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ORGANIC-INORGANIC PEROVSKITES

A lower threshold for nanowire lasers

Hybrid perovskite is introduced as a new member of nanowire nanolasers. One-dimensional nanostructures of these perovskites can be optically pumped to lase with tunable wavelength at relatively low threshold, which marks a step toward their use in integrated photonics.

Anthony Fu, Peidong Yang

Semiconductor nanowires are excellent candidates for the realization of miniaturized lasers; in fact, their faceted structure naturally behaves as an optical cavity in which light can resonate, and the gain medium they are made of provides the optical amplification required to trigger lasing action.[1] Bottom-up fabrication approaches have unlocked the synthesis of nanowires based on a broad range of materials that are inaccessible through conventional top-down techniques, especially for materials with complex compositions. Writing in *Nature Materials*, Haiming Zhu and colleagues now show that hybrid organic-inorganic metal halide perovskites, which have recently transformed photovoltaic research[2], are also an outstanding member of this materials family.[3]

The low-temperature synthesis of organic-inorganic metal halide perovskite nanowires using solution-processed methods is nontrivial. In fact, this material is known to be generally unstable in water and in many polar organic solvents. In addition, the traditional vapor-liquid-solid process for the synthesis of semiconductor nanowires requires a metal droplet to initiate the one-dimensional crystal growth,[4] but it is unlikely that a metal catalyst can be found for this complex organic-inorganic metal halide perovskite. An alternative, catalyst-free approach has been proposed for the synthesis of semiconductor nanowires, in which screw dislocations (linear crystallographic defects) in seed particles are used to initiate the nanowire growth.[4] The strain induced in the crystallographic structure by these defects promotes fast one-dimensional growth of the crystal in a helical trajectory, in a direction along the axis of the screw dislocation.

The team was able to synthesize, at temperatures as low as 80 °C, perovskite nanowires following this second route. They deposited a polycrystalline film of lead acetate onto a glass substrate and dipped it into a solution of isopropyl alcohol and CH_3NH_3X, where X = Cl, Br, I, or a halide mixture. According to the growth mechanism suggested by the researchers, at this stage part of the lead acetate layer reacts with the solution and is converted into a thin film of $CH_3NH_3PbX_3$ with many dislocations. This initial perovskite film is a diffusion barrier that prevents further rapid reaction between the solution and the lead acetate remaining underneath this film. The slow dissolution of Pb from the unreacted lead acetate produces an intermediate precursor, PbI_4^{2-}, which promotes the growth of crystalline nanowires driven by the dislocations in the perovskite seed layer.

Through various characterization techniques, the researchers observed that each nanowire is a single crystal with smooth facets, which makes these structures efficient nanoscale optical cavities. This result is particularly intriguing considering that high temperatures are generally needed to grow inorganic crystals with sufficient quality for lasers and solar cells, and traditional inorganic semiconductor nanowire lasers are generally grown at temperatures greater than 400 °C in a typical gas phase deposition process[1,4].These perovskites defy conventional expectations by combining the low-processing temperatures of organic materials with the extended translational symmetry of inorganic crystals, which is favorable for charge transport.

The nanowires showed an extremely high light-emitting efficiency, higher than 87% for the iodide samples. Importantly, the researchers observed lasing emission at optical stimulation as low as 220 nJ cm^{-2}, with tunability of the lasing wavelength across the visible spectrum obtained by modifying the material composition (Fig. 1). Lasing from films[5] or platelets[6] of hybrid organic-inorganic perovskites has been already reported, yet the performance of these first prototypes was not optimal, possibly as a result of the limited crystalline quality of the materials used. The exceptional low lasing threshold of these perovskite nanowire lasers, lower than that of any other semiconductor nanowire to date, is a direct proof of the significant reduction of structural defects obtained with the growth approach used in this study; in fact, optical losses due to scattering or to imperfect reflections of the mirror end-facets are strongly attenuated.

A complete understanding of the growth mechanism of these nanowires will require further investigation. Although imaging by means of transmission electron microscopy would provide direct confirmation of the screw-dislocation driven growth, such analysis has proved to be challenging, because perovskites materials are unstable under the electron-beam irradiation conditions required by this technique. Hence, alternative approaches will have to be used to validate the one-dimensional growth model proposed by these researchers. In addition, a complete rate equation model describing the photophysical processes taking place in these materials may help to improve our understanding of the threshold behavior. Lastly, the demonstration of electrically-injected lasing will require the development of fabrication strategies and device architectures that minimize the detrimental increase of optical losses due to the deposition of metallic contacts on the cavity.

It is interesting that these ionic perovskite materials seemingly have optical properties that are comparable to classic covalent semiconductors such as gallium arsenide. However, this very ionic character also contributes to their sensitivity to air and moisture, and is likely to limit their potential application in advanced photonic circuits if this stability issue is not addressed. Yet, the exceptional performance reported by Zhu and colleagues already put hybrid organic-inorganic perovskites at the forefront of laser research.

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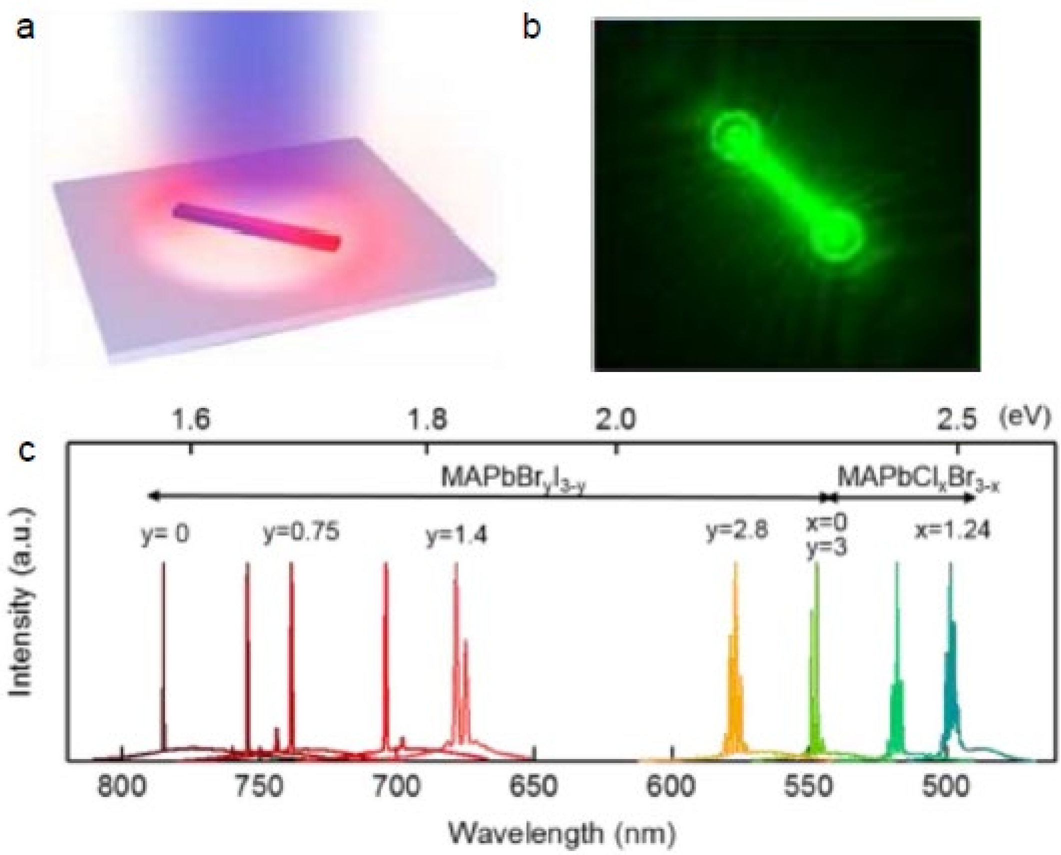

Figure 1| Lasing in hybrid organic-inorganic metal halide perovskite nanowires. **a,** Illustration of an optically pumped perovskite nanowire on a Si substrate with 300-nm-thick SiO_2. **b,** Optical image of a 13.6 μm-long $CH_3NH_3PbBr_3$ nanowire showing lasing emission. **c**, Lasing spectra of various alloy compositions of mixed lead halide perovskite nanowires demonstrating widely tunable laser emission at room temperature.