Nanoscale optical device enables independent control of light intensity and phase using electricity

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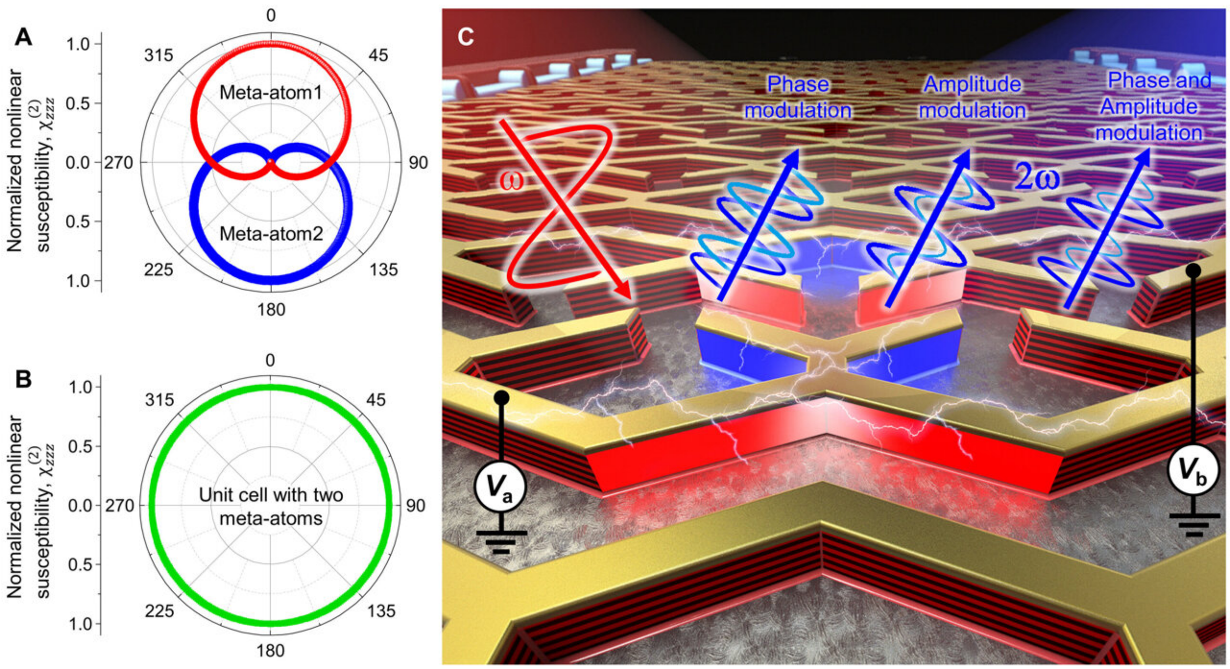

Electrical complex amplitude control of SHG using nonlinear polaritonic metasurface. Credit: *Science Advances* (2025). DOI: 10.1126/sciadv.adw8852

A nanoscale optical device has been developed that allows independent control over the intensity and phase of light. By applying voltage, this innovative device can freely manipulate the phase and magnitude of second-harmonic (SH) light, opening new avenues for advanced quantum communication and information processing technologies. The research is published in *Science Advances*.

Professor Jongwon Lee and his research team in the Department of Electrical Engineering at UNIST created an electrically operated nano-optical component capable of complete, independent modulation of the phase and intensity of SH light. This device represents a significant advancement in nonlinear optics, a field that involves altering light properties through interactions with specialized materials—a fundamental process in generating entangled photon sources and other quantum optical systems.

The nano-optical device is remarkably small—only about one ten-thousandth the size of a fingernail—enabling it to replace bulkier materials and paving the way for lighter, more compact optical systems. Unlike conventional nano-optic components that operate passively, this device can be actively controlled by applying voltage, allowing for the precise adjustment of both phase and amplitude. Such control enables the encoding of more complex information, which is critical for next-generation quantum technologies.

Experimental results demonstrated nearly 100% modulation depth of the SH signal intensity, with the phase tunable over the full 0-to-360-degree range. Additionally, the nonlinear response could be adjusted within a range of approximately 0 to 30 nm/V, indicating that the device can achieve complete electrical control over the complex amplitude in both magnitude and phase space.

Leveraging this technology, the team successfully demonstrated the creation of phase and amplitude gratings, enabling dynamic control of diffraction patterns of the output light. These capabilities have promising applications in real-time wavefront shaping, high-speed data encoding, and contactless optical switching.

The key to this breakthrough lies in the device's surface design, which incorporates nanostructures combining quantum wells and metal nanocavities arranged in pairs with opposite phases (180° difference). This precise engineering allows for highly efficient and independent tuning of nonlinear optical responses.

Professor Lee commented, "We have, for the first time, surpassed the physical limitations of existing nonlinear optical devices by introducing a miniaturized platform that achieves high-speed, high-precision optical control solely through electrical signals.

"This technology has the potential to serve as a foundational platform for active quantum optics systems, such as entangled photon sources and quantum interference control."

More information: Jaeyeon Yu et al, Full complex amplitude control of second-harmonic generation via electrically tunable intersubband polaritonic metasurfaces, *Science Advances* (2025). DOI: 10.1126/sciadv.adw8852

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