132 Stress and quality control of anisotropic crystals by means of optical methods

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Abstract. The evaluation of mechanical and optical properties of crystals for high-energy physics and biomedical devices (e.g. scintillators) is crucial for the understanding and the prediction of light performances, reliability and possible failures. High-quality performances are linked to the overall crystal quality which is related to the structural and residual stress condition. In this work we study the elasto-optic behaviour of optically biaxial (Monoclinic and Orthorhombic groups) and uniaxial (Trigonal and Hexagonal) crystals. We evaluate the photoelastic constants, the optic angle and the optic plane associated to various states of stress, in terms of the components of the Piezo-Optic tensor. The knowledge of those parameters allows for an estimate of the internal stress state. The final result is a non-destructive (no contact) optical method for the quality control of a large crystal family by means of the internal stress measurements. In fact, tensional states can be also the signature of crystal defects. Finally, we generalize to these crystals the Brewster law for isotropic materials.

Introduction

The method is based on the distortion of the Bertin surfaces (Figure 1) [1] [2] [3] when acted by stress. The first order Bertin surfaces section, normal to the optic axis bisector (OB), are Cassini-like (CL) closed curves similar to ellipses in low stress regime[4][5]. We define the Ellipticity Ratio C [6](Eq. 1)

$$C = \frac{a}{b} - 1 > 0 \tag{1}$$

where a and b are the major and minor axis of the CL as shown in Figure 2.

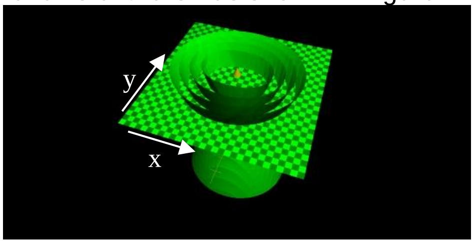

Figure 1 Bertin Surfaces, the section with a plane normal to OB generates the Cassini-Like curves

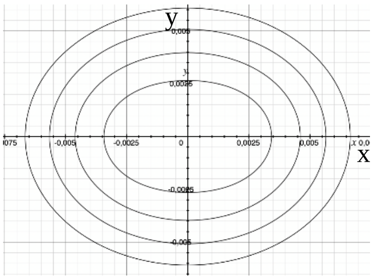

Figure 2 CL curves, the first order x (a) and y (b) intercept are valued in Eq. (1)

As Eq. 1 is a function of stress, we can express C in small stress regime

$$C(\mathbf{T}) = C(\mathbf{0}) + \mathbf{F}_\sigma \cdot \mathbf{T} + o(\|\mathbf{T}\|^2)\,, \quad \mathbf{F}_\sigma = \frac{\partial C}{\partial \mathbf{T}}\Big|_{\mathbf{T}=\mathbf{0}} \tag{2}$$

Where **T** is the stress tensor and F_σ is the Photoelastic constants tensor which depends on the piezo-optic tensor Π. By means of optic methods and Eq. 1, 2 it is possible to evaluate C(**T**) in the linear regime. Moreover, it is possible evaluate the tilt of the optic plane γ and the optic angle β. The knowledge of these 3 quantities allows to evaluate the plane stress also if the components of Π are unknown.

Optical methods: Photoelastic Conoscopic Technique

The photoelastic methods used to achieve information about the Bertin surfaces and the Cassini-like curves are based on the classical plane polariscope equipment [7]. Special optical lay-outs are used to obtain images of the first orders fringe patterns in Fig. 3. In one case the light is confined in a conoscopic volume of the crystal (laser conoscopy) [8] in the other case an infinite focusing lens is used to get the interferogram of the Bertin surfaces (diffused light conoscopy) [8]. A precision positioning system and dedicate software grabs and processes the images to extract the 3 photoelastic parameters F_σ, γ and β.

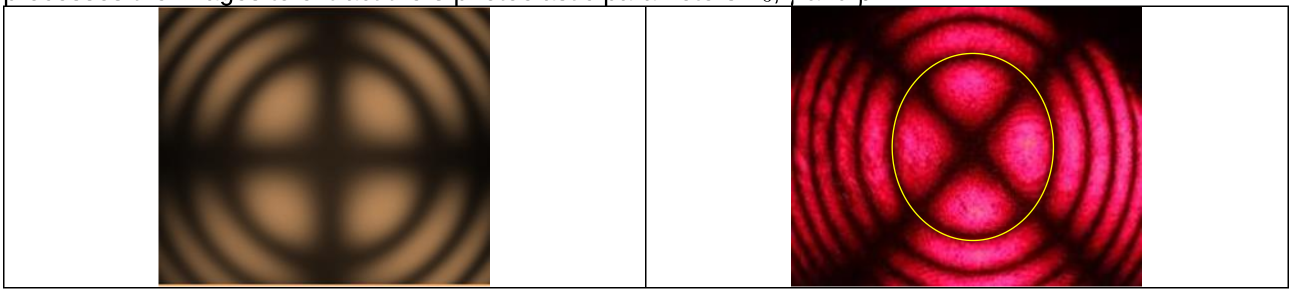

Figure 3 Fringe pattern acquired by diffused light polariscope in conoscopic madality. Unstressed Uniaxial crystal on the left, acquired by diffused light polariscope. Compressed Uniaxial crystal on the right, acquired by laser conoscopic technique; the yellow line is the fitted CL into the first fringe order by which the stress state is evaluated.

Results and Conclusions

The described method allows to evaluate the stress state by the means of no-contact optical measurements. The assessment of the Π and/or the evaluation of the stress condition of several anisotropic crystal structures is obtained. In fact, for Monoclinic and Orthorhombic (Biaxial), Trigonal and Hexagonal (Uniaxial) the explicit formulation of the optic plane γ and the optic angle β is given; moreover, for all the above-mentioned classes the expression of the F_σ constants is obtained, leading to a possible generalization of the Brewster law for the anisotropic crystals. If on the other hand the Π tensor components are known, the linearization furnishes a straightforward expression for the stress. Otherwise, as three parameters can be evaluated, the plane stress can be estimated. This technique already proved to be a useful tool to measure internal stress and quality control in scintillating crystals for high energy-physics and biomedical applications.

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