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New insights into optical switching processes through extremely rapid light-matter interactions

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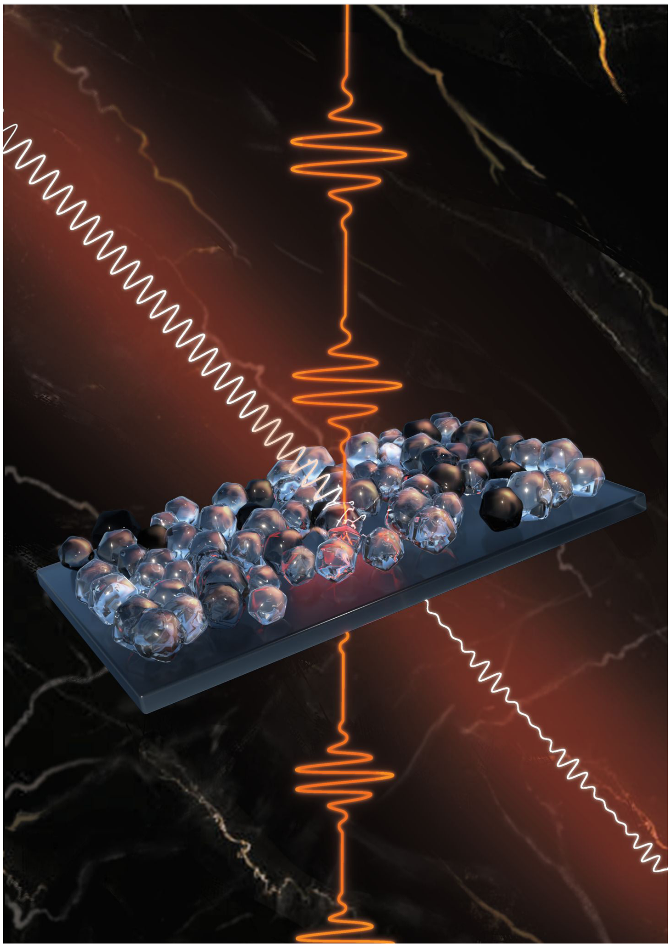
Just as an antenna interacts with radio waves, light interacts with metallic nanostructures. Therefore, understanding how a structure influences field oscillations provides valuable insights into the structure's physical properties. An international research team, including scientists from the Max Planck Institute for the Science of Light (MPL), is investigating the changes in field oscillations that occur when light interacts with indium tin oxide (ITO) nanocrystals. This will deepen our understanding of how the interaction between light and these nanocrystals depends on time.

Precise and high-speed control of light is crucial to optical communication. It opens up the possibility to transmit data more quickly and efficiently in the future. Optical switches, which can activate or deactivate light pulses selectively, are a key component in achieving this.

To ensure optimal performance and prevent delays caused by switching times, the switches must respond very fast. Ideally, they also have the highest possible modulation depth. This refers to the difference in brightness between the light transmitted in the "on" and "off" states. Additionally, a suitable switch exhibits the same predictable behavior each time it is used.

ITO nanocrystals exhibit switchable optical behavior

It is known that ITO nanocrystals exhibit these properties. In a collaborative research project involving MPL and the Politecnico di Torino, scientists used a field-resolved technique for the first time to investigate the interaction between light (in the form of short laser pulses) and ITO nanocrystals. "We observed that the interaction between light and nanocrystals occurs so rapidly



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The optical transparency of ITO nanocrystals can be selectively modified using short laser pulses. As a result, this material shows great potential for use in high-speed optical switches. @ Soledad Cook-Ordone (Artistic rendering).

that its effect can be observed between individual cycles of the oscillating light wave," says Dr. Andreas Herbst, the study's first author and postdoctoral researcher in Dr. Hanieh Fattahi's

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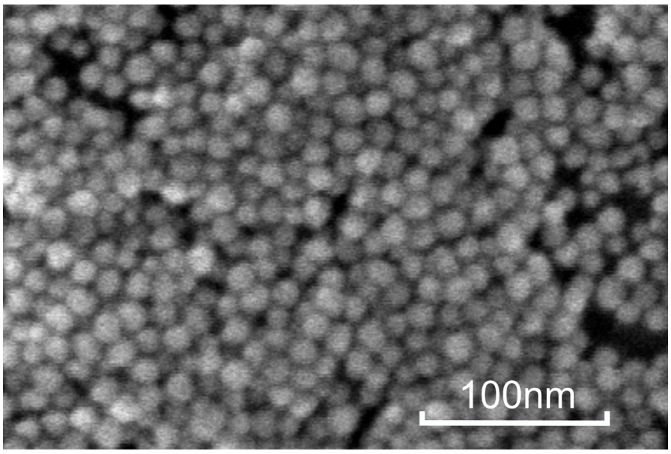
research group “Femtosecond Fieldoscopy” at MPL. “In this process, the end of the pulse is affected more strongly than the beginning.”

in addition, the researchers investigated how the material becomes more transparent as light intensity increases. This effect can be interpreted as a switch between “on” at high intensity and “off” at lower intensity, making this material suitable for this application.

Fieldoscopy provides a direct view of electric light fields

The ITO nano crystals have a diameter of 15 nm, much smaller than the wavelength of the light used in the experiment, which is approximately 2,000 nm. When excited by a light wave of the corresponding frequency, the electrons on their surface oscillate at a specific frequency. The oscillating electrons (localized surface plasmons) couple back to the light wave that excites them, similarly to how an antenna distorts an incident radio wave. The material becomes excited and less transparent



Scanning electron microscope image of ITO nanocrystals. They have a diameter of approximately 15 nm and form a uniform film on a glass substrate. Provided by Ilka Kriegel’s research group at the Politecnico di Torino.

to light of the corresponding wavelengths.

A field sampling measurement can be used to visualize the influence of the nanocrystals on the light. The electric field oscillation of a short laser pulse is measured directly to provide information about the optical properties of a sample. This enables researchers to study the interaction between light and matter on timescales shorter than the period of the optical waves used.

Intense light fields alter switching behavior

The transparency of the ITO nano crystals increases with higher intensity, which can be interpreted as "on" state. Within a certain range of light intensities, this effect is reversible so that the transmission returns to its original “off” state, allowing the switch to be reused. However, if the light is too strong, the switch does not return to its original state and remains permanently switched “on.” Using fieldoscopy, these effects were measured on a femtosecond timescale. This demonstrates the material’s limitations for this application and must be considered in future experiments.

This study provides valuable insights into how ITO nanocrystals behave in the context of optical switching. It also shows how much information about solid samples can be obtained by directly measuring field oscillations. These results underscore the versatility of fieldoscopy and its applicability to solid samples.

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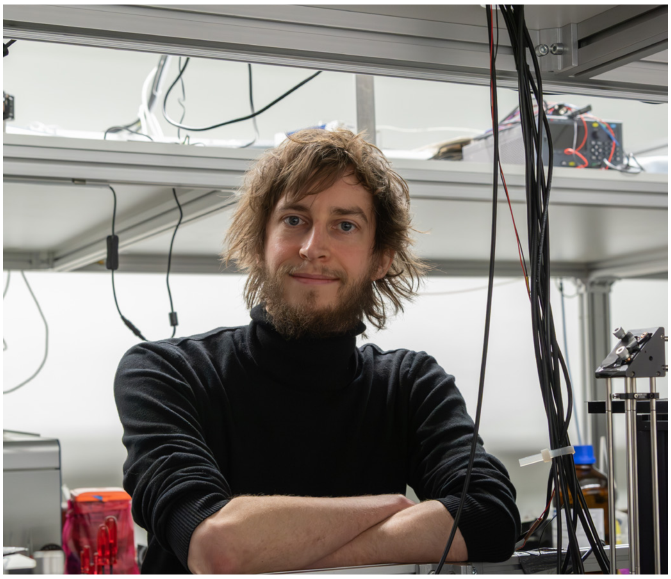

Dr. Andreas Herbst, the study's first author and postdoctoral researcher at MPL, Research group Femtosecond Fieldoscopy.

Research at the Max Planck Institute for the Science of Light (MPL) covers a wide range of topics, including nonlinear optics, quantum optics, nanophotonics, photonic crystal fibres, optomechanics, quantum technologies, biophysics, and – in collaboration with the Max-Planck-Zentrum für Physik und Medizin – links between physics and medicine. MPL was founded in 2009 and is one of the over 80 institutes that make up the Max Planck Society, whose mission is to conduct basic research in the service of the general public in the natural sciences, life sciences, social sciences and the humanities.

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