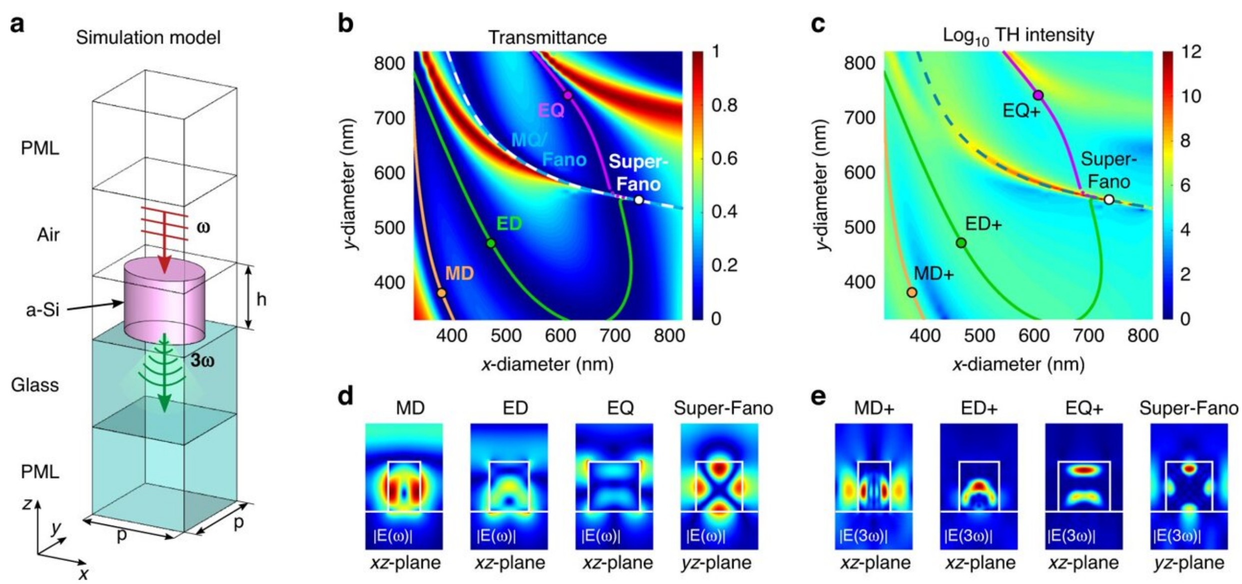
Researchers improving technology to generate high harmonics in nonlinear nanostructured metasurfaces

May 18 2023



Numerical analysis. a Simulation model of a unit cell for the infinitely periodic metasurface consisting of a-Si resonators. b Calculated transmittance and c TH intensity (log scale) maps as a function of elliptical diameters d_x and d_y of the resonator. The colored curves plotted in both maps highlight the paths of the FF mode resonances (b). d, e Calculated electric near-field plots of modes for different resonators with diameters indicated by points in the maps at (d) pump 1560 nm and (e) TH 520 nm wavelengths. The periodicity of the unit cell and the resonator height are p = 916.7 nm and h = 590 nm, respectively. The maximum of the generated TH is indicated by the dot with label Super-Fano in both maps for the resonator with diameters d_x = 740 nm and d_y = 550 nm. Credit: *Light: Science & Applications* (2023). DOI: 10.1038/s41377-023-01134-1

Natural and artificial crystals can change the spectral color of light, which is known as the nonlinear optical effect. Color conversion is used for numerous applications, including nonlinear microscopy for biological structures and material examinations, LED light sources and lasers in optical communications, and in photonics and its resulting technologies such as quantum computing. Researchers from Paderborn University have now found a way to improve the physical process underlying the phenomenon. The results have been published in the journal *Light: Science & Applications*.

"The process is based on the anharmonic potential of crystal atoms and often prompts a precise multiplication of the light frequency, known as generating 'higher harmonics'—similar to the overtones heard when the string on a musical instrument vibrates," Paderborn physicist Professor Cedrik Meier explains.

Although the effect occurs naturally in many crystals, it is often extremely weak. Given this, there have been various approaches to increasing the effect, for example by combining different materials and their structures on a micro and nano scale. Paderborn University has conducted intensive, successful research in this area in recent decades.

One focal point of this research into photonics is metamaterials, and in particular metasurfaces. This involves structured elements being applied in the nanometer range to a thin substrate, which then interacts with incoming light and for example produces optical resonances. With a longer duration and greater focus, the light can generate higher harmonics more efficiently.

An interdisciplinary collaboration sees the research groups run by Professor Cedrik Meier (Nanophotonics & Nanomaterials), Professor

Thomas Zentgraf (Ultrafast Nanophotonics) and Professor Jens Förstner (Theoretical Electrical Engineering) at Paderborn University working together as part of the "Tailored Nonlinear Photonics" Collaborative Research Center/Transregio 142 to develop an innovative approach to generating higher harmonics more efficiently. By using specifically proportioned applications of microscopically small elliptical cylinders made of silicon, they can take advantage of the Fano effect—a particular physical mechanism where multiple resonances intensify each other.

The researchers initially used digital simulation to determine the ideal geometric parameters and investigated the underlying physics. They then created nanostructures using state-of-the-art lithography processes, and conducted optical examinations. They were able to prove through both theory and experimentation that this enables third harmonics—i.e., light with triple the frequency of the incoming light—to be generated much more efficiently than with previous known structures.

More information: David Hähnel et al, A multi-mode super-fano mechanism for enhanced third harmonic generation in silicon metasurfaces, *Light: Science & Applications* (2023). DOI: 10.1038/s41377-023-01134-1

Provided by Universität Paderborn