Novel nanomaterials for cheap and thin electrically responsive films

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Oblique incidence scanning electron microscope image of a plasmonic electro-optic metasurface covered with barium titanate nanoparticles. Credit: Artemios Karvounis

Is it possible for the next generation of optical nanomaterial films to outperform high-purity crystals? Can nanomaterial films form cheap screens that respond faster than liquid crystal displays?

My colleagues and I from ETH Zurich, in Switzerland, have developed a novel type of nanomaterial film with switchable optical properties. In this proof-of-concept report in *Advanced Optical Materials*, we presented an enabling platform to produce electro-optic (EO) films out of novel nanomaterials.

Why are nanomaterial films important?

My advisor Professor Grange wanted to develop a nanomaterial out of tiny particles with EO properties. This would allow us to obtain switchable films at low cost and at a large scale, using bottom-up fabrication methods. As a result, our first task was to identify the optimal EO material. We decided to proceed with barium titanate (BTO), as it is a well-known EO crystal, and it is readily available in suspension or powder form. This approach may have a large advantage for the development of low-cost optical films, as nanoparticles in solutions can be deposited on any type of substrate, including flat, curved or even nanostructured surfaces.

Optical films technology has made huge investments to realise thinner, cheaper and more highly responsive films in recent years. The progress of smart cut methods have enabled the transfer of very thin semiconductor films; however; this is an expensive and complicated process requiring strict conditions between the transferred film and the substrate. This study offers an enabling platform to produce nanomaterial films that maintain the properties of bulk crystals with lower cost and less fabrication burden.

How do nanomaterial films differ from bulk crystals?

Barium titanate is a ferroelectric crystal that concentrates a unique combination of optoelectronic properties; we were surprised to see that the nanomaterial films maintain most of the properties of bulk crystals, though not to the same extent. In terms of linear optical properties, nanomaterial films have a lower refractive index than bulk crystals due to the porosity of the films. Furthermore, the films remain optically nonlinear and generate a considerable second-harmonic signal.

However, the key point of our approach relies on the fact that BTO nanoparticles are precluded from any process that could modify the nanocrystal structure or damage the nanomaterial properties. We managed to demonstrate EO modulators of 300 nm thickness by covering a plasmonic metasurface with the nanomaterial film. The EO coefficients of the film are comparable with commercial bulk EO lithium niobate crystals.

How can you make such thin electro-optic films?

First, BTO has the largest electro-optic coefficient among many other EO crystals in bulk form. Therefore, the EO coefficient of bulk BTO crystals exceeds commercial electro-optic crystals by more than 20 times, so a nanoparticle film can still maintain an EO response stronger than most commercial modulators. Second, we employed a plasmonic metasurface to reduce the size of the device. Metasurfaces are human-engineered nanostructured films that have properties unavailable in nature, allowing them to control light in weird ways. Light can be focused on deeply subwavelength spots called localised surface plasmons, when a plasmonic nanostructure, e.g., a nanowire array is irradiated by light. Researchers have designed and fabricated such an array of a plasmonic nanowire arrays in a gold film of 200-nm thickness and period of 550 nm. The plasmonic metasurface was then covered by the nanomaterial film (see figure). Each pair of nanowires was connected alternately to two electrical terminals on opposite sides of the device and permitted the electrical actuation of the BTO nanoparticles.

Operation principle

The EO devices are illuminated with linear polarised light at the wavelength of 1064 nm. The operation wavelength can be tuned by the geometric characteristic and the refractive index of the films. We choose this wavelength as it is adequate for several pulsed-laser systems with applications in telecommunication networks, medicine and optical tweezers. The nanoparticles are biased under a DC voltage of a few volts, while a train of sub-microsecond electric pulses was applied to the metasurface that controls optical reflectivity dynamically.

Next steps

We want to improve our instrumentation system and test the EO response at higher speeds while upgrading the mechanical stability of nanomaterial films. We are also planning to fabricate increasingly complex structures that can deliver more sophisticated optical functions. For example, this approach could be used to make switchable, ultra-thin metasurface lenses and other flat-optical components.

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More information: Artemios Karvounis et al. Electro-Optic Metasurfaces Based on Barium Titanate Nanoparticle Films, *Advanced Optical Materials* (2020). DOI: 10.1002/adom.202000623

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Bio:

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