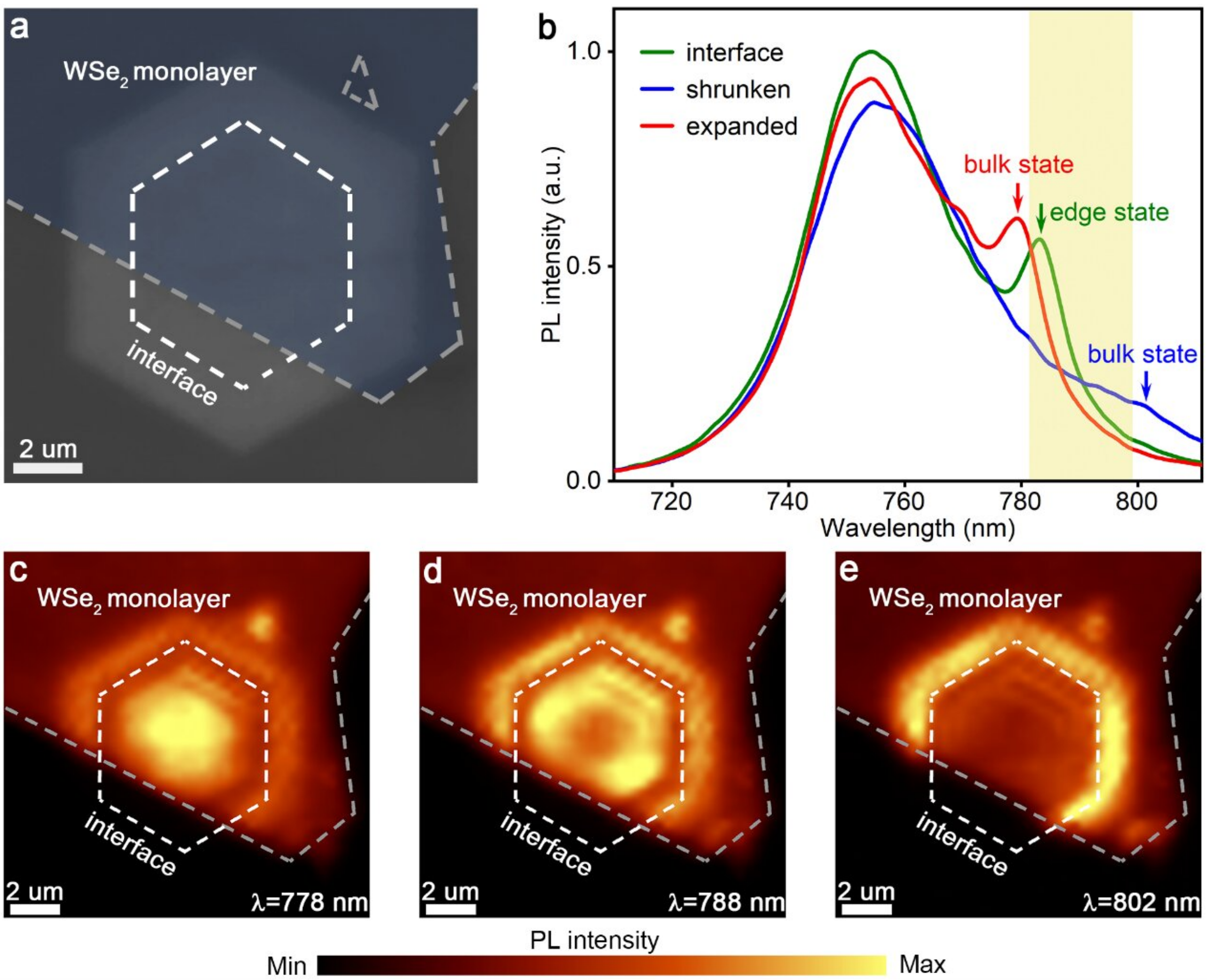
Research on the photonic crystal topological state beyond the optical diffraction limit

May 5 2022



Characterization of the Z2 topological edge state and its dark line. Credit: Compuscript Ltd

A new publication from *Opto-Electronic Advances* considers research on photonic crystal topological states beyond the optical diffraction limit.

The ubiquitous light shows different characteristics in different materials. If the material is selectively periodically arranged at the wavelength level of the light, causing regularly repeating regions of high and low dielectric constant, the propagation behavior of the light can be controlled. These periodic structures are called photonic crystals, and wavelengths that propagate are called modes. Based on photonic crystal, there are lots of applications such as low and high reflection coatings on lenses and mirrors, photonic-crystal fibers, optical sensors, etc.

One of the major difficulties in the photonic crystal manufacturing process is the defect, which can cause the scattering of light that is propagated in photonic crystals. These defects are hard to avoid, as there are always some imperfections in the fabrication process. To overcome this problem, topology as a mathematical concept that is concerned with invariant properties under continuous deformation was introduced into photonics to describe the global property of photonic crystals. Topological photonic crystals focus on overall characteristics and are not sensitive to local defects. And if the photonic crystal is topological non-trivial, it supports optical states at its boundary, which are also not sensitive to local defects. These robust boundary states can enable great applications for optical communication and quantum emissions, such as unidirectional waveguide and single-mode laser.

However, because of the diffraction limit of light, details of optical states with a featured length around 300 nm or shorter are hard to obtain. Some novel physical phenomena have not been fully studied by using traditional optical microscopy, such as a dark line that exists with the crystalline symmetry-protected topological edge state.

Recently the research group of Professor Zheyu Fang from Peking

University showed research on the photonic crystal topological edge state. In this research, the optical diffraction limit is broken by using the cathodoluminescence (CL) nanoscopy. The dark line is imaged at deep-subwavelength resolution and the mechanism of the dark line is elucidated with the electromagnetic field distribution which calculated by numerical simulation. Their investigation provides a deeper understanding of topological edge states and may have great significance to the design of future on-chip topological devices.

The research group of Professor Zheyu Fang from Peking University realized the Z_2 topological edge state in the visible range and characterizes its dark line with the cathodoluminescence (CL) nanoscopy. Their structure is composed of an outer topological trivial photonic crystal region and an inner topological non-trivial photonic crystal region. The topological edge state is confined at the interface between these two types of photonic crystals.

The topological edge state is directly imaged from the designed photonic crystal structure with the enhanced photoluminescence (PL) of the WSe_2 monolayer that covered on the top. The radiative optical local density of states of the edge state is further characterized by using CL nanoscopy with a resolution around 10-nm-level, breaking the optical diffraction limit. It is founded that the dark line of the edge state is exactly localized at the neighboring nontrivial unit cell region near the interface.

And the dark line is interpreted with the artificial p-d orbital field distribution by analyzing simulated topological edge states in detail. They found that the energy of the Z_2 topological edge state is localized at the interface and gradually decays into the vicinity area, while the proportions of p and d orbitals are different depending on the distances to the interface. This leads to different radiation characteristics of the Z_2 topological edge states at different positions. The dark lines at the neighboring nontrivial unit cell region near the interface are mainly composed of d orbital components, so the radiation of the Z_2 topological edge state is weak in this region.

This can be directly used to either enhance the quantum efficiency of topological edge state lasing (p orbital component) or inhibit the quantum emission (d orbital component). Moreover, this deep subwavelength resolved CL characterization can be adapted to any other photonic topological mode analysis. This work strengthens the detailed understanding of Z_2 topological edge states and makes a vital instruction for the exploration and design of on-chip topological devices, benefiting the development of future optical communication and quantum optics.

In the field of micro-nano photonics, the research group of Prof. Zheyu Fang from Peking University focuses on the theories, materials, applications, AI designs, and cathodoluminescence characterization methods. They studied the preparation and characterization of plasmonic nanostructures, nano-scale optical focusing and waveguide design, hot-electron interface doping and detection, two-dimensional material exciton behavior and luminescence characteristics, etc. Many innovative research results have been achieved on key scientific issues like the miniaturization of high-efficiency photodetectors and the modulation of plasmonic structures photoelectric characteristics under the external field.

More information: Xiao He et al, Field distribution of the Z_2 topological edge state revealed by cathodoluminescence nanoscopy, *Opto-Electronic Advances* (2022). DOI: 10.29026/oea.2022.210015

Provided by Compuscript Ltd

(2022, May 5) retrieved 25 April 2024 from https://phys.org/news/2022-05-photonic-crystal-topological-state-optical.html