Study: Giant ultrafast dichroism and birefringence with active nonlocal metasurfaces

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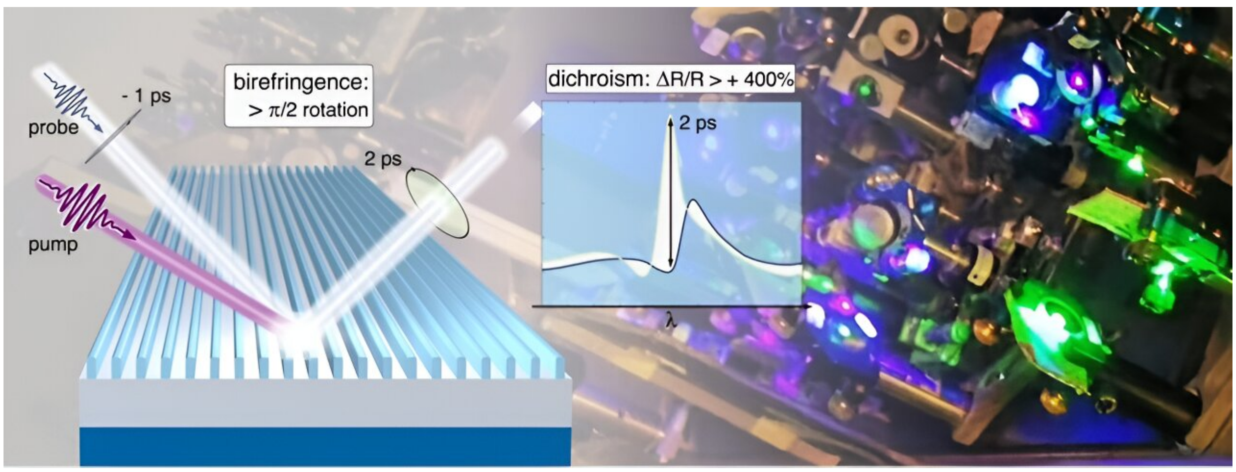

Left: sketch of the working principle of the all-optical modulation of light polarization. The dielectric metasurface is illuminated by an intense laser pulse ("pump", depicted as the purple beam), and its optical properties are transiently changed, following the interaction with light. A second laser pulse ("probe") experiences a modified nanostructure, thus enabling e.g. to commute from linear to circular polarization with giant amplitude modulations on the picosecond timescale. In the background, the ultrafast polarization-resolved spectroscopy setup at work. Credit: *Light: Science & Applications* (2024). DOI: 10.1038/s41377-024-01545-8

The fine and efficient control of the properties of light at ultrafast speed down to the picosecond timescale is a challenging task, crucial for many scientific applications and technologies. For instance, in free-space optical links, manipulating on demand the attributes of light can be exploited to encode and transfer digital information robustly, over long distances and without optical fibers.

In this context, ultrathin nanopatterned materials (metasurfaces) in combination with ultrashort light pulses have gained momentum as a promising, flexible platform operating all-optically. That is, a first intense light pulse transiently changes the system optical properties for a short time interval, while a second weak pulse, interacting with the structure in this time window, is accordingly modified for instance in amplitude or polarization. This modification can be exploited to encode an ultrafast "bit" for communication or computation.

An international team of researchers, led by Professor Giuseppe Della Valle from the Department of Physics of Politecnico di Milano (Italy), has proposed a metasurface capable of extremely efficient modulations of light polarization, achieving notably large variations in amplitude (>400%) and phase (>90°) under low-power photoexcitation.

A new paper with these results has been published in *Light: Science & Applications*. Scientists from Université Paris-Cité in Paris (France) have fabricated the metasurface, while the design, experiments and numerical simulations have been carried on in Milan. The study has been conducted in collaboration with the Italian Institute of Technology, the University of Sofia (Bulgaria) and Australian National University, as part of the H2020 FET-OPEN project METAFAST.

The nanopatterned material is constituted by a few hundreds of nanometers thick (namely less than a hundredth the thickness of a hair) wires of a semiconductor material, AlGaAs, arranged periodically to compose a quasi-flat surface. On this platform, the experiments have shown exceptional performances in the modulation of the polarization of light.

Specifically, the photo-excitation allows for transiently modifying the metasurface dichroic properties: this means that the structure responds in a radically different way to light beams linearly polarized in orthogonal directions, with picosecond variations as high as 470%.

Moreover, for selected wavelengths, this strategy makes it possible to transiently convert linear to almost circular polarization (modulation of birefringence), as in an ultrafast quarter waveplate photo-activated on demand. The exceptional efficiency of these processes is achieved by exploiting the peculiar properties of photoexcited material, combined with a rational design of the metasurface geometrical parameters via numerical simulations.

These results point to a promising approach for the efficient all-optical modulation of light properties, where large contrasts induced by low control pulses are critical for real-world applications. The general validity of the proposed concept can be easily extended to other semiconductor-based platforms and attributes of light, opening exciting routes towards the on-demand manipulation of optical signals for telecommunication and beyond.

More information: Giulia Crotti et al, Giant ultrafast dichroism and birefringence with active nonlocal metasurfaces, *Light: Science & Applications* (2024). DOI: 10.1038/s41377-024-01545-8

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