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Non-Intrusive Measurement of Stress in Transparent Materials

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The CRi Abrio and Abrio IM are birefringence imaging systems that enable measurement of stress in transparent materials on the microscopic and macroscopic scales respectively. As an example of the utility of this approach, we discuss stress measurement in glass - metal interfaces. These are common in electro-optical devices and often create stress as a result of a differential CTE. This stress can lead to leaking, cracking, or other failures that degrade performance.

When designing electro-optic devices, engineers will often need to measure the stress at these interfaces, to help improve design and manufacturing processes. But how can one conveniently measure this stress? A well-accepted approach is to measure the optical birefringence that stress creates and that results in measurable optical retardance. Once the retardation is measured, it can be converted to mechanical stress if the following assumptions can be made: a) the stress is uniform or approximately uniform along the light path, which is usually the case when the thickness along the light path is small relative to the dimensions orthogonal to the light path, and b) the sample is unconstrained in one of the directions orthogonal to the light path. If these conditions are met, the conversion from retardation to stress is straightforward:

Stress (in mega Pascal, or MPa) = Retardation (nm) / (thickness (mm) * stress-optic constant)

Stress-optic constants for most glasses fall into the range of 2 to 4.

Conventional approaches to measuring retardation using polarized light microscopes are time-consuming if a distribution of measurements needs to be made over an area of interest. The CRi Abrio and Abrio IM take advantage of electro-optic devices and the power of PC-based digital imaging and processing to automatically measure distributions of optical retardance, and thus mechanical stress. Each uses a liquid crystal "universal compensator" and a CCD imaging sensor. These systems, which either integrate into a microscope or operate as a stand-alone macroscopic imager, measure a 2-dimensional array of points simultaneously.

The image shown in Figure 1 is an example of a glass-to-metal interface. It is a cross-section of a wire electrode passing through glass, such as one would find in a light bulb. The image is shown in pseudo color to make it easier to discriminate the levels of retardation. The images produced by the Abrio and Abrio IM systems are quantitative, where the values at each pixel are accurate measures of the retardation at the corresponding image point on the sample, as shown in the look-up table inserted in the image. Since this sample does not satisfy the condition of being unconstrained in one of the directions orthogonal to the light path, determination of stress requires some finite element modeling to determine the actual mechanical stress. This image took about 4 seconds to generate, providing hundreds of thousands of individual measurements of retardation.

The system also measures the orientation of the retardation, which can be used to determine whether the stress is tensile or compressive. Shown in Figure 2 is the same sample as shown in Figure 1 but in grayscale, where a grayscale value of 255 equals 76 nm of retardation, with a yellow vector overlay superimposed on the image to show the retardation “slow,” or “extraordinary”, axis. The slow axis is the direction of the larger refractive index. In this example, the vectors indicate radial compression and/or circumferential tension.

These new automated retardation measurement and imaging systems provide valuable information and insight into stress levels and concentration points, enabling engineers and scientists to improve designs and processes and to provide products that perform better and are more reliable.

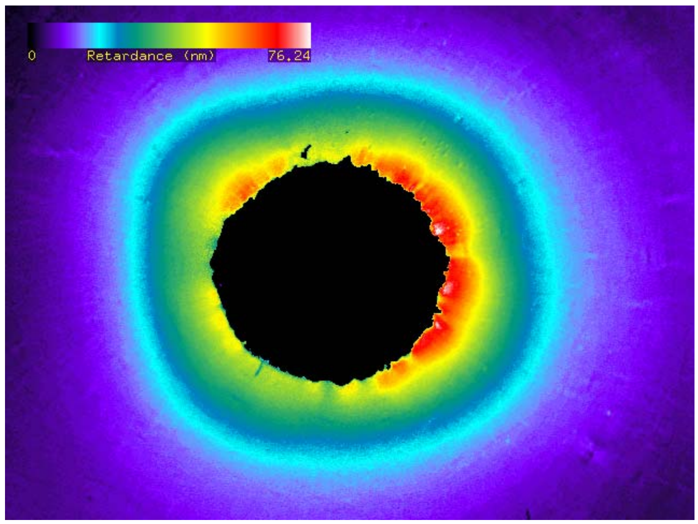

FIG. 1. Birefringence stress pattern in the glass around a wire electrode. A pseudo color look-up table was used to provide convenient discrimination of stress levels.

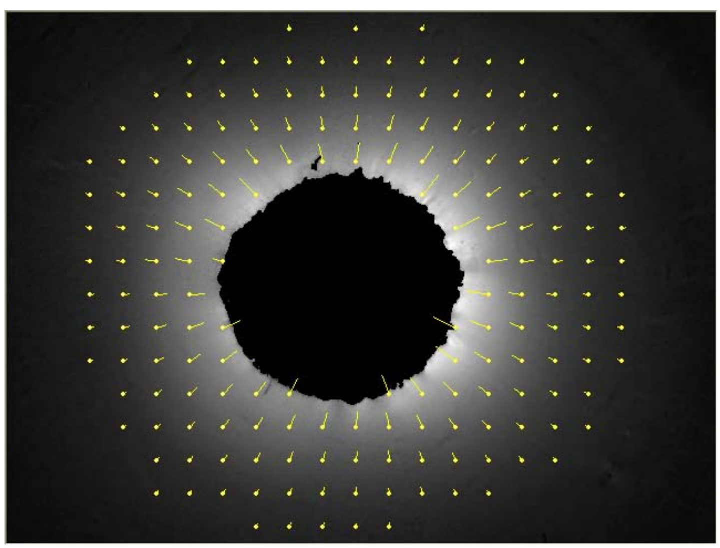

FIG. 2. An image of the same sample shown in Fig.1 but in grayscale and with a vector overlay indicating birefringence axis orientation. These vectors indicate radial compression and/or circumferential tension.

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