Command surface controlled liquid crystalline waveguide structures as optical information storage

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We report on optical waveguide structures in which light propagates within a liquid crystal (LC) thin film. In this configuration, the orientation, and therefore the optical properties of the LC waveguide structure are controlled by two photochromic command surfaces, consisting of an ultra thin film of a polymer with azobenzene side chains [K. Ichimura, Y. Suzuki, T. Seki, A. Hosoki, and K. Aoki, Langmuir **4**, 1214 (1988)]. When exposed to light of appropriate wavelength, the azobenzene side chains undergo a *trans*↔*cis* photoisomerization process inducing a commensurate change in the LC alignment and therefore, in the set of refractive indices of the LC film. Using this effect we could reversibly write information into the LC cell. The size of our test structure was in the range of 50 μm. The stored information was read out by optical waveguide microscopy [W. Hickel and W. Knoll, Appl. Phys. Lett. **57**, 1286 (1990)]; the storing times were in the range of several hours. © *1994 American Institute of Physics.*

It is well known that the orientation of a LC strongly depends on the surface properties of its substrate. Therefore, when applying a photochromic command surface, the orientation of a LC can be altered under the influence of light Langmuir–Blodgett–Kuhn (LBK) films,[1] prepared from poly (venyl alcohol) with azobenzene side chains (mAzn-PVA), proven to be very efficient for this purpose.[2] In such a surface structure, the *trans*↔*cis* transition of the azobenzene side groups induces a homeotropic↔parallel transition in the alignment of a nematic LC [see Fig. 1(a)].[3–7]

In a recent paper[8] we presented an optical waveguide structure with a nematic LC sandwiched between two photochromic command surfaces of 6Az10-PVA. In this configuration, the light propagation properties of the optical waveguide change during exposure to light of appropriate wavelength as a result of the change in alignment of the LC molecules. We could show that these switching processes are reversible and highly reproducible. In this short communication, we concentrate on the use of such a layered structure in optical data and image storage devices, based upon the technique of optical waveguide microscopy[9,11] [see Fig. 1(b)].

For the preparation of a LC cell, as shown in Fig. 1(b), we deposited 35 nm silver onto a glass slide and, in order to prevent quenching processes, covered it by a thin SiO_2 film. The command surfaces consisting of 6Az10-PVA[2] were prepared according to the LBK technique at a lateral pressure of π=13 mN/m. After deposition, the glass slides were attached face to face with a thin foil (polyethylene teraphthalate, Goodfellow, d=3 μm) as a spacer between the command surfaces. The prepared cell then was filled with the nematic LC (DON-103, RODIC).

As light source for sample illumination, we used a high pressure mercury lamp (Oriel, 200 W) with an appropriate set of filters: UG11 (Schott) and WG 360 for UV exposure (*trans*→*cis*) and an interference filter for exposure at 450 nm (*cis*→*trans*). The lamp power could be adjusted to values between 0.5 mW/cm^2 and 10 mW/cm^2.

For optical waveguide mode excitation, we used a He-Ne laser with reduced laser power (down to a few nW) to prevent heating of the sample. For optical waveguide microscopy, the laser beam was expanded to a diameter of 0.5 cm. In order to match the wavevectors of the incident laser beam to the wavevectors of the waveguide modes according to

$$k_{\text{mode}} = k_x = k_{\text{laser}} n_{\text{prism}} \sin \phi \qquad (1)$$

we applied a 90° glass prism (BK 7, Schott), attached on top of the LC cell. The reflected laser beam was recorded by a photo diode, or in the case of the optical waveguide microscopy Fourier transformed by a lens (f=70 mm), forming an image on the chip of a CCD camera (Hamamatsu C 3057).

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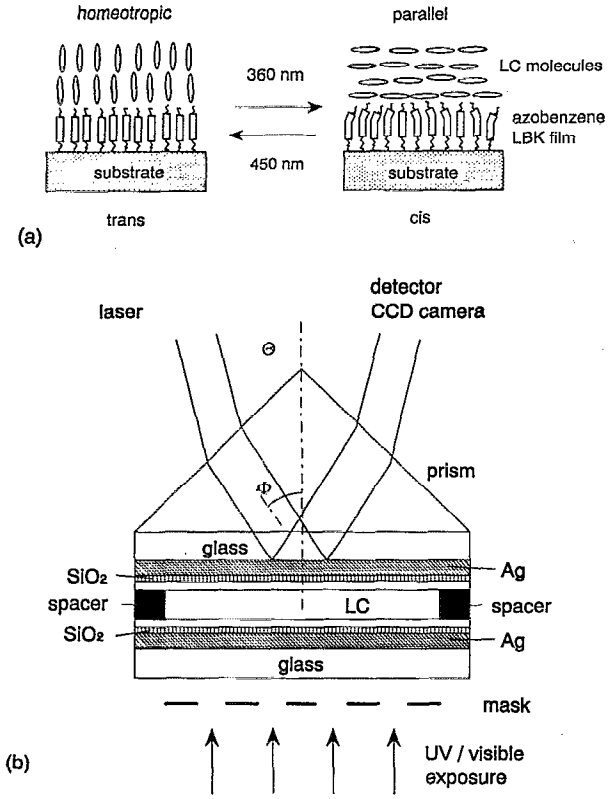

FIG. 1. (a) Illustration of the nematic LC alignment changes induced by a photochromic command surface of a polymer with azobenzene side chains. (b) Set up for optical waveguide spectroscopy and microscopy on command surface controlled liquid cells.

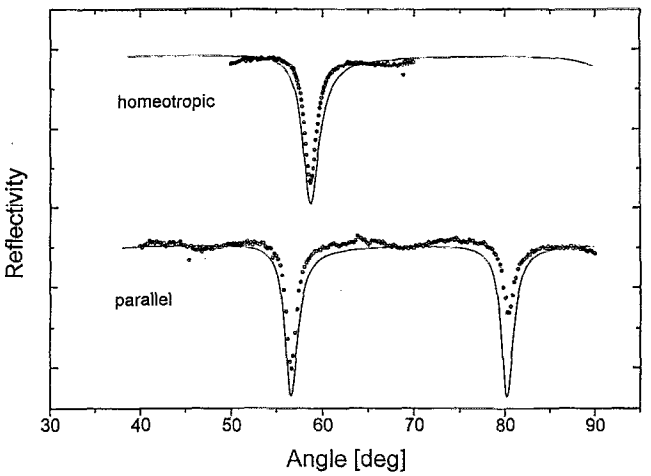

FIG. 2. Reflectivity for TM-polarized waveguide modes of a LC cell, recorded as a function of the angle before and after exposure with UV light. The reflectivity for parallel alignment was recorded under permanent light exposure.

Since we found that TE polarized waveguide modes remained almost unaffected from UV exposure, all experiments were performed with p-polarized light.

Figure 2 shows the reflected intensities as a function of the incident angle for the laser light. Comparing the measured reflectivities to Fresnel calculations provide the following refractive indices: In the homeotropic phase, n_z, (n_z=1.567) the out-of-plane refractive index corresponds to n_e, the extra ordinary refractive index of the LC, whereas n_x, the in-plane corresponds to n_0, the ordinary refractive index (n_e=1.567, n_0=1.479). During UV exposure the refractive indices n_x and n_z exchange, indicating a change in the LC alignment from homeotropic to parallel which follows the ratio of *trans* to *cis* chromophores in the photochromic command surface. The homeotropic↔parallel transition of the LC is reversible and very reproducible with switching times of about 70 s for homeotropic→parallel and 30 s for the parallel→homeotropic transition. For more details please refer to Ref. 8.

Since the angles for resonant excitation of optical waveguide modes are different when the LC is in the homeotropic or in the parallel phase, the reflected intensities at the excitation angles are different, too. Therefore, optical waveguide microscopy permits read out of a homeotropic-parallel pattern, written into the layered structure. In order to demonstrate this, we wrote a test structure into the waveguide structure: we first exposed the whole sample to blue light (λ=450 nm) in order to have the LC in the homeotropic phase over

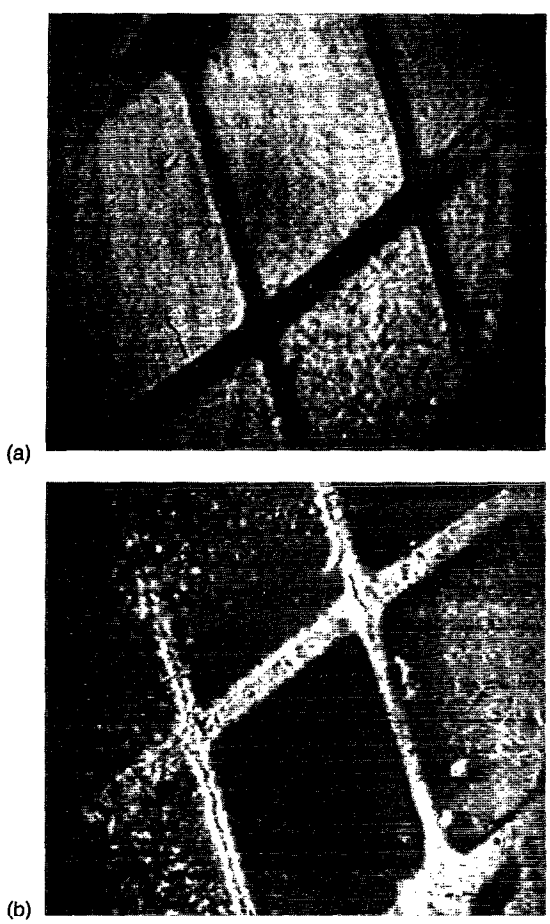

FIG. 3. Waveguide microscopy image of the LC thin film. (a) Image taken at Θ=58.6°. In the dark areas (width: 50 μm) the LC is in the homeotropic phase, whereas in the bright areas the LC is switched to the parallel phase. (b) is the inverted image, taken at Θ=56.6°.

the whole sample. We then exposed the sample to UV light through a mask (λ 360 nm, 10 mW/cm^2), providing parallel areas surrounding by homeotropic areas, where the UV light was blocked by the mask.

When setting the incident angle to that resonant for optical waveguide excitation in the homeotropic areas (Θ=58.6 for m=3), optical waveguide modes are excited in the unexposed areas, and therefore these areas appear dark. Since the exposed areas reflect the incident laser light they appear bright [Fig. 3(a)]. Contrast inversion can be achieved by rotating the prism to the resonance angle for waveguide mode excitation in the parallel areas (Θ=56.6 for m=3). Now the parallel areas appear dark, whereas the homeotropic ones reflect the incident laser light [Fig. 3(b)]. The images written into the film proved to be quite stable with decay times of several hours due to the thermal back-reaction of the *cis* state, when keeping the sample in the dark. The images can be erased by exposing the sample to blue light.

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