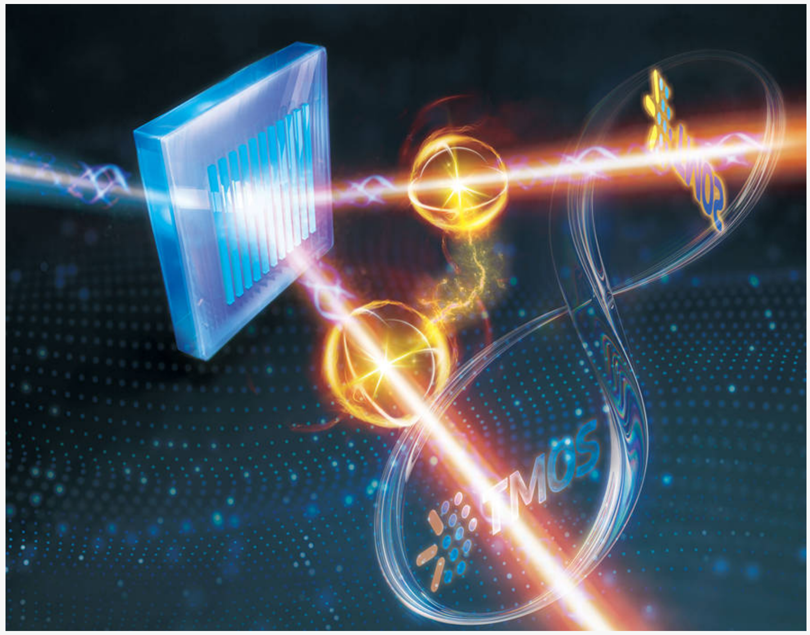
Quantum imaging breakthrough achieved with ultra-thin nonlinear metasurfaces

GA, UNITED STATES, February 10, 2025 /EINPresswire.com/ -- Researchers have experimentally demonstrated a groundbreaking quantum imaging method using ultra-thin nonlinear metasurfaces. The study predicts unprecedented resolution and field of view by combining ghost imaging and all-optical scanning techniques, outperforming conventional bulky systems. This innovation has transformative potential for quantum sensing, imaging, and communications technologies.



Concept of new quantum imaging with ultra-thin nonlinear metasurfaces.

Scientists from the ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS) nodes at the Australian National University (ANU) and University of Melbourne (UoM) have pioneered a new quantum imaging protocol using spatially entangled photon pairs generated by an ultra-thin nonlinear metasurface. This revolutionary approach combines ghost imaging and all-optical scanning methods to reconstruct images with exceptional resolution, demonstrating a significant leap forward in the field of quantum optics and imaging technology.

The study, published in eLight, addresses the limitations of conventional quantum imaging systems that rely on bulky nonlinear crystals. Traditional methods are restricted by their size, narrow angular emission, and limited field of view, making them impractical for many real-world applications. In contrast, the TMOS team utilized a subwavelength-scale silica meta-grating integrated with a thin film of lithium niobate. This nanoscale structure enables the efficient generation of spatially entangled photon pairs while offering a compact and highly tunable platform for quantum imaging.

“A key innovation of the study lies in the ability to manipulate photon emission angles all optically by simply tuning the wavelength of the pump beam. This unique property eliminates the need for mechanical scanning, allowing seamless and precise optical scanning in one dimension while maintaining broad anti-correlated photon emissions in the other," said co-lead author Jinliang Ren, PhD student at TMOS, ANU.

Using these features, the researchers successfully combined optical scanning with ghost imaging to reconstruct two-dimensional objects. This approach uses a simple one-dimensional detector array in the idler path and a bucket detector in the signal path, dramatically reducing the hardware requirements compared to conventional systems.

The researchers experimentally validated their method by reconstructing images of two-dimensional objects at infrared wavelengths and predicted a significant improvement in both resolution and field of view. They found that the number of resolution cells achieved by their metasurface-based imaging system can exceed conventional quantum ghost imaging setups by over four orders of magnitude. This remarkable performance stems from the absence of longitudinal phase-matching constraints, which limit the field of view in conventional bulk crystals.

Dr. Jinyong Ma, the study's lead researcher, highlighted the potential impact of this innovation. "Our work demonstrates the first practical potential of metasurface-based quantum imaging systems for real-world applications. Their compact design and tunability make them ideal for free-space applications, where size, stability, and scalability are critical. This technology enables integration into modern photonics systems, paving the way for advancements in free-space quantum communication, object tracking, and sensing applications." Furthermore, performing optical scanning without mechanical components allows for ultra-fast imaging, essential for dynamic imaging scenarios such as quantum LiDAR and object tracking.

Looking ahead, the researchers are exploring ways to further enhance the photon pair generation efficiency of metasurfaces. "We are investigating new materials with higher nonlinear coefficients and optimizing the metasurface design for triple resonances at the pump, signal, and idler wavelengths, which can potentially achieve photon-pair generation rates comparable to or exceeding those of conventional bulky systems. This development will significantly improve the speed, sensitivity, and signal-to-noise ratio of metasurface-based quantum imaging systems, bringing them closer to widespread practical use." said co-author Dr. Jihua Zhang, a former TMOS research fellow who recently moved to Songshan Lake Materials Laboratory.

"The implications of this work extend beyond imaging alone. Quantum technologies relying on entangled photon pairs, such as secure communication networks, quantum LiDAR, and advanced sensing systems, could benefit from the compact, highly efficient photon-pair sources enabled by nonlinear metasurfaces. Combining optical tunability, nanoscale integration, and high-resolution imaging provides a versatile platform for a wide range of quantum applications," said Professor Andrey Sukhorukov, the leader of the research group.

This research represents a major milestone in quantum optics and highlights the transformative potential of metasurface-based technologies. By replacing bulky and rigid optical components with scalable, ultra-thin structures, the TMOS team has laid the foundation for a new generation of quantum imaging and sensing devices that are more compact, efficient, and adaptable than ever.

DOI
10.1186/s43593-024-00080-8

Original Source URL
https://doi.org/10.1186/s43593-024-00080-8

Funding information
This work was supported by the Australian Research Council (DP190101559, CE200100010).

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