Tomographic measurement of dielectric tensors

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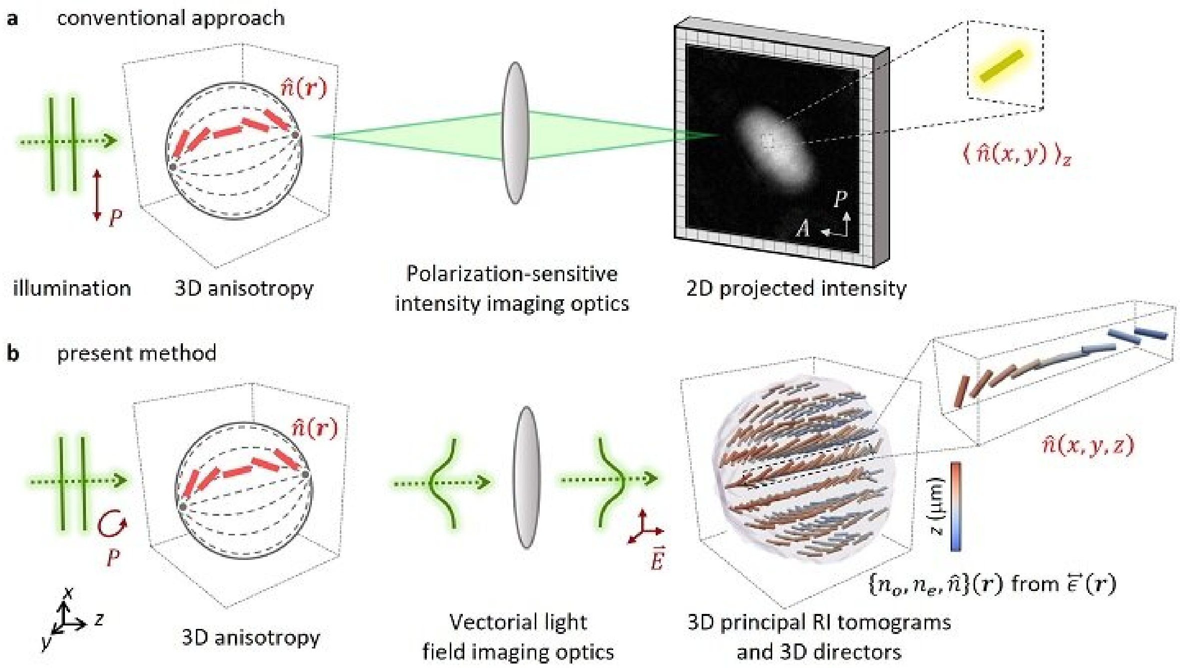

A 3D anisotropic sample is illuminated by polarized light (P), and its 2D images are recorded after passing through the analyser (A). This 2D polarization-sensitive imaging particularly conceals the axially inhomogeneous information of 3D anisotropy. The red rods depict the directors. á ñz denotes the average along the z axis. b, The present method directly visualizes 3D anisotropy. By solving the vectorial wave equation, 3D distribution of optical anisotropy is quantitatively reconstructed. no, ne, and e denote the ordinary RI, the extraordinary RI, and the dielectric tensor. Credit: The Korea Advanced Institute of Science and Technology (KAIST)

A research team reported the direct measurement of dielectric tensors of anisotropic structures including the spatial variations of principal refractive indices and directors. The group also demonstrated quantitative tomographic measurements of various nematic liquid-crystal structures and their fast 3D nonequilibrium dynamics using a 3D label-free tomographic method. The method was described in *Nature Materials*.

Light-matter interactions are described by the dielectric tensor. Despite their importance in basic science and applications, it has not been possible to measure 3D dielectric tensors directly. The main challenge was due to the vectorial nature of light scattering from a 3D anisotropic structure. Previous approaches only addressed 3D anisotropic information indirectly and were limited to two-dimensional, qualitative, strict sample conditions or assumptions.

The research team developed a method enabling the tomographic reconstruction of 3D dielectric tensors without any preparation or assumptions. A sample is illuminated with a laser beam with various angles and circularly polarization states. Then, the light fields scattered from a sample are holographically measured and converted into vectorial diffraction components. Finally, by inversely solving a vectorial wave equation, the 3D dielectric tensor is reconstructed.

Professor YongKeun Park said, "There were a greater number of unknowns in direct measuring than with the conventional approach. We applied our approach to measure additional holographic images by slightly tilting the incident angle."

He said that the slightly tilted illumination provides an additional orthogonal polarization, which makes the underdetermined problem become the determined problem. "Although scattered fields are dependent on the illumination angle, the Fourier differentiation theorem enables the extraction of the same dielectric tensor for the slightly tilted illumination," Professor Park added.

His team's method was validated by reconstructing well-known liquid crystal (LC) structures, including the twisted nematic, hybrid aligned nematic, radial, and bipolar configurations. Furthermore, the research team demonstrated the experimental measurements of the non-equilibrium dynamics of annihilating, nucleating, and merging LC droplets, and the LC polymer network with repeating 3D topological defects.

"This is the first experimental measurement of non-equilibrium dynamics and 3D topological defects in LC structures in a label-free manner. Our method enables the exploration of inaccessible nematic structures and interactions in non-equilibrium dynamics," first author Dr. Seungwoo Shin explained.

More information: Seungwoo Shin et al, Tomographic measurement of dielectric tensors at optical frequency, *Nature Materials* (2022). DOI: 10.1038/s41563-022-01202-8

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