New quantum tool: Experimental realization of neutron helical waves

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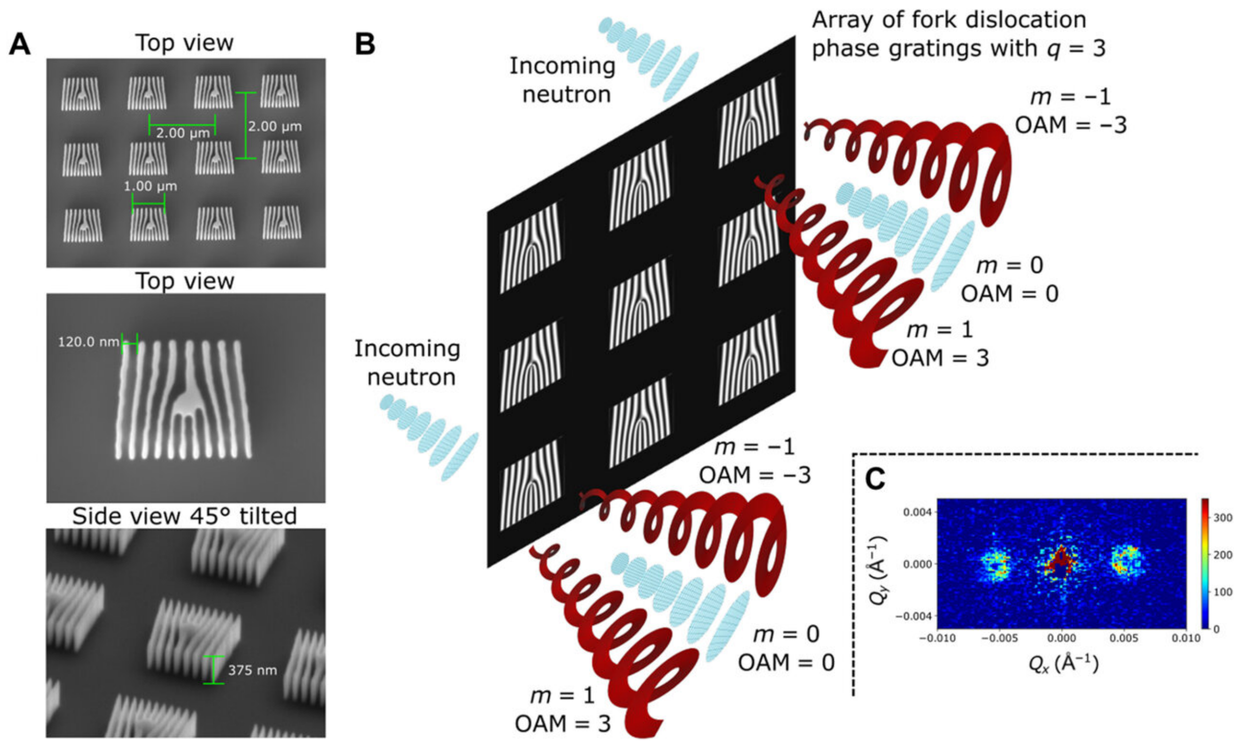

Holographic approach to generating neutron helical wavefronts that carry well-defined OAM. (A) SEM images characterizing the array of fork dislocation phase gratings used to generate the neutron helical wavefronts. The arrays covered an area of 0.5 cm by 0.5 cm and consisted of 6,250,000 individual 1 µm–by–1 µm fork dislocation phase gratings that had a period of 120 nm, had a height of 500 nm, and were separated by 1 µm on each sides. Three arrays with topological charges of q = 0 (standard grating profile), q = 3 (shown here), and q = 7 were used in the experiment. (B) Each phase grating generates a diffraction spectra consisting of diffraction orders (m) that carry a well-defined OAM value of $\ell = m\hbar q$. (C) Intensity in the far field is the sum over the signal from all of the individual fork dislocation phase gratings. Shown is an example of the collected small-angle neutron scattering (SANS) data. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.add2002

For the first time in experimental history, researchers at the Institute for Quantum Computing (IQC) have created a device that generates twisted neutrons with well-defined orbital angular momentum. Previously considered an impossibility, this groundbreaking scientific accomplishment provides a brand new avenue for researchers to study the development of next-generation quantum materials with applications ranging from quantum computing to identifying and solving new problems in fundamental physics.

"Neutrons are a powerful probe for the characterization of emerging quantum materials because they have several unique features," said Dr. Dusan Sarenac, research associate with IQC and technical lead, Transformative Quantum Technologies at the University of Waterloo. "They have nanometer-sized wavelengths, electrical neutrality, and a relatively large mass. These features mean neutrons can pass through materials that X-rays and light cannot."

While methods for the experimental production and analysis of orbital angular momentum in photons and electrons are well-studied, a device design using neutrons has never been demonstrated until now. Because of their distinct characteristics, the researchers had to construct new devices and create novel methods for working with neutrons.

In their experiments, Dr. Dmitry Pushin, IQC and Department of Physics and Astronomy faculty member at Waterloo, and his team constructed microscopic fork-like silicon grating structures. These devices are so minuscule that in an area of only 0.5 cm by 0.5 cm, there are over six million individual fork dislocation phase-gratings.

As a beam of single neutrons passes through this device, the individual neutrons begin winding in a corkscrew pattern. After traveling 19 meters, an image of the neutrons was captured using a special neutron camera. The group observed that every neutron had expanded to a 10 cm wide donut-like signature.

The donut pattern of the propagated neutrons indicates that they have been put in a special helical state and that the group's grating devices have generated neutron beams with quantized orbital angular momentum, the first experimental achievement of its kind.

"Neutrons have been popular in the experimental verification of fundamental physics, using the three easily accessible degrees of freedom: spin, path and energy," Pushin said.

"In these experiments, our group has enabled the use of orbital angular momentum in neutron beams, which will essentially provide an additional quantized degree of freedom. In doing so, we are developing a toolbox to characterize and examine complicated materials needed for the next generation of quantum devices such as quantum simulators and quantum computers."

The paper Experimental realization of neutron helical waves by Sarenac, Pushin and collaborators from the University of Waterloo, the National Institute of Standards and Technology and the Oak Ridge National Laboratory was recently published in the journal *Science Advances*.

More information: Dusan Sarenac et al, Experimental realization of neutron helical waves, *Science Advances* (2022). DOI: 10.1126/sciadv.add2002

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