Determination of 2D Stress Distribution in Semiconductor Glass As_2Se_3 with Infrared Imaging Polarimeter

Krupych O., Smaga I., Vlokh R.

Institute of Physical Optics, 23 Dragomanov Str., 79005 Lviv, Ukraine,
e-mail: vlokh@ifo.lviv.ua

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Abstract

In this paper the optical polarimetric method for determination of inhomogeneous 2D stress distribution in semiconductor samples is presented. The infrared imaging polarimeter is tested on the example of As_2Se_3 semiconductor glass possessing the induced inhomogeneous stresses. The reconstructed distribution of the shear stress tensor component σ_6 and the difference (σ_1-σ_2) of the principal tensor components are in a satisfactory agreement with those predicted theoretically.

Key words: infrared, imaging polarimetry, semiconductors, mechanical stress.

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Introduction

Development of non-destructive methods for stress checking is one of the central problems in the optical material science, design of different types of devices and the material and construction resistance. A lot of the earlier studies have been devoted to the problem of stress-field distribution reconstruction by using the optical polarimetric data (see, e.g., [1-3]). We have recently demonstrated a possibility for obtaining 2D stress fields (or optical anisotropy distributions), using the imaging polarimeter [4,5] that operates in the visible spectral range (see [6,7]). However, this polarimeter cannot be applied for determining the stressed state of semiconductors since they are non-transparent for the visible optical radiation. On the other hand, determination of stresses in semiconductor materials and the devices on their basis represents an urgent question. We should remind of many related problems, e.g. the existence of non-compatible strains in epitaxially grown layers in heterostructures. Another, though simpler, problem of the same kind is observation of interference fringes in samples placed between the crossed polarizers, which appear due to residual stresses. Eventually, this represents a usual procedure for testing transparent optical details. It would be rather difficult to conduct the same studies in the case of semiconductor materials. As far as we know, the infrared (IR) imaging polarimeter for determining 2D stress distributions in semiconductors has not yet been constructed. According to the said above, the present paper is just aimed at the demonstration of possibilities for determining the 2D stress distributions with the aid of IR imaging polarimeter constructed by the authors, using the As_2Se_3 glasses as an example.

Experimental

In comparison with [4] the suggested initially setup was modified for the aims of IR polarimetry and the 2D stress distribution determination. The He-Ne laser with the radiation wavelength of 1.15μm was used as a light source.

The measurements consisted in searching a global light intensity minimum while scanning the polarizer's azimuth in the range of 90° and determining the dependences of local minimum azimuth on the polarizer's azimuth. In the vicinity of the global minimum, the dependence of local minimum azimuth versus the polarizer's azimuth is linear. It is possible to calculate the retardation for each pixel of the image from the slope angle φ of the dependence on the basis of the following formula:

$$\Gamma = \arccos(\tan\varphi)\,. \qquad (1)$$

Then the optical birefringence is defined by

$$\Delta n = \frac{\Gamma\lambda}{2\pi d}\,, \qquad (2)$$

where d is the sample thickness.

The optical indicatrix orientation for each pixel of the image was determined by searching of the extinction position of the sample between the crossed polarizers.

The sample had the shape of parallelepiped and was placed on the plane basis. The top face of the sample was loaded with the aid of cylindrical rod of a small diameter (see Figure 1). The problem of the stressed solid state is analogous to the well-known contact problem of mechanics dealing with the action of a concentrated (or, in somewhat other terms, point) load upon a half-space (see, e.g., [8]).

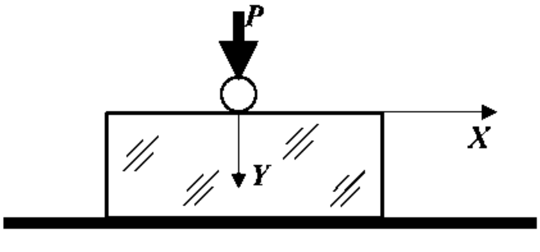

Fig. 1. Scheme of sample loading.

The piezooptic coefficient $C = 0.5 \cdot n_0^3(\pi_{11} - \pi_{12})$, which is needed for calculations of the stress distribution, was measured under the conditions of applying a homogeneous compressive stress and using the same polarimetric method described above.

Experimental Results

The tests performed on the As_2Se_3 semiconductor glass in its initial state (i.e., without any external loading) show a presence of a small birefringence (of the order of 10^{-5}) in the sample, which should be optically isotropic. This is probably induced by the internal residual stresses. As seen from Figure 2, both the optical retardation and the optical indicatrix orientation are characterized by a complex distribution in XY-plane and their values approach to zero in the lower right part of the sample.

The results of study of the retardation and the optical indicatrix orientation for the loaded sample ($F \approx 30$ N) are presented in Figure 3.

When studying the birefringence increment under the application of homogeneous compressive stress, the value of piezooptical coefficient is determined as being equal to $C = 1.295\times10^{-11}$ Pa^{-1} (λ=1.15μm).

Discussion

When the wave vector direction coincides with the z axis of Cartesian coordinate system associated with the sample (see Figure 1), the optical indicatrix equation

$$\begin{aligned}&(B_0 + \pi_{11}\sigma_1 + \pi_{12}\sigma_2)x^2 + \\ &+(B_0 + \pi_{12}\sigma_1 + \pi_{11}\sigma_2)y^2 + \\ &+(B_0 + \pi_{12}\sigma_1 + \pi_{12}\sigma_2)z^2 + \\ &+2(\pi_{11} - \pi_{12})\sigma_6 xy = 1\end{aligned} \qquad (3)$$

gives rise to the conclusion that the azimuth ξ_3 of the indicatrix orientation is expressed by the formula

$$\tan 2\xi_3 = \frac{2\sigma_6}{\sigma_1 - \sigma_2}\,. \qquad (4)$$

After measuring the optical retardation along the z direction and solving the equation system

$$\begin{cases}(\sigma_1 - \sigma_2) = \dfrac{2\Delta n_{12}\cos(2\xi_3)}{n_o^3(\pi_{11} - \pi_{12})} \\ \sigma_6 = \dfrac{1}{2}(\sigma_1 - \sigma_2)\tan(2\xi_3)\end{cases}, \qquad (5)$$

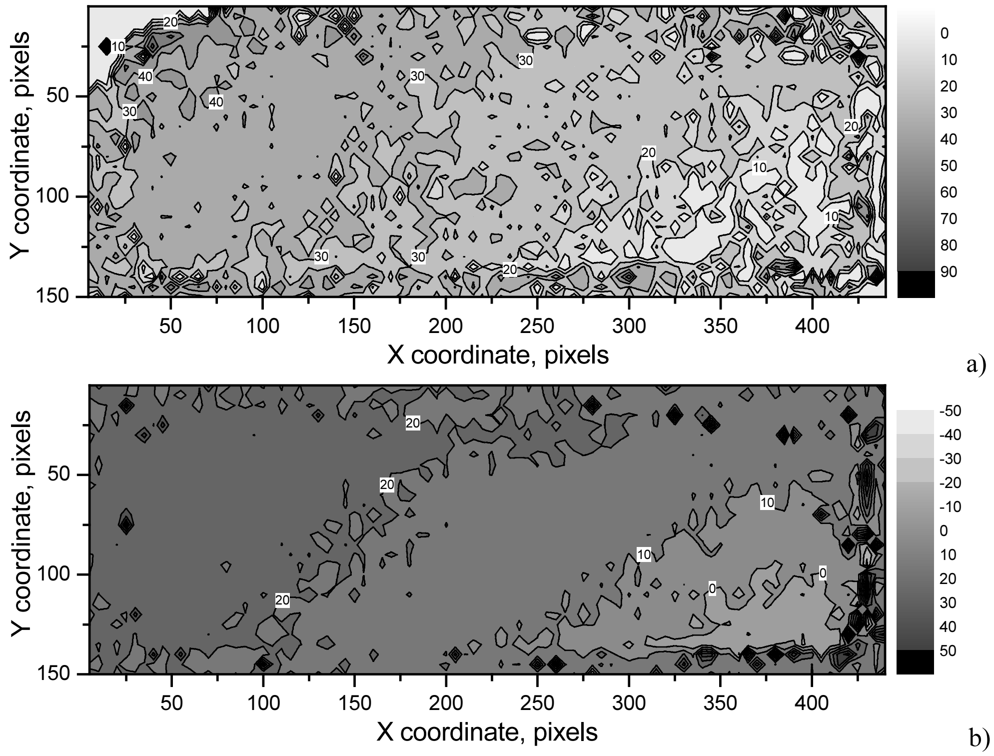

Fig. 2. Maps of the initial optical retardation (a) and the angle of optical indicatrix orientation (b) (in degrees).

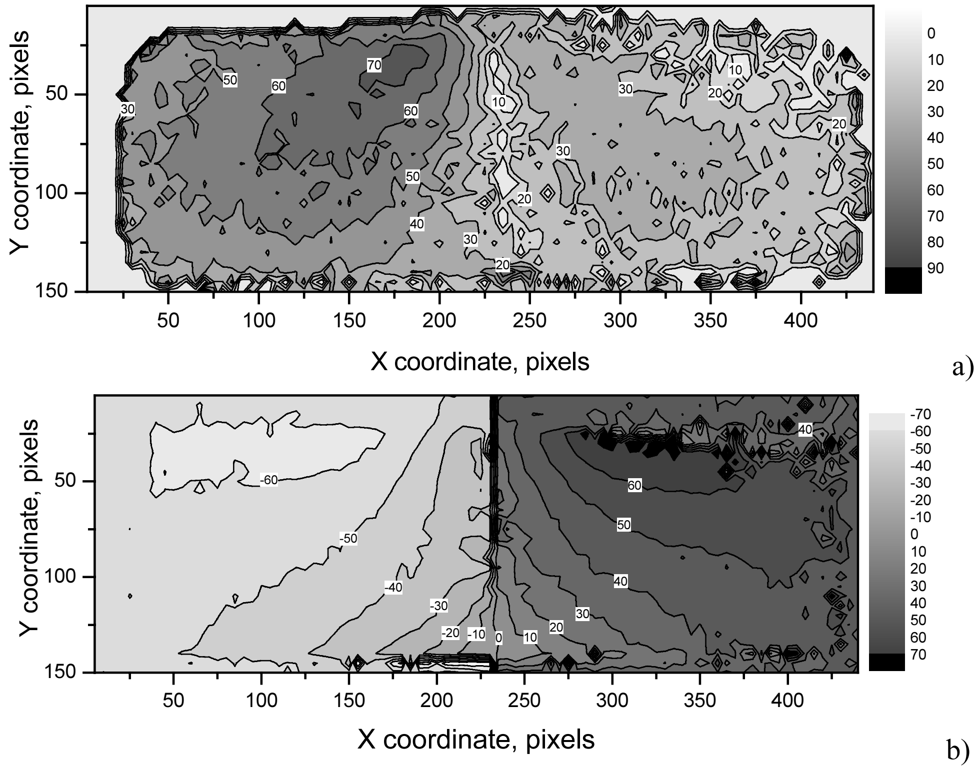

Fig. 3. Maps of the optical retardation (a) and the angle of optical indicatrix orientation (b) in the loaded ($F \approx 30$ N) sample (in degrees).

it is possible to calculate the difference between the stress tensor components (σ_1-σ_2) and the shear tensor component σ_6.

The results for the mechanical stress distribution are presented in Figure 4. As already mentioned above, from the viewpoint of a solid-state elasticity, the problem of mechanical stress inducing represents a contact problem of the action of concentrated load on the half-space [8]. The equations describing the stress tensor component distribution may be written as

$$\sigma_1 = -\frac{2P}{\pi d}\cdot\frac{x^2 y}{(x^2+y^2)^2}$$
$$\sigma_2 = -\frac{2P}{\pi d}\cdot\frac{y^3}{(x^2+y^2)^2}\ , \qquad (6)$$
$$\sigma_6 = -\frac{2P}{\pi d}\cdot\frac{xy^2}{\pi(x^2+y^2)^2}$$

where P is the loading force and d the sample thickness. Since the polarimetric experiment can only give the difference of the principal stresses (σ_1-σ_2),

$$\sigma_1 - \sigma_2 = \frac{2P}{\pi d}\cdot\frac{y(y^2-x^2)}{(x^2+y^2)^2}, \qquad (7)$$

and the shear stress component σ_6, we have compared the results obtained experimentally with those predicted theoretically (see formulae (6) and (7)).

It is clear from Figure 5 that the experimental results are in a quite satisfactory agreement with the theoretical one. The deviation of experimental data from theoretical fitting is caused, first of all, by the fact that the sample under test has a finite size and a definite shape, so that the “half-space” model may be considered as only a rough approximation. Moreover, existing of the some residual optical anisotropy is available in the left half-part of the sample, where the deviations turn out to be especially significant.

Conclusions

We have shown that the IR imaging polarimetry could be a useful tool in determining 2D distributions of stresses in semiconductor materials. The automatic IR imaging polarimeter constructed by us has been tested on the example of As_2Se_3-glass parallelepiped given to the action of the “concentrated” load. The obtained experimental results for distribution of the stress tensor components agree satisfactorily with the data predicted theoretically.

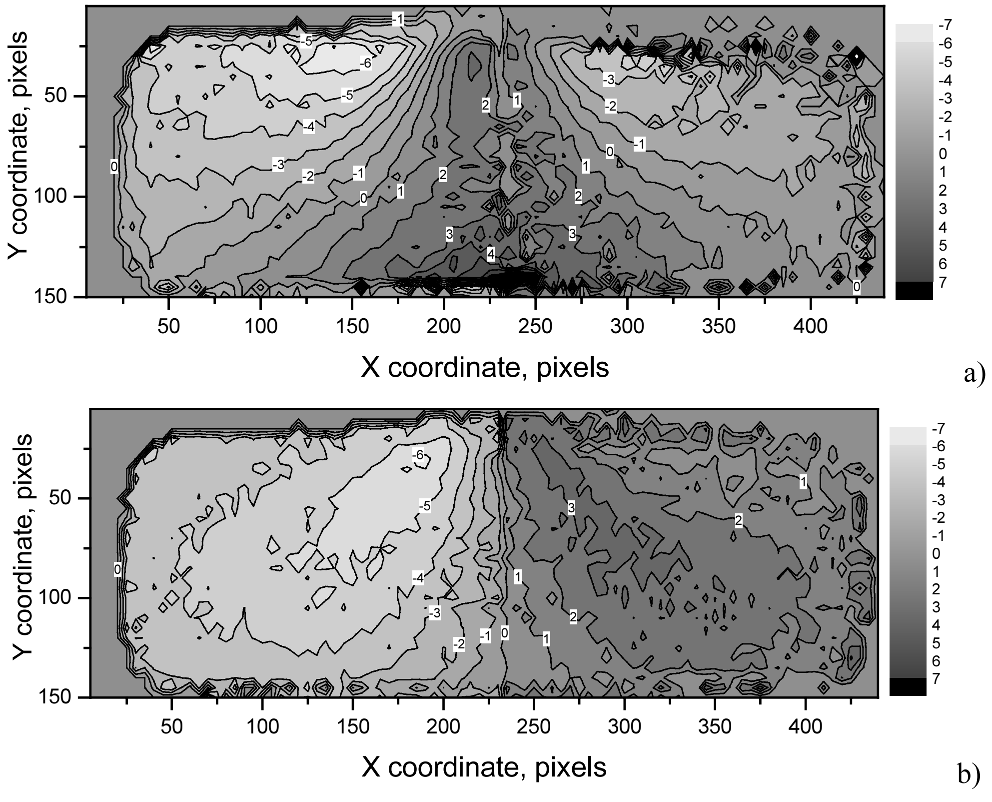

Fig. 4. Maps of (σ_1-σ_2) (a) and σ_6 (b) for the loaded state of sample (in MPa).

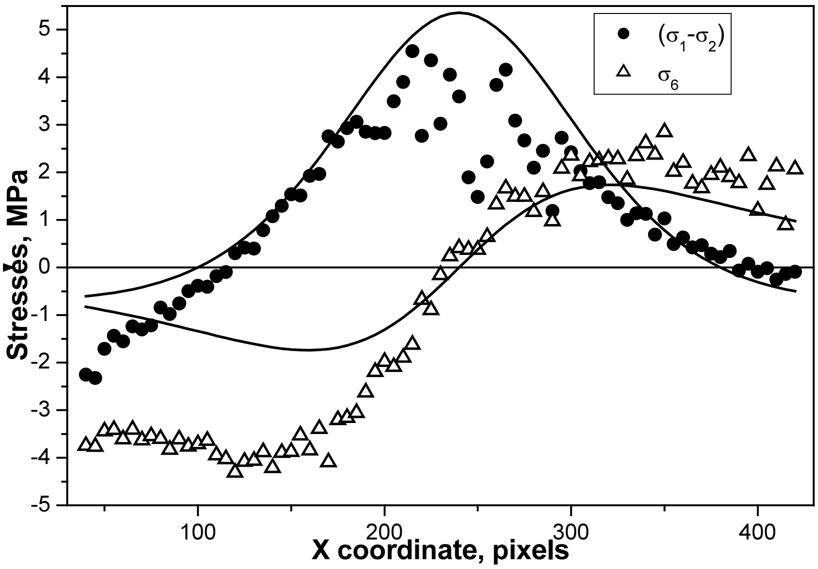

Fig. 5. Dependences of the stress components on *X*-coordinate at *Y* = 125 pixels. The dots and triangles correspond to experimental data and the solid curves to fitting with formulae (6) and (7).

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