HOLOGRAPHIC RECORDING IN "DYE—IONIC SMECTIC" DOUBLE-LAYER CELLS

YU.A. GARBOVSKIY, G.V. KLIMUSHEVA, S.A. BUGAICHUK, O.G. KOLESNIK

Institute of Physics, Nat. Acad. Sci. of Ukraine
(46, Nauky Ave., Kyiv 03028, Ukraine; e-mail: garbov@iop.kiev.ua)

UDC 532.738; 548.14

The recording of dynamic gratings in double-layer cells by nanosecond-sized pulses of laser emission has been investigated. A double-layer cell consisted of a solid dye layer and the layer of an ionic lyotropic liquid crystal (ILLC) of the smectic-A type. The dependences of the self-diffraction efficiency in the first diffraction order on the energy of the writing emission pulse and the grating period have been found. The obtained values of the diffraction efficiency (5—6%) exceed analogous values for doped ILLCs by an order of magnitude. The time behavior of a holographic recording has been studied, and the characteristic time of the grating relaxation has been found to be 30 μs.

1. Introduction

The researches of nonlinear optical phenomena in novel media, in particular, the holographic recording of dynamic gratings, have attracted a more and more attention during last years. Such a tendency is caused by the rapid development of information technologies, including the methods of optical information treatment. Liquid crystals are known [1] to be perspective nonlinear optical materials. The most widespread mechanisms that stimulate the appearance of optical nonlinear effects in the mesophase are orientational effects, temperature-induced variations of the medium's refractive index, and photo-induced transformations of molecules [2]. The search for new liquid crystal media and the development of optimal cells for the highly effective holographic recording are of significant interest. Promising in this respect are the cells proposed by us, which are based on new ILLCs and include the solid films of various dyes.

ILLCs are produced by dissolving the salts of alkane acids with a monovalent metal ion in water with a weight proportion of 1:1 at room temperature [3]. The structure of prepared ILLCs corresponds to that of a thermotropic smectic A. The molecules are packed in double layers which are composed of hydrophobic alkane chains and electrostatic layers, the latter involving metal cations and the anions of a carboxyl group in water. Such ILLCs with a structure of the smectic-A type (ILLC-SmA's) are characterized by the intrinsic ionic conductivity that is 3—4 orders of magnitude higher than the extrinsic conductivity of molecular liquid crystals [4], as well as by the substantial heat conductivity and viscosity [3].

It has been shown earlier on [5] that, in a cell filled with an ILLC doped by polymethine dyes, one can record a dynamic grating making use of the laser nanosecond-sized pulse emission. The concentration of the dopant was varied in a wide interval (from 0.01 to 1 wt.%), but the diffraction efficiency achieved in the first order of self-diffraction did not exceed 0.5%. Therefore, a problem arose to increase the efficiency of the holographic recording in another way. This work is aimed at elaborating the effective recording of dynamic gratings in ILLC-SmA-based cells with a solid dye film and studying their basic holographic characteristics.

2. Experimental Technique

The aqueous solution of potassium caproate with a weight proportion of 1:1 was used as an ILLC at room temperature

For a double-layer cell to be fabricated, first, a drop of the cyanine dye solution was deposited onto a glass substrate. After the solvent having evaporated, a solid film was obtained, which was covered with an ILLC layer. In the obtained micron-sized solid dye film,

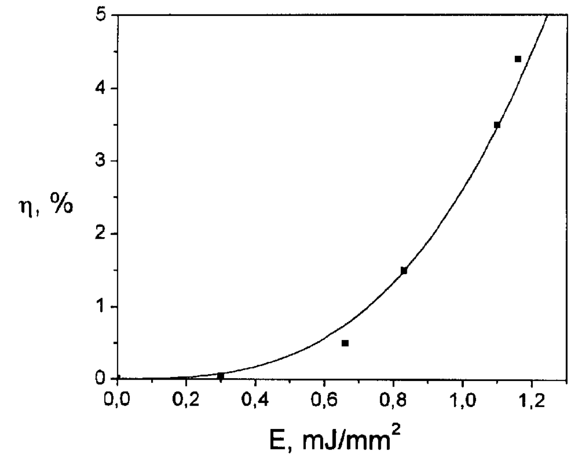

Fig. 1. Dependence of the efficiency η of self-diffraction into the first order on the energy density E in the writing pulse for a double-layer cell with a CN1 dye film (the grating period $\Lambda = 14$ μm)

molecules were packed in micro- and nanocrystals. The ILLC became self-organized into a planar smectic A with the confocal texture, a part of dye molecules penetrating into the liquid crystal matrix. At the dye–ILLC-SmA interface, there appeared a heterolayer. To prevent water from evaporation, the cells were glued. The cell thickness was regulated by Teflon spacers within 10—30 μm.

In this work, we studied ILLC-SmA cells with CN1 cyanine dye. As a rule, we experimented with specimens, the optical density of which at a wavelength of the writing pulse laser emission of 539.8 nm was 1—1.5. It should be noted that only the dye film absorbed, because pure potassium caproate is transparent within the range 400—700 nm.

To study the recording of dynamic gratings, the two-beam setup was applied. We used the emission of the second harmonic of an Nd:YAP pulse laser which operated in the Q-modulation mode (the TEM_{00} mode, $\lambda = 539.8$ nm, $\tau = 20$ ns, $\nu = 3$ Hz). Laser emission linearly polarized in the horizontal plane was treated by the converter of the second harmonic and passed, in sequence, through a filter which did not transmit the infra-red radiation of the first harmonic, a diaphragm of 1 mm in diameter, and a beamsplitter (composed of an optically translucent cube and a mirror). In such a way, we obtained two beams with approximately identical intensities, which were afterwards converged on the cell. Changing the angle of convergence between the beams and adjusting the laser emission intensity by neutral filters with known factors, we managed to investigate the corresponding dependences of the self-diffraction efficiency. With the help of photodiodes, we registered the reflexes of the zeroth and first diffraction orders (signals from photodiodes were applied to the input of a digital oscillograph).

In order to study the time characteristics, the recorded holographic gratings were read out with the help of the probing non-polarized emission of a continuous-wave He-Ne laser ($P = 2$ mW). The probe beam diffracted into the first order was registered by a photodiode, the signal from which was applied through an amplifier to the input of a digital oscillograph.

3. Experimental Results and Their Discussion

For the self-diffraction to be observed in a double-layer cell, one 20-ns pulse of the laser emission turned out to be sufficient. Usually, we observed several diffraction orders, which testifies to that the recorded dynamic gratings were thin (for the grating period $\Lambda = 14$ μm and the cell thickness $d = 25$ μm, the Cook–Klein parameter $Q = 0.3$). To reveal how the absorption factor of the double-layer cell (dye film—ILLC-SmA) changes with the variation of the energy density E, we investigated the dependence of the optical density D of the specimen on E at an emission wavelength of 539.8 nm. It turned out that the optical density of the cell medium ($D \approx 0.9 \div 1$) depends very weakly on the energy density at $E < 0.7 \div 0.8$ mJ/mm^2. At the same time, within the interval $E = 0.8 \div 1.1$ mJ/mm^2, the optical density decreases to the value $D \approx 0.4 \div 0.5$.

The dependence of the diffraction efficiency η in the first order of self-diffraction on the energy density E in a single writing pulse was obtained at a fixed period of the grating of 14 μm (Fig. 1). From this figure, one can see that the diffraction efficiency of the recording reaches 5% at $E = 1.2 \div 1.3$ mJ/mm^2. We recall that the maximal diffraction efficiency achieved in the case where doped ILLCs were used did not exceed 0.5%.

Making use of the known expression $\eta_A = (\Delta k d/4)^2$, one can estimate the contribution of the absorption factor k to the diffraction efficiency of the grating. In our case, $\Delta k d \approx \Delta D \approx 0.4$, so that $\eta_A \approx (0.4/42)^2 = 1\%$. The observed 5%-efficiency of the self-diffraction into the first order evidences for the presence of a phase grating, with the contribution of the latter exceeding that of the amplitude grating to the self-diffraction efficiency. Using the known expression for the diffraction efficiency of a phase grating, $\eta_P = (\pi \Delta n d/\lambda)^2$, the modulation of the refractive index can be estimated as $\Delta n \approx 10^{-3}$.

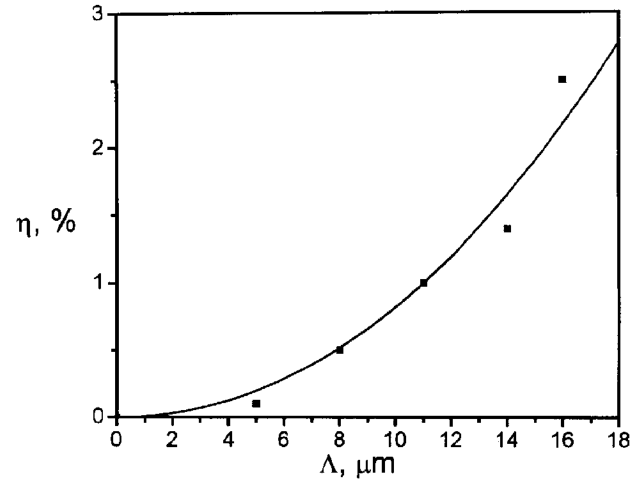

Fig. 2. Dependence of the efficiency η of the self-diffraction into the first order on the grating period for the double-layer cell with a CN1 dye film (the energy density $E = 0.8$ mJ/mm^2)

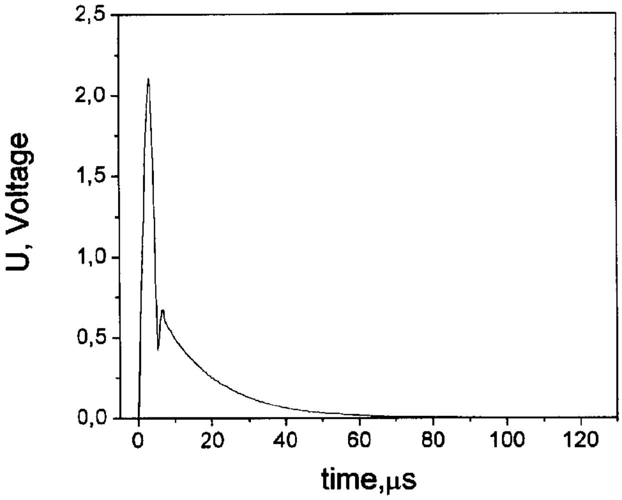

Fig. 3. Oscillogram which illustrates the variation of the level of a signal diffracted into the first order of the probing beam for the double-layer cell with a CN1 dye film ($E = 1.3$ mJ/mm^2, $\eta = 2.5\%$, and $\Lambda = 12$ μm)

The dependence of the self-diffraction efficiency η into the first order on the period of a recorded dynamic grating Λ in the double-layer cell, provided that the energy density in a laser emission pulse is constant, is shown in Fig. 2. The period was varied from 5 to 20 μm at the constant energy density $E = 0.8$ mJ/mm^2. A gradual growth of the diffraction efficiency is observed as the period increases.

For the pulse energy density $E \approx 1.3$ mJ/mm^2 and the grating period $\Lambda = 12$ μm, we have studied the relaxation kinetics of recorded dynamic gratings in the double-layer cell with a CN1 dye film. As was mentioned above, a single 20-ns pulse was enough for the self-diffraction to be observed, which testifies to the high rate of recording within this time interval. Fig. 3 exposes the oscillogram that illustrates a variation of the level of a signal diffracted into the first order during the reading out of the grating by a continuous-wave He-Ne laser. The oscillogram shows that the recorded grating relaxes exponentially with the characteristic time $\tau_e \approx 30$ μs.

Thus, our experimental data testify to that the employment of double-layer cells dye–ILLC-SmA allows the dynamic gratings to be recorded within nanoseconds and to be totally erased within 100–150 μs. The application of a dye film allows the diffraction efficiency of the recording to be enhanced considerably owing to a drastic increase of the concentration of absorbing centers. It is worth noting the role, which is played by ILLC-SmA in the double-layer cell. The experiments showed that the laser emission can record only stationary gratings in pure dye films without ILLC-SmA. The covering of the solid dye film with an ILLC-SmA layer to fabricate a double-layer cell makes the dynamic recording of gratings possible.

A clarification of the mechanism of the grating recording in the considered double-layer specimens requires a separate complex research. Nevertheless, basing on experimental data, one can talk about the presence of a resonant nonlinearity which is caused by the absorption saturation effect, when dye molecules fulfill a two-level transition. Under the action of intense irradiation with the frequency close to that of the transition, the upper energy level becomes occupied, and the medium bleaches, as is observed in our experiments. The grating relaxation runs due to the presence of the ILLC-SmA layer which is in a close contact with the dye film. The exponential character of the grating relaxation within 100–150 μs can be connected with the relaxation of the energy supplied by the writing laser emission into ILLC-SmA and absorbed by the dye. It is worth noting that there are no destructive and orientational modifications in the specimens under investigation in the course of the grating recording and relaxation.

4. Conclusions

For the first time, a double-layer cell based on ILLC-SmA and a solid dye film has been proposed for the recording of dynamic gratings. It has been elucidated that the holographic recording is most effective provided the energy density is 1—1.5 mJ/mm^2 in a pulse and the grating periods are more that 10—15 μm and amounts to 5—6%, which is by 1—2 orders of magnitude higher than the diffraction efficiency of gratings recorded in doped ILLCs [5]. The exponential character of the recorded grating relaxation with a characteristic time of about 30 μs has been established.

1. *Palffy-Muhoray P.* Handbook of Liquid Crystals. — Weinheim: Wiley, 1998. — Vol.1. — P. 569—582.

2. *Arakelyan S.M., Chilingaryan Yu.S.* Nonlinear Optics of Liquid Crystals. — Moscow: Nauka, 1984 (in Russian).

3. *Mirnaya T.A., Prisyazhnyi V.D., Shcherbakov V.A.* // Usp. Khim. — 1989. — **58**, N 9. — P. 1429 — 1450.

4. *Volynets M.V., Klimusheva G.V., Kovalchuk O.V. et al.* // Ukr. Fiz. Zh. — 2002. — **47**, N 4. — P. 365 — 368.

5. *Volynets M.V., Derev'yanko N.O., Ilyin A.G. et al.* // Ibid. — 2001. — **46**, N 7. — P. 697 — 700.

Received 15.03.05.
Translated from Ukrainian by O.I. Voitenko

ГОЛОГРАФІЧНИЙ ЗАПИС ГРАТОК В ДВОШАРОВИХ КОМІРКАХ БАРВНИК–ІОННИЙ СМЕКТИК

Ю.А. Гарбовський, Г.В. Клімушева, С.А. Бугайчук, О.Г. Колесник

Р е з ю м е

Досліджено запис динамічних граток наносекундним імпульсним лазерним випромінюванням у двошарових зразках, що складаються з твердої плівки барвника та шару іонного ліотропного рідкого кристала (ІЛРК) типу смектика А. Отримано залежності ефективності самодифракції в першому дифракційному порядку від енергії записуючого імпульсного випромінювання та періоду гратки. Одержані значення дифракційної ефективності (5—6 %) на порядок перевищують аналогічні величини для домішкових ІЛРК. Вивчено часові характеристики голографічного запису та встановлено характерний час релаксації граток — приблизно 30 мкс.