Letter

Evidence for Holographic Image Storage in a Fullerene-Doped Liquid-Crystal Film

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We report on our observation of holographic grating formation induced by an input pattern in company with a reference wave in a fullerene-doped liquid-crystal film. Evidence concerning the reconstruction of holograms indicates that this photorefractive liquid crystal can, indeed, serve as a hologram-recording medium.

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Photorefractive materials are known to possess unique electro-optical and mechanical properties for potential applications in the areas of holographic recording, real-time holography, interferometry, image amplification, optical limiting, phase conjugation, and other optical information processing techniques [1]. Since the first prediction and observation of the photorefractive effect in nematic liquid crystals (LCs) [2-4], considerable progress has been achieved in the photorefractive performance of these materials. Indeed, LCs are intriguing owing both to the low characteristic voltage required for application to the material for the realization of wave mixing and to the high modulation of the refractive index induced with a rather low power density of light beams. Moreover, photorefractive LCs have the advantage of ease of fabrication which has been developed in the display industry. We note that twisted nematic liquid-crystal spatial light modulators have been widely used to produce computer-generated phase holograms or kinoforms [5].

Dramatic enhancement of the diffraction efficiency and beam-coupling effect has been observed in buckminsterfullerene (C_{60})-doped nematics in the Raman-Nath regime [6-9]. The phase-shifted index grating induced by the two-wave mixing of coherent optical beams, in conjunction with an applied dc field, was shown to be electrically switchable [9]. Furthermore, orientational photorefractive Bragg gratings can be recorded in high- and low-molar-mass nematic LC mixtures incorporating C_{60} [10-12]. In spite of the evident observation of both transient and persistent phase gratings, to the best of the authors’ knowledge, the main body of the research on photorefractivity of the fullerene C_{60}-doped nematics has been devoted entirely to grating formation via two-wave mixing, and the ability for holographic image storage of this material has been left untouched to date.

In this Letter, we describe a simple experimental setup, involving a photomask as an object, which shows that the C_{60}-doped nematic liquid-crystal film used as a photorefractive element is
indeed capable of storing holographic images. We attempted holographic image storage in a 100-
¹ m-thick LC cell filled with E7, a mixture of four low-molar-mass nematogens from Merck Ltd.,
as well as a trace amount (» 0.05 % by weight) of buckminsterfullerene (99.95+% ultra pure)
from SES Research. The cell windows were coated with a transparent electrode of indium tin
oxide (ITO) for application of an external dc field. Planar alignment of the liquid crystal was
provided by polyvinyl alcohol (PVA) treated on the inner surface of both cell windows and rubbed
in a unidirectional manner. Fig. 1 shows the conceptual scheme of the experiment for testing
the ability of the material used for holographic image storage. A photomask of the letter H was
employed as the object. The object and reference beams, both derived from a p-polarized Ar+
laser (Spectra-Physics, Stabilite 2017-04S) operating at 514.5 nm, had equal power of » 4 mW.
The sample sat upright and was oriented in such a way that the unperturbed liquid-crystal director
axis lay on the horizontal incident plane. The incident angle was set at » 40° between the normal
of the sample and the bisector of the two focused recording beams. An external dc electric field,
varying from 0 to 1 kV/cm, was applied across the LC film. The writing process was monitored
with a CCD camera, which captured the +2nd Raman-Nath order diffraction beam for the output
pattern.

Fig. 2 shows the experimental results acquired under an operating dc field of 1 kV/cm.
The transient holographic gratings were observed in the presence of the reference beam and
the object beam. The output pattern disappeared gradually as the reference beam was blocked. This fact clearly indicates that the holographic diffraction grating was formed in the LC film,
rather than the focused image of the object being stored in the cell. This nematic film was
then exposed simultaneously to the writing beams for an uninterrupted duration of » 20 min; the
resulting interference pattern recorded in the film constitutes the hologram that contained all of the
information needed to reproduce the wave field of the object. Note that such persistent gratings,
that can be hidden by turning the dc electric field off [9], are most likely due to a light-induced
modulation of the easy axis caused by electric charges at the interface of the nematic film and the
alignment layer. It is also worth mentioning that the obvious limitations in the image quality, as
revealed in Fig. 2, are primarily attributed to background noise; i.e., light scattering caused by the
inhomogeneity of the doped nematic.

In order to examine the response of the film to the applied electric field, the +2nd-order
diffracted beam was monitored as the external dc voltage varied. Fig. 3 illustrates a series of
reconstruction processes of the holographic image upon irradiation with a single beam, similar to
FIG. 2. Diffracted pattern of the +2nd-order beam in the presence of the object beam. The reference beam is (a) blocked or (b) allowed to propagate through the recording film.

FIG. 3. Process of the holographic image reconstruction. The 1-kV/cm applied field is turned on for (a) 0, (b) 3, (c) 15, and (d) 60 s.

The properties of those periodic gratings reported in previous works [2-4; 6-12] certainly ensure one to expect a much superior holographic reconstruction in a C_{60}-doped LC than in an undoped counterpart [13]. In summary, we have reported the storage of a recognizable image in a fullerene-doped LC film. We recognize that the major limitation in the image quality can be attributed to our poor technique of dispersing the dopant C_{60} into the nematic. Still, in addition to the promising electric field sensitivity, light-intensity dependence, and sample absorbance.
characteristics, our results indicate that birefringent nematics doped with the fullerene C₆₀ are attractive candidates for molecular optical devices. Recently, some interesting wave-mixing phenomena in a nematic LC impregnated with the allotrope carbon nanotubes have been reported [14]. The present work justifies thorough investigations of the spatial resolution, contrast, access rate, and storage capability of LCs doped with such carbon materials. Studies with these emphases are currently being pursued in this laboratory.

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References