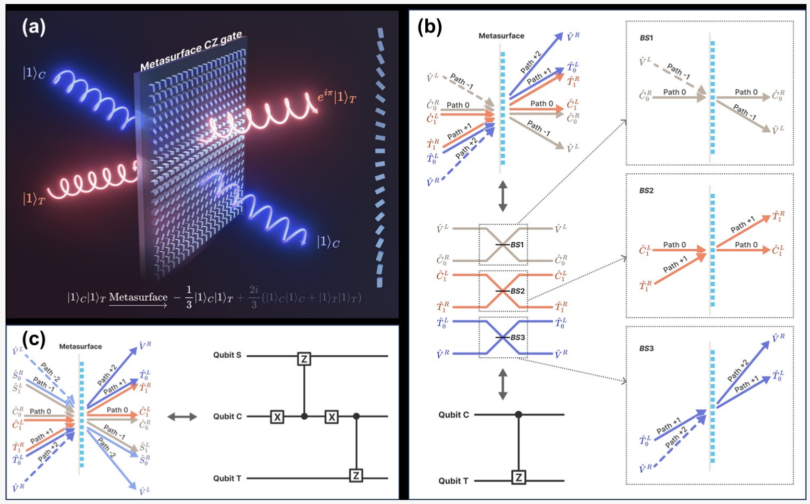
Quantum CZ gates on a single gradient metasurface

GA, UNITED STATES, May 27, 2025 /EINPresswire.com/ -- Researchers from Peking University and collaborators have proposed a novel scheme to realize quantum controlled-Z (CZ) gates using a single gradient metasurface. This innovation enables high-density and multifunctional quantum integration on a chip, paving the way for efficient on-chip quantum information processing.



(a) Schematic diagram of polarization-encoded quantum CZ gate through single gradient metasurface. (b) Mechanism of polarization-encoding quantum CZ gate with the help of parallel beam-splitting on the metasurface. (c) Two quantum CZ gates are cascaded on

Quantum computing and on-chip quantum information processing are rapidly advancing fields with the potential to revolutionize traditional computation and communication. However, integrating quantum gates—the building blocks of quantum circuits—into scalable and efficient on-chip systems remains a major challenge. Traditional approaches using bulk optical components or waveguides are often limited by size, scalability, and efficiency.

In a new paper published in Light Science & Application, a team of researchers led by Professor Ying Gu from Peking University, in collaboration with colleagues from Southern University of Science and Technology, University of Science and Technology of China, has proposed a novel solution using a single gradient metasurface to realize quantum controlled-Z (CZ) gates. Metasurfaces are emerging as powerful tools for manipulating light at the micro-nano scale, offering precise control over multiple degrees of freedom of light. In this study, the researchers utilized the unique parallel beam-splitting feature of gradient metasurfaces to design a scheme for implementing quantum CZ gates. This design allows for both polarization-encoded and path-encoded CZ gates, with the potential for high-density integration and multifunctionality.

“The true excitement lies in scalability. Traditional setups require multiple optical elements, but our design condenses these elements into a sub-wavelength-thick metasurface," explained Dr. Qi Liu, the first author of the study. "Our design not only enables independent CZ gates but also allows for cascaded CZ gates, which can be used for various quantum operations. Through the metasurface architecture, we have for the first time realized an array of quantum gates that can be independently controlled on a single metasurface, providing a new solution for the fabrication of scalable quantum chips."

Compared to traditional methods, the proposed metasurface-based CZ gate scheme has several advantages. "Our metasurface design enables efficient error filtering and detection," said Ying Gu, the corresponding author of the study. "The path-polarization-locked property of the gradient metasurface ensures that bit-flip errors from beam-splitting processes can be efficiently filtered out. Additionally, the metasurface can leverage multi-degree-of-freedom correlations to detect quantum errors and generate high-dimensional entangled states."

This work represents a significant step forward in the field of integrated quantum photonics. By integrating multiple quantum CZ gates into a single metasurface, the researchers have opened new avenues for high-density, multifunctional quantum logic integration. Their findings could have far-reaching implications for on-chip quantum information processing, including applications in quantum computing, quantum communication, and quantum sensing.

References
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