Fixation of the stressed state of glass plates by coating them with thin films using a plasma focus installation

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Abstract. Elastic deformation in transparent mediums is usually studied by the photoelasticity method. For opaque mediums the method of film coating and strain gauge method are used. After the external load was removed, the interference pattern corresponding to elastic deformation of the material disappears. It is found that the elastic deformation state of the thin glass plate under the action of concentrated load can be fixed during the deposition of a thin metal film. Deposition of thin copper films was carried out by passing of plasma through the copper tube installed inside the Plasma Focus installation. After removing of the load, interference pattern on the glass plates was observed in the form of Newton's rings and isogers in non-monochromatic light on the CCD scanners which uses fluorescent lamps with cold cathode. It is supposed that the copper film fixes the relief of the surface of the glass plate at the time of deformation and saves it when the load is removed. In the case of a concentrated load, this relief has the shape of a thin lens of large radius. For this reason, the interference of coherent light rays in a thin air gap between the glass of the scanners flatbed and the lens surface has the shape of Newton’s rings. In this case, when scanning the back side of the plate, isogyres are observed. The presented method can be used in the analysis of the mechanical stress in a various optical elements.

1. Introduction

Determination of mechanical strain (stress) in solids is an urgent task. Elastic deformation in transparent media are usually investigated by photoelasticity [1-4]. Film coating techniques or moir fringes are used for non-transparent media [5-6]. Strain methods are laborious and provided information about the deformations in a limited number of points [7]. Methods of optical ellipsometry are complex and require a certain skill when analyzing the measurement results [8]. Measurement of deformations in samples is usually performed at the time of application of force. In the case of elastic deformation after unloading samples they return to its original state and the stress distribution pattern disappears. There are a limited number of methods to observe the deformation pattern in a solid after removal of the load. The photoelasticity method is based...
on samples of photosensitive transparent plastics, in which the heating and subsequent cooling leads to "freezing" of picture of internal stresses. [2,6]. By this method by cutting the samples into thin plates the stress distribution inside the samples is determined. In the method of moir fringes, on the contrary, the studied model is cut into thin plates, and then the optical grating is applied to each of the plates. Collected from the plate model is subjected to external forces, and then by studying the deformation of moir fringes that existed at the time of loading. Collected model from the plates is subjected to external forces, and then by studying the deformation of moir fringes that existed at the time of loading. The aim of this work is to study the pattern of the "frozen" (fixed) state deformation (stress) in the thin glass plates in situ by deposition of a thin metal film on a plasma focus installation.

2. Experimental methods
For the study, glass plates of thickness 1.5-3 mm and in size 40x40 mm were used. Before the experiment the glass samples were degreased in alcohol. Samples were subjected to elastic deformation by use of a special device (Figure 1), which was placed in a discharge chamber of plasma focus (PF-4, Lebedev Phys. Inst.). Applying force $\sim 1$ Pa for all glass plates was the same. The plates were pressed against the surface of the sample holder at the corners by means of copper straps.

![Figure 1](image-url)

Figure 1. The device for monitoring "frozen" picture of deformation (stress) in a glass plate on the Plasma Focus Installation: 1 - copper tube; 2 - of plasma jet with the metal vapor; 3 - plasma region spreading over the surface of the glass plate; 4 - copper film; 5 - glass plate; 6 - sample holder (steel Art.20); 7 - the screw, creating a concentrated load to the glass plate.

The spraying of thin copper film was carried out under the scheme based on the plasma chemical reactor PF setting [9]. The discharge chamber was filled by argon gas at a pressure in the chamber $\sim 1$ Torr. The stored energy in the capacitor bank was $\sim 3.6$ kJ. The quarter of period of the electric discharge was equal $\sim 3 \mu$s. The plasma jet was passed through the copper tube of 8.0 mm diameter and 70 mm in length. The distance between the edge of the copper tube and the surface of the glass plate was equal 28 - 30 mm. Received copper films were conductive and semi-transparent for the light. The electrical surface resistance of the films was $\leq 10^4 - 10^5$ Ohms/square. The structure of the films had the insular character. The observing the interference pattern on the surface of glass plates was carried out in non-monochromatic light on the CCD scanners with fluorescent lamps with a cold cathode [10]. Scanners of following models: HP Scanjet 3800, Epson Perfection 1650 Photo and Cano Scan D6604 were used to control observing the interference pattern. Due to the fact that the interference patterns were identical in the future we use only the scanner HP Scanjet 3800. The CIS scanners (Contact Image Sensor) on the LED strip were not considered in the work, because when they are used, the interference pattern is not turned.
3. Experimental results

Figure 2a shows a typical interference pattern on the original glass plate, which was scanned by the scanner HP Scanjet 3800. The character of the pattern indicates some deformation of the surface of the glass plates and the presence of the air gap in the form of a wedge between it and the plane of the document table glass, which leads to an interference pattern in the form of strips of equal thickness. Figure 2b shows a glass plate with a film deposited on the PF no-load applications. It is seen that the interference region around the spray pattern is not observed.

**Figure 2.** Interference pattern on the original glass plate (a) and on the plate exposed to the PF plasma pulse without the application of external force (b).

Figure 3 shows the interference pattern on the glass plate after spraying copper film at the...
time of application of a force. When scanning the plate on the sputtered film side the Newton interference rings are observed, and on the reverse side - interference fringes are seen in the form of hyperbolas disposed symmetrically relative to the force application point to the glass plate. The quality of the picture is significantly affected by the intensity of the plasma jet passing through the copper pipe. At high intensity of plasma the glass is destroyed and the observation of the interference pattern becomes difficult (Figure 4).

![Figure 4. The interference pattern on a glass plate at a high intensity plasma jet.](image)

4. Discussion of the results
The interference pattern in the form of Newton rings (Figure 3a) is typically observed in coherent interactions of light rays incident normal to the thin lens surface lying on the glass plate surface [11]. The role of the thin-lens in this case carries a metal film on the surface of the glass plate, curved in the form of a hemisphere. The solution of a particular problem for a semi-infinite thin plate under the action of a concentrated force is considered in [12]. It is known that the interaction of electromagnetic waves with the metal surface and the passing phase of the reflected waves are determined by the surface impedance and are 0 or $\pi/2$ [13]. However, in the case of "bad" conductors permittivity depends weakly on its complex parts, because the $\sigma \to 0$.

In this case, the thin copper film thickness of the wavelength order, and the character had islet surface resistance $\sim 10^4 - 10^5$ ohms / square. A feature of the observed interference pattern (Figure 3a) is the emergence of strong intensity interference rings in the green region of the spectrum and more faint rings pink. The maximum transmission of thin films of Cu is in the range $\lambda = 0.558$ $\mu$ (green-yellow region of the spectrum), the near-infrared region of the spectrum is a strong reflection of the long-wave radiation. It can be assumed that the interference associated with the coherent interaction of light rays reflected from the copper film with rays of light passing through the film deep into the glass plate.

Currently, the nature of "freezing" the deformation structure in a thin glass plate during deposition of the metal film is not clear. Glass - fragile amorphous material and the diagram "stress - strain" does not have the field of plastic flow, i.e., it should not have a residual strain [14]. On the other hand, on the surface of glass has a thin damaged layer associated with the
manufacture of glass technology, there are various kinds of chemical compounds, oxides. Thus, between the Cu deposited film and the glass an intermediate layer exists, which is more plastic than glass [15]. We can therefore expect that when the load is removed the more ductile layer allows you to save a whole picture of the metal film strain.

In fact, during the deposition of the metal film the thin shell in the form of a hemisphere is obtained. Reflection of incoherent light from the hemisphere gives the converging beam in the center of a sphere of radius R. Evaluation according to the formula for the radius of Newton’s rings [11] give values $\sim 80$ m. However, when scanning the back side of the glass plate we observe the complex interference pattern (Figure 3b), indicating the coherent interaction of light rays from the surface of the hemisphere which is modulated due to glass deformation during of the application of a force. Light and dark interference fringes are in the form of hyperbole and are arranged symmetrically with respect to the point of force application. Externally, they resemble isogyre in photoelasticity method [1, 2]. However, in this case they arise through the interaction of coherent light converging rays reflected from the surface of modulated strain. It is seen that the maximum stress in the center of the plate falls off rather rapidly to its edges. Attraction methods of elastic deformation theory and the comparison with the data obtained from the processing of interference patterns, can serve as a way of determining the stress in dealing with various applications.

5. Conclusion

It is shown that the scanners such as CCD (Charge Couple Device) which use the fluorescent lamps with cold cathode allow the observing the ”frozen” interference patterns in thin glass plates in situ after application of a force and a thin metal film deposition. It is proposed to use this technique in the analysis of deformations in the flat solids in the solution of applied problems of elasticity theory.

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