastomers literally dance under structured light. They are certain to play a key role in the emerging robotics–human interface."

Vineet Venugopal

Heteroepitaxial nickel-alloy thin films grown on diamond

With the demand for ever smaller and more powerful laptops and smartphones, there is a continuing need to develop new electronic materials. Diamond offers an exciting prospect in the search for new, hardier materials that can be employed in extreme and novel environments.

A team of researchers in Moscow have taken a significant step toward diamond-based electronics—which are useful for high-temperature, high-power microwave electronics—with work detailed in a recent issue of *Crystal Growth & Design* (doi:10.1021/acs.cgd.5b01520). Using previous advances in growing high-quality diamond on metal as a starting point, Stanislav Evlashin of the Russian Academy of Sciences (RAS) and Lomonosov Moscow State University and colleagues sought to further improve the processing and properties of metal films on diamond. They focused their study on the heteroepitaxy of nickel-based (Ni-Cu, Ni-Cu-Cr, and Ni-W) alloys on the surface of diamond.

Speaking about the inception of the work, Evlashin says, "The main idea to 'flip' the task of the growth of a diamond on metals to the growth of heteroepitaxial

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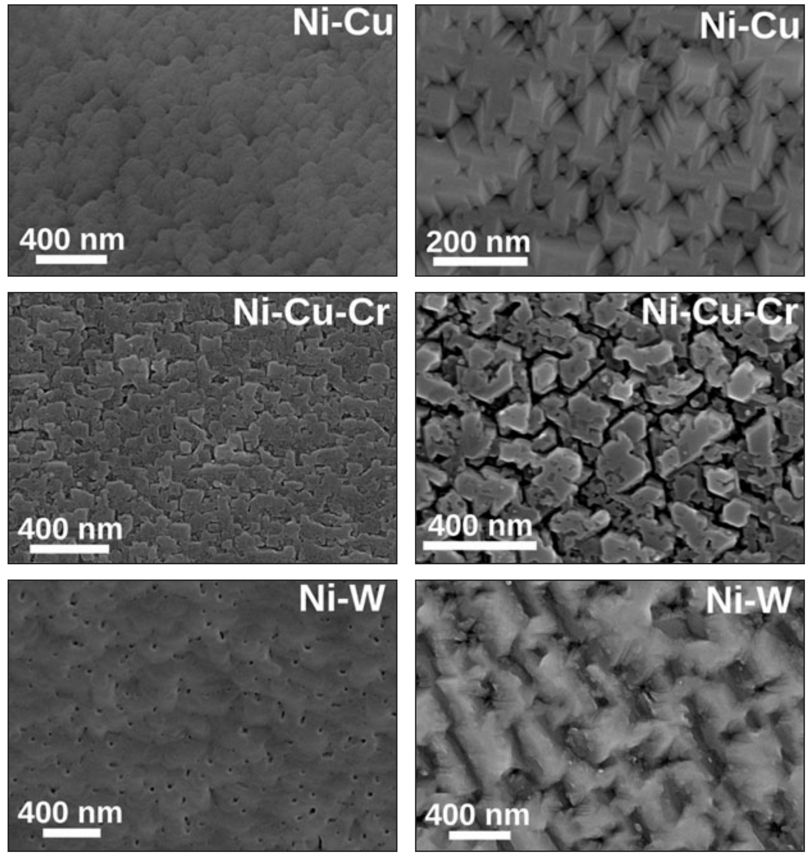
layers of metals on a diamond belongs to Nikolay Suetin [of Lomonosov Moscow State University].” This “flip” allowed the use of magnetron sputtering, a commercially available and economical technique. But growing ultrathin high-quality solid metal films on diamond presented other challenges.

Due to its chemical stability, metal adhesion to diamond tends to be poor. One solution is to form a metal carbide, although these often have undesirable properties. Iridium adheres to diamond without forming a carbide, but Evlashin and his team found that their iridium films were of poor quality—strain caused by the large mismatch between the film and substrate lattices ruined the film. Roman Khmelnitsky (RAS) suggested nickel-based alloys, which have a lattice parameter that is nearly identical to that of diamond, thereby solving the mismatch problem. They hoped that heteroepitaxy would provide sufficient adhesion. These alloys also should not form carbides at the relatively low growth temperatures. With a few carefully chosen Ni-Cu alloys, Evlashin and his colleagues grew and characterized several films.

“The big surprise was that heteroepitaxy had been achieved at a temperature of 290°C, and the parameters of the crystal lattice of [the diamond substrate] and the films differed by less than 0.5%,” Evlashin says. They had achieved high-quality, ultrathin heteroepitaxial films at a much lower temperature than expected. Furthermore, the combination of magnetron sputtering and low deposition temperature reduced fabrication costs dramatically, which is encouraging for future work. And the 0.5% mismatch is especially good—“It’s a record,” Evlashin says.



Scanning electron micrographs of heteroepitaxial films on diamond. Credit: *Crystal Growth & Design.*

The vitality of diamond electronics depends on the ability to create durable and effective metal contacts on diamond. But this work also has applications in radiation sensing, and may have impact as far reaching as nanophotonics and quantum computing. Evlashin and colleagues have opened the door to a new avenue of research and discovery in electronic materials.

Antonio Cruz

Thermoelectric power of texture revealed in SnSe

The thermoelectric materials community has recently been turning its attention to tin selenide (SnSe), whose thermoelectric properties were generally overlooked until a record value of 2.6 for the thermoelectric figure of merit *ZT*, the parameter expressing the efficiency of heat-to-electricity conversion, was recorded in a SnSe single crystal (*Nature*, doi:10.1038/nature13184). This outstanding result was associated with structural anisotropy and the strongly anharmonic bonding that together yield an ultralow intrinsic thermal conductivity. That SnSe comprises abundant and environmentally friendly elements has further motivated the study of polycrystalline SnSe, which is better suited to industrial scale-up than single crystals.

Doping and texturing have been exploited to improve the performance of polycrystalline SnSe, but early results suffered from uncertainty and failed to deliver $ZT > 1$. In a recent report in the *Journal of Materials Chemistry C* (doi:10.1039/c6tc00204h), a team of researchers from Scotland and France have further explored the impact of texturing on the thermoelectric behavior, revealing how small regions of structural disorder dramatically affect the thermal conductivity of SnSe samples. “The optimization of the thermoelectric performance is already challenging for nominally isotropic materials, but is of even greater complexity in materials such as SnSe, where texturing

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