Images Worth a Thousand… Birefringent Molecules

An image is worth a thousand words when describing complex physical phenomena such as temperature distributions, air flows and brain waves; a recently developed technique can now help us actually picture birefringent fluids at the nanoscale.

From magazines to billboards, images that we see everyday fill our hearts, put color into our lives and feed our imagination. Even so, we seldom realize what a powerful tool they are for physicists; they give an intuitive appearance to complex phenomena such as temperature distributions, air flows and brain waves. Unfortunately though, most of these phenomena do not yet have a way of actually being visualized. For example, do we know what the molecular orientation profile of a birefringent fluid looks like? Until very recently, we did not. Now, however, such an image can be obtained thanks to the new optical nanotomography technique, developed at Case Western Reserve University (Ohio, US) by Charles Rosenblatt and coworkers.

The term *birefringence* literally means *double refraction*. Light in a birefringent material is decomposed in two rays which are refracted in different directions with different angles depending on their polarization. The way in which this process actually takes place is, however, a very complex and, in many respects, still unresolved issue. Moreover, an even further level of comprehension is required to fully understand the process of bifringence because birefringent fluids, such as liquid crystals, have a vast impact on our everyday lives. For instance, the technology of modern displays from cell-phones to GPS units, and from laptops to flat panel TV sets, are all based on the technology of liquid crystals.

This innovative technique developed at Case Western University could help shed new light on many unanswered questions: Do liquid crystals behave differently near a surface? What would happen if liquid crystals were subjected to an external stressor or a temperature change? Will their bi-

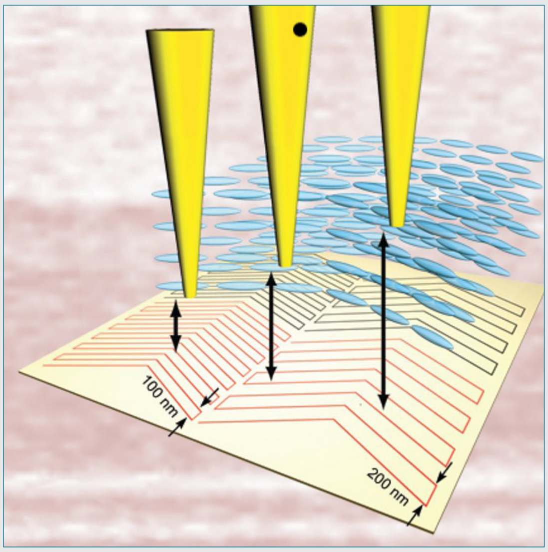

Figure 1: Nanotomography. The novel optical tomography technique allows the reconstruction of a 3D topographical map of the orientation of liquid crystal molecules by scanning a fiber tip inside the sample and collecting the polarized light transmitted by the liquid crystals.

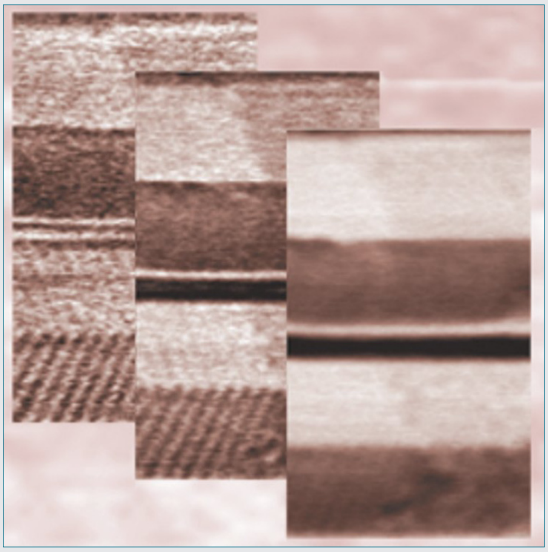

Figure 2: Images worth a thousand molecules. Transition from a fishbone-like orientation of the liquid crystal molecules to a more random one scanning the fiber at different heights from the surface.

refringent properties be substantially affected? "Many phenomena occurring in birefringent fluids," explains Rosenblatt, "have only been predicted theoretically or by computer simulation so far, because of limitations in previous experimental techniques. Our proposal could finally study them experimentally near a contact surface or in bulk."

The newly developed optical tomography technique closely resembles the more established Near-Field Scanning Optical Microscopy (NSOM) technique. In a standard NSOM, a nanometer-sized probe, usually made of a fiber or a metallic tip, is scanned over a certain sample in order to collect surface information locally with a resolution of up to 50 nanometers, below the diffraction limit. Even though a standard NSOM can only work within close proximity of a particular surface, the optical tomography technique actually goes a step further, allowing us to collect information not only near the contact surface, but also in bulk.

How does this novel technique work in detail? Just like in a NSOM experiment, in optical tomography, "an optical fiber is used as a probe for delivering polarized laser light into the sample," Antonio De Luca and Valentin Barna, coauthors of the work, explain. "By scanning the fiber tip back and forth at different heights inside the sample and collecting the polarized transmitted light, we could reconstruct a 3D mapping of the orientation of the liquid crystal fluid's molecules with unprecedented lateral resolution of 150–200 nanometers and vertical resolution in the order of 10 nanometers, by far the most important features of our technique." Such information about the fluid molecular orientation was therefore carried out by measuring how the incident light is transmitted by the molecules, since different molecular orientations of a birefrigent material will affect a well-defined polarization of the incident light in different ways.

What the researchers at Case Western Reserve University observed is that the liquid crystal molecules closest to the top of the surface on which they were located were oriented according to some fishbone-like nanopatterns written on the same surface. By moving the fiber away from the surface, they were also able to track the molecular relaxation of these liquid crystals, which were progressively losing their fishbone-like orientation to adopt a more random one.

"Such a technique," De Luca and Barna envisage, "could bring significant results and answers to fundamental scientific questions while facilitating improvements to existing devices and making entirely new applications possible." Furthermore, even though the present optical tomography technique requires birefringent materials, it could be easily adapted to study non-birefringent systems. De Luca and Barna point out that "any material that can be slightly modified by using a birefringent molecular tag or embedded in a birefringent medium could be studied with our technique by indirectly determining the material properties from its interaction with the host environment, for example."

Oleg D. Lavrentovich at Kent State University (Ohio, US) is convinced that the results presented by Rosenblatt and his colleagues clearly demonstrate that their approach has an enormous potential in the imaging of birefringent objects. "Their work," he states, "adds a new level of complexity to the interaction between polarized light and liquid crystals due to the fact that this interaction is occurring in the presence of a NSOM probe which could possibly perturb the orientation of the liquid crystals. As in any new advancement, especially in the field of instrumentation, some questions will be left unanswered for a while, such as the degree of invasiveness of the tip. Nevertheless, what may be an insurmountable complexity for some might be an opportunity to advance our knowledge for others."

Giorgio Volpe

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