Deformable Polymer Dielectric Films in Phase Light Modulators

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Abstract. Experimental study of the deformation amplitude of the dielectric polymer gel films directly right in the display device of optical information was conducted. The deformation amplitude of the gel film was measured during its change by controlled constant voltage on the electrodes. On the basis of polymer gel deformational layer the display devices of optical information and registration of electrostatic potential of charged dielectric thin films in the presence of defects are considered.

1. Introduction
The devices based on polymer gel atmospheres (GA) are developed to display of information in optical form [1, 2]. The devices based on GA are developed in two directions of recording information: by electron beam and at the electrode controlling. At the electrode controlling the service life of polymeric GA is increased; the size and power of the device are reduced. It is also important to know the necessary values of GA deformation for getting the maximum light output.

2. Display device of optical information record
Figure 1a shows scheme of the display devices of optical information on basis on polymer deformational gel layer.

The device works in the following way. Capacitor 1 displays filament body of the light source 2 on the opening of input diaphragm 3; after that through the lens 4 a transparent conductive layer 6 and parallel light stream, directed on the GA 5 through the prism of total internal display 7, are formed. Next, the light, reflected from the interface of "GA – air gap", secondarily passes through GA, the electrically conductive layer 6 and the prism of total internal display 7, and then focuses on the opaque output diaphragm 12 by the lens 8. Control voltages from source of control signals 10 are fed on the strip electrodes 9 of the raster on the second glass plate 11. GA surface is deformed in accordance with the voltage on the electrodes. GA relief changes the direction of light propagation; rejected light beams will pass to the screen, bypassing the opaque output diaphragm 12. Lens 8 focuses this light on the screen 13 in the form of light strips. The brightness of the light strips is proportional to the amplitude of the control voltages. The light output of the device was measured as the dependence of the light line brightness on the screen on the voltage value on the control electrodes.
Two semitranslucent 14, 15 and reflecting mirrors 16 are included in the scheme for measuring the amplitude of the deformations of GA surface. These mirrors create two arms of the Mach–Zehnder interferometer; they form an interference picture on the screen 13 during setting. Since the deformable gel layer is in one arm of the interferometer under the action of the control voltage, the interference picture shows the increasing phase incursion of light due to change of the deformation amplitude. A source of coherent radiation (helium-neon laser) was used as radiation source.

Figure 1b shows dependence of the light output ($\rho$) on the constant electrical voltage $U$ on the electrodes. It follows from the graph that the sensitivity of the method of defocusing is considerably higher sensitivity of the method of dark field on 100 V.

Control voltage amplitude $U$ increases sharply with increasing of air gap between the GA and strip electrodes 9 (Figure 1a); it is a condition for getting of maximum light output. Light output function equal to 0 at the gap ~ 100 µm at any voltages between control and rasterized electrodes. Reduction of light output is possible to 0 at simultaneous feeding a control voltage on the electrodes of raster 9, when the voltage has a value, close to the breakdown voltage of the working air gap between the electrically conductive substrate 6 GA film 5 and the electrodes 9 (with the gap of 40 µm). This is because the density of the ponderomotive forces of harmonic components decreases exponentially with the increasing of the air gap; the light output depends on the density of the ponderomotive forces of harmonic components. At the same time, the density of the ponderomotive forces of constant component varies slightly with the increasing of the gap. Light output decreases sharply for a time of 10÷20 seconds at feeding the control voltage on all the control electrodes and electrodes of raster 9. This change of light output occurs because of the leakage of the charge in the electrode gaps due to the final value of the electrical conductivity of the substrate and potential leveling of control plane of the film, respectively. If raster electrodes are connected to zero potential, then slow decreasing of light output occurs exponentially at disconnecting of the source of control voltage from the control electrodes. This phenomenon can be used as an electrostatic memory.

Light output and GA strain amplitude can be measured for the same conditions. The light output curve can be represented as the dependence of strain value on the control voltage; it shows that a small increment of amplitude of the order of 0.18 µm is required for getting maximum light output. This is consistent with theoretical estimates of phase increment taking into account the double passage of light through the surface relief of GA [2]. Relative elongations do not exceed 1% of the polymeric composition of GA with thick of 20 µm. Therefore, the equations of continuum mechanics in the
linear approximation can be used at the calculation of deformation amplitude value. Performed studies show a good optical quality of the spatial-time light modulators based on polymer GA.

3. Control device of defects in thin films
The need to control the heterogeneity of the surface properties and defects of technological thin layers of dielectrics appears during development and study of films in microelectronics [3, 4], electret [5–7] and the active thin film materials [8–12]. One of effective methods of testing is a principle of spreading of excess charge on a controlled surface; in this case the charge drains arise in the locations of defects (or inhomogeneities). It leads to considerable heterogeneity of potential relief of surface film of charged dielectric. Heterogeneity of potential relief of surface indicates location and defect size.

Vibrating electrode method with compensation of external electric field is used for registration the potential relief of surface of charged dielectric materials, for example, electrets [13]. The method has high measurement accuracy with an error not exceeding ±1%. In this case, vibrating electrode (as a probe) is necessary to implement structurally with small area that is making significant edge effect of the electrode in the measuring cell; it leads to significant increasing measurement error at low resolution.

The above-described electro-optical principle of gel dielectric layer of GA (as a probe) in measuring cell can be used to solve the problem of registration of potential relief with high resolution. Layer deformation of GA is carried out by external electric field $E_0$ as charged dielectric in system of flat capacitor and by supplying external voltage into electrodes of capacitor. It allows studying the picture of charge distribution on the surface in the form of light inhomogeneities with subsequent signal processing.

Figure 2 shows schematic diagram of measurement system based on electro-optical sensor (EOS) with GA, where 1 is charged dielectric layer of sample, coated on hypotenuse side of prism, 2 is sensitive GA, 3 is transparent electrically conductive electrode, 4 is photo receiving optical device of recording by dark field method, 5 is prism, 6 is source of the plane-parallel light beam, 7 is supply source, 8 is electrode, 9 is regulated constant-voltage source, 10 is defect in the film, 11 is display device of information.

Figure 2. Schematic diagram of measurement system based on electro-optical sensor.

The device (Figure 2) works as follows. Charged sample of film dielectric 1 with thickness $L$ on the substrate 8 is placed in cell of flat capacitor formed by plane-parallel electrodes 3 and 8 with fixed gap $d_0$. Electric field $E_0$ is generated in gap $d_0$ of the capacitor by dielectric charge with effective density of surface charge $\sigma$. It causes deformation of the surface of GA 2 by ponderomotive forces of

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interaction. Plane-parallel light beam from source 6 passes through prism 5, optically transparent electrode 3 and GA 2; it is reflected from GA boundaries, returns to the prism 5 and then falls into photodetector 4 (PD), for example, CCD camera.

Transformation of distribution picture of electric potential of charged surface of studied film 1 occurs in EOS with gel layer of GA (electric signal $\sigma \rightarrow U_0 \rightarrow E_0$ into output optical signal in form of light image). PD 4 registers and visualizes a picture of light field on the screen of display device of optical information 11.

Surface charge flows on the substrate 8 is significantly faster in the defect region 10 of film 1 and forms a region of reduced surface charge density $\sigma$. Gel layer 2 of EOS of electric field has a maximum value of deformation in non-uniform charge region on the dielectric surface 1, i.e. in film defect region. Therefore, PD 4 registers more bright fluorescence in this region of picture of light display.

Thus, charge regions on surface with greater or lesser charge density appear on picture of light display as different intensity of emission in this defect region. Brightness in predetermined region of picture can change to certain light intensity by varying the constant electric voltage from source 9 on the electrode 8. Voltage value $U_K$ of compensation field $E_0$ is recorded at full compensation of the electric field in gap at $E_0=0$; charge density $\sigma$ in the controlled region is calculated according to equation $\sigma = \sigma_0 - U_K / L$. The light picture of field shows complete picture of potential relief of controlled dielectric surface in the form of two-dimensional light field with presence of light spots corresponding to defects 10 of investigated layer 1 of film dielectric. Use of standard optic in control system (with the gap between sample and GA) allows to determine defects in the form of dots and spots of size less than 50 microns at resolving of potential of dielectric surface of not more ±5 V.

5. Conclusion

Experimental studies of deformation amplitudes of gel films directly in optical pickup device of potential relief of charged dielectric show that it is possible to control parameters of sensitivity and registration accuracy of optical information by feeding external constant electric voltage.

Device of registration and defects control in thin and nano-sized dielectric films in microelectronics is proposed on the basis on the studied phenomenon of gel layer deformation under action of the ponderomotive forces of electric field.

Discussed method also allows carrying out research of potential relief picture of charged dielectrics.

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