Flexible photonic crystal from liquid thin-film metasurface

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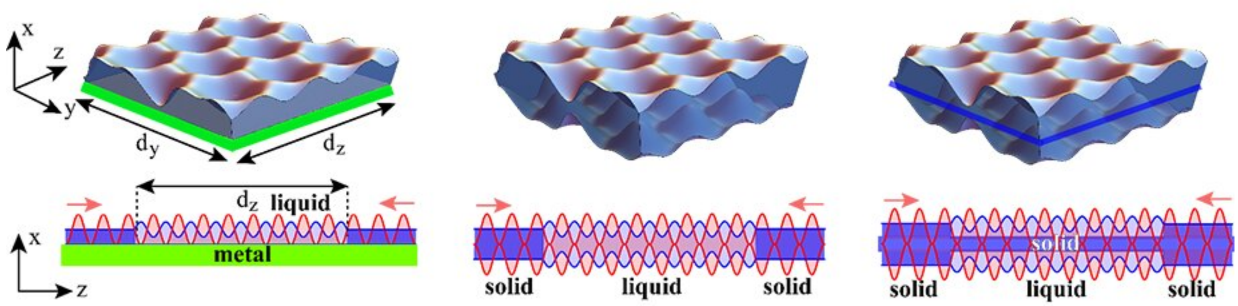

Schematic presentation of TLD film deformation forming optical liquid lattices (blue) due to surface tension effects triggered by interference of surface optical modes (red). (a) 2-D plasmonic liquid lattice formed by interference of SPPs. (b), (c) Suspended and supported photonic liquid lattice, respectively, formed by interference of photonic slab WG modes. Gain can be introduced into the suspended structure (c) either to the liquid or to the dielectric supporting membrane. The lateral dimensions of the liquid slots, which are bounded by solid dielectric walls (not shown) are dy and dz. (d)–(f) The corresponding 1-D optical liquid lattices in a liquid slot of length dz induced by pairs of (d) counterpropagating SPPs or (e) and (f) slab WG modes. Credit: The Authors. Published by SPIE and CLP under a Creative Commons Attribution 4.0

Photonic crystals are predicted to be one of the wonders of the 21st century. In the 20th century, new understanding of the electronic band structure-the physics that determines when a solid conducts or insulates-revolutionized the world. That same physics, when applied to photonic crystals, allows us to control light in a similar manner to how we control electrons. If photonic crystals live up to their promise, all-optical transistors that consume little power and enable even more powerful computers could become a reality.

But, that destination isn't in sight yet. The problem is one of control. We have exquisite control over the fabrication of electronic integrated circuits, and semiconductors and electrons are very flexible-if you want to change the energy of an electron, just apply a voltage.

Controlling the fabrication of photonic crystals is more difficult. Each tiny structure has to be manufactured and precisely replicated and placed. Once made, a photonic crystal is unchanging, which makes it very inflexible. Likewise, photon energies can't be changed as efficiently as electron energies. The upshot being, if photonic crystals are the future of computing, we will have to learn how to make them in a way that allows them to be modified on the fly.

Rippled fluid films as metasurfaces

In a new *Advanced Photonics* paper, Shimon Rubin and Yeshaiahu Fainman from University of California San Diego have shown how it might be possible to create a flexible yet durable photonic crystal from a liquid. They performed a series of calculations to predict the formation and performance of a photonic crystal based on very localized heating in liquid thin films.

Liquids are generally not considered a great choice for a photonic crystal because liquids don't have a fixed structure. The optical properties of a photonic crystal depend on light being able to reflect millions of precisely placed structures. But liquids ebb and flow, so structures are quickly washed away.

However, Rubin and Fainman noted that at the interface between a thin liquid film and a solid or gas, the interplay between the liquid's surface tension and the local temperature can create a small structure (e.g., the liquid piles up to create a little hill). However, it wasn't known if the structures were significant enough to function as a metasurface (a type of photonic crystal) and modify light propagation.

The researchers investigated several arrangements of liquid films that readily allow light to be guided (at least partially) within the liquid. To obtain a structure, the researchers considered how light absorption might heat the liquid. By using light waves that cross each other at different angles inside the film, a pattern of bright and dark patches is created-this pattern is called a standing wave pattern. The liquid absorbs energy only from the bright patches, hence, the liquid will only heat up at very specific locations.

Flexible fluids

The researchers used the optical and thermal properties of the liquid, combined with fluid dynamic equations and light propagation to calculate the heat absorbed by the fluid, and how that would cause it to locally deform. The researchers showed that periodic arrangements of hills and valleys in the liquid film could be obtained by crossing between two and four light waves. Two light waves create lines of hills and valleys, three light waves create hexagonal arrangements of hills and valley, while four light beams create a chess-board arrangement. Optical properties were then calculated from these spatial arrangements.

To demonstrate the usefulness of their proposed metasurface, the researchers calculated the threshold of a laser. If a gain media like a dye is added to the fluid, the periodic deformation of the liquid as described above can lead to formation of resonators, capable to support lasing modes. Modifying the symmetry of the photonic liquid crystal then enables control of the frequency and emission direction of the lasing mode.

Liquid photonic crystals seem to have some very nice properties. Because light is used to create the pattern in liquid, the pattern forms naturally and without errors. And, the pattern can be changed on the fly by changing the angle between light waves, or wavelength of the light used to create the pattern. Even moving patterns can be created by modulating one of the light waves. This inherent flexibility should enable many interesting applications in, for instance, computation and health care. However, the success of this approach will depend on a physical demonstration of the basic concept.

More information: Shimon Rubin et al. Nonlinear, tunable, and active optical metasurface with liquid film, *Advanced Photonics* (2019). DOI: 10.1117/1.AP.1.6.066003

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