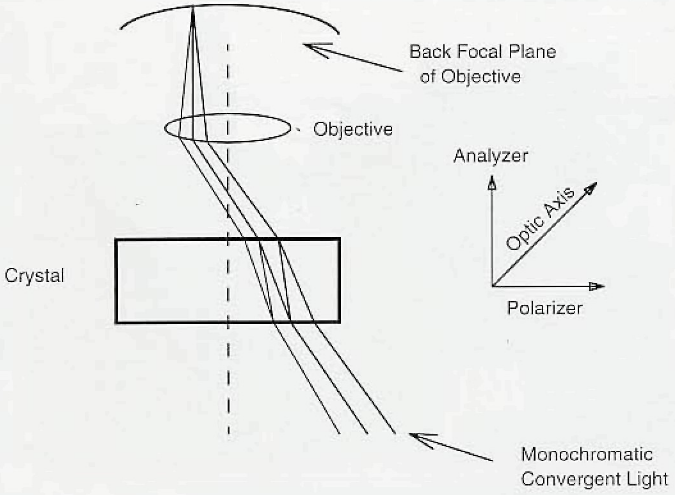
Determination Of Birefringence Of Uniaxial Crystals: The Use Of Conoscopy For Quantitative Measurements

Mohan Srinivasarao, North Carolina State University

Often times one is asked the question "how can the optical microscope be used to make quantitative measurements?" The microscope certainly lets one observe the sample (whatever the sample may be) and make qualitative statements about what is it one is looking at. It has been used for various purposes from just visual observation in brightfield, reflection and the one that is near and dear to my heart, observations under crossed polarizers. This certainly allows one to identify materials as being isotropic or anisotropic. If one works on materials like liquid crystals, an optical microscope is a tool that is used all the time. It certainly allows for identification of various phases of liquid crystals based on the defects and textures that can be observed. All of this is somewhat qualitative in nature. By that I mean that the observations do not lend themselves to obtain, say for example, refractive index or birefringence of the material. I would like to describe a technique that will allow one to do just that. This is applicable for materials with uniaxial symmetry, like quartz crystals. The method certainly can be used with materials that are biaxial as well but we shall not discuss that here.

The method consists of illuminating the desired sample, in this case a quartz crystal, by a highly convergent laser light beam[1,2]. A schematic of the arrangement is shown in Figure 1. One can use a He-Ne laser whose wavelength is 633 nm. The laser can be coupled to a microscope and should be aligned so that the beam propagates along the optic axis of the microscope. This is easily accomplished by a microscopist who is well adept to aligning the microscope for proper illumination. The only difference here is that the light source is laser beam and care must be taken so that one does not look directly into the beam through the microscope optics. One must also spread the beam to get an even illumination in the field of view and this is not necessarily easy with a laser beam due to gaussian beam profile. One simple way to accomplish this is to have a rotating ground glass plate in the path of the beam before it enters the substage condenser. The rotation also takes care of the speckle pattern that usually degrades the image in the microscope. In illuminating the sample with a highly convergent laser beam, one is able to probe the sample at many different propagating angles of light simultaneously. This method is especially useful for samples with large birefringence or large retardation.



Schematic diagram showing the principle of conoscopy.

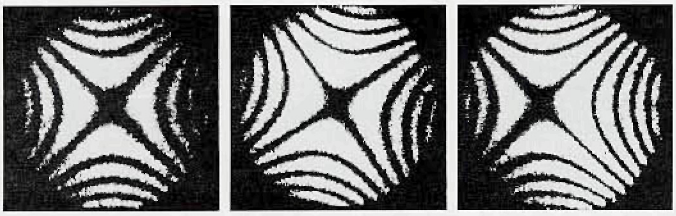


Figure 2: The interference pattern from a quartz crystal. The cross in the middle figure shows the direction of the analyzer and polarizer. The left interference figure shows the crystal with its optic axis normal to the optic axis of the microscope. The middle interference figure shows the crystal with its optic axis rotated in a plane normal to the optic axis of the microscope and the right interference figure shows the crystal with its optic axis tilted.

The consocopic figures which result from interference of the ordinary and extraordinary beams are viewed in the back-focal plane or the rear-focal plane of the objective. One of the requirements is that the objective should have a large enough numerical aperture (NA) to collect the convergent beam. It is of course obvious that the best results are obtained when the NA's or the objective and the condenser are matched. To view the rear focal plane one then uses the Bertrand lens which brings the rear-focal into the field of view. If the microscope does not have Bertrand lens then the rear-focal plane can be viewed by removing the eyepiece which allows the rear-focal plane to be viewed. The position of the optic axis of the crystal is revealed by rotation of the conoscopic interference pattern about its center of symmetry as the sample is rotated in the sample plane, or by translation of the pattern if the optic axis tilts out of the sample plane. For uniaxially symmetric materials, the conoscopic interference figures are hyperbola-like principal isochromates (curves of zero intensity) placed along and orthogonal to the optic axis (or director) of the material. Such an interference figure is shown in Figure 2. The top figure shows that the crystal is centered on the optic axis of the microscope, the middle figure shows that the crystal has been rotated by a small amount in the plane of the microscope stage and the bottom figure shows the crystal tilted out of the plane of the microscope. For a material with positive birefringence, and retardation $\delta = 2m\pi + \delta'$ for light propagating normal to the sample plane, m being an integer and $0 < \delta' < 2\pi$, the successive fringes along the optic axis have retardation $2m\pi$, $2(m-1)\pi$, ..., 2π on moving away from the center, and those along the orthogonal axis have retardation $2(m+1)\pi$, $2(m+2)\pi$, ... on moving outward. For the quartz crystal studied here, M=20 or more, due to the thickness of the quartz crystal (~4 mm). The birefringence of the samples can be measured if one measures the distance between successive fringes that are placed normal to the optic axis of the crystal. This is due to the fact that the difference in retardation between successive sets of fringes is 2π which is equal to $[2\pi h \triangle n\ (1/\cos\theta_2 - 1/\cos\theta_1)]$, where h is the thickness of the sample, $\triangle n$ is birefringence and θ_1 and θ_2 are the propagating angles of the beam corresponding to the successive sets of fringes. Experimentally, the distance between the fringes can be measured using a calibrated eyepiece on the microscope or by using a photograph of the interference figures. Knowing the NA of the objective leads to a calibration of the distance in terms of the propagating angles for the light beam. Using this method the birefringence of quartz can be easily obtained. Details of this can be found elsewhere[3,4]. This is not limited to just quartz crystals but can be used for any material with uniaxial symmetry. If the optic axis of the crystal is normal to plane of the sample then a set of concentric circles are seen as the interference pattern[2]. This method then allows one to identify where the optic axis of the crystal lies. This method is quite powerful and is rather elegant. One hopes that it will find considerable use as a tool for making quantitative measurements of the optical properties of crystals. ■

1. F. Don Bloss, *An Introduction to the Methods of Optical Crystallography*, Holt, Reinhart and Winston, New York (1961) P. 120.
2. M. Bom and E. Wolfe, *Principles of Optics*, Sixth Ed. Pergamon Press (1980), P. 695.
3. Mohan Srinivasarao, "Rheology and Rheo-optics of Polymer Liquid Crystals" *Int. J. Mod. Phys.* B, 9, 2515-2572 (1995).
4. H. Mattoussi, Mohan Srinivasarao, P.G. Katz and G.C. Berry, "Birefringence, Order Parameter and Dispersion of Refractive Indicies of a Polymer Liquid Crystal", *Macromolecules*, 2.5, 2860 (1992).

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