Study shows polariton condensate can occupy two energy levels to form quantized vortex clusters

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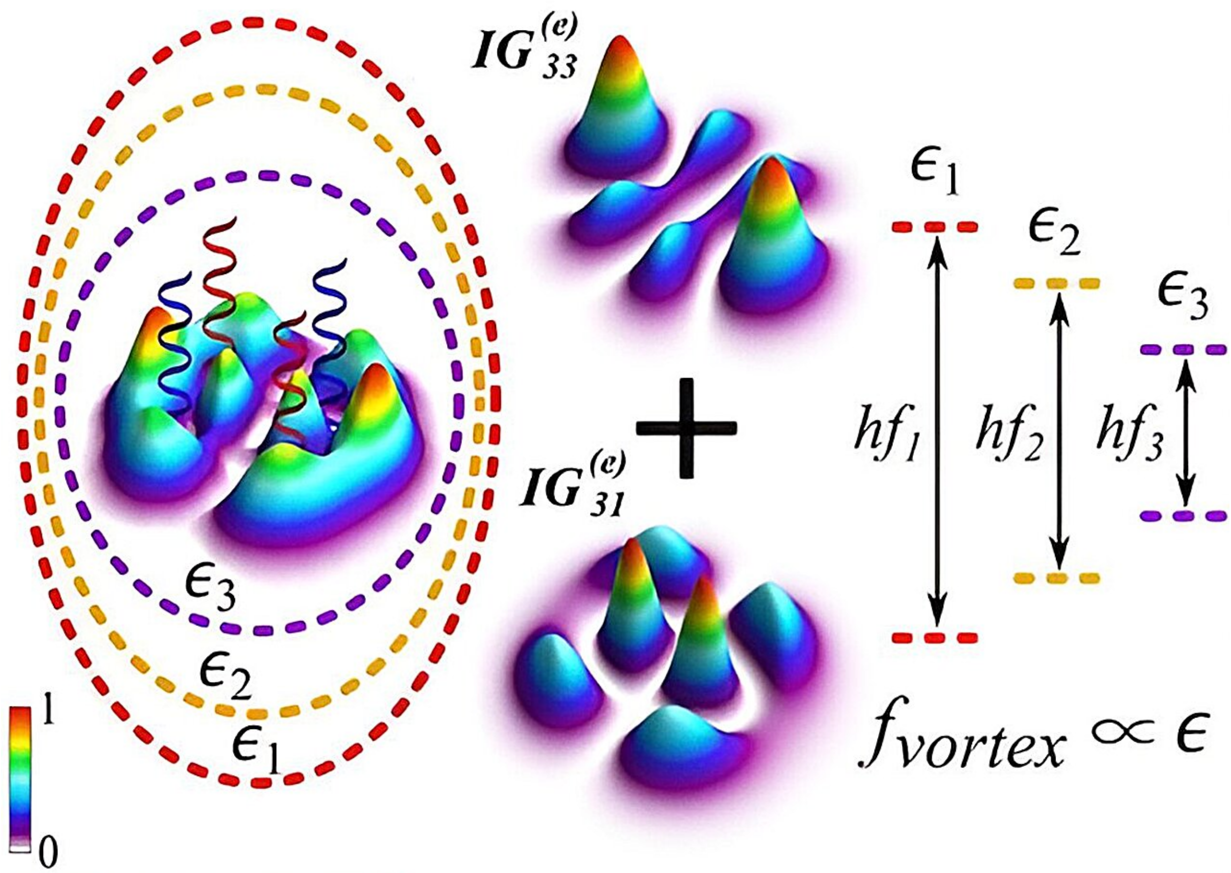

From the journal cover featuring the research. Credit: *Applied Physics Letters*, Skolkovo Institute of Science and Technology

In a paper published in the *Applied Physics Letters* journal, a group of scientists demonstrated that under optical excitation, a polariton condensate can simultaneously occupy two closely spaced energy levels, which results in the formation of quantized vortex clusters. The outcomes of the study are prominent for optical tweezers, increasing the width of the data transmission channel in optical communication lines and other research areas.

The new study is based on previous work on optical vortices—optical beams that have their phase twisted in a spiral around the propagation axis. In 2022, Skoltech researchers, together with their colleagues from the University of Iceland and the University of Southampton, were the first to show how a cluster of quantized vortices with periodically flipping charges is formed in polariton condensates.

The authors experimentally observed a cluster of four vortices and detected periodic flips of the signs of their charges with an interval of one-fifth of a nanosecond.

"Polaritons are quasi-particles consisting of light and matter. They can form a macroscopic coherent state—Bose-Einstein condensate. This state behaves, roughly speaking, like one particle and is described by a single wave function," says Kirill Sitnik, the first author of the study, a junior research scientist at the Skoltech Photonics Center's Laboratory of Hybrid Photonics.

"But the condensation of polaritons in inorganic microresonators is achieved not at room temperature, but at extremely low ones. Therefore, to observe the condensation of polaritons, we place the sample in which they appear in a cryostat, where it is cooled to four degrees Kelvin."

"In 2006, it was demonstrated that polaritons can exhibit the same physics as cold atoms, such as the formation of quantized vortices. At the same time, the experimental technique for achieving the condensate is much simpler. Therefore, we are investigating the physics of condensates on polaritons," Sitnik continued.

"We have found that when a polariton condensate is optically excited and captured in an optical trap, it can simultaneously occupy two closely spaced energy levels, which can form clusters of quantized vortices with periodically changing topological charges."

The experiments revealed two spatial states corresponding to different energy levels due to implementing an elliptic trap instead of the most commonly used circular trap. Periodic flips of the sign of the topological charge are caused by the beatings between these states, which leads to periodic changes in the direction of rotation of the vortex.

The Skoltech research team varied the ellipticity of the optical trap in their experiments, and thereby controlled the frequency of topological charge sign flips of quantized vortices in polariton condensates.

To theoretically confirm the experimental results, the authors used a model of a quantum harmonic oscillator, which demonstrated a well-defined and predictable frequency tuning trend. The model also predicts the nonlinear behavior of this frequency.

More information: Kirill A. Sitnik et al, Control of the oscillation frequency of a vortex cluster in the trapped polariton condensate, *Applied Physics Letters* (2024). DOI: 10.1063/5.0199548

Provided by Skolkovo Institute of Science and Technology

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