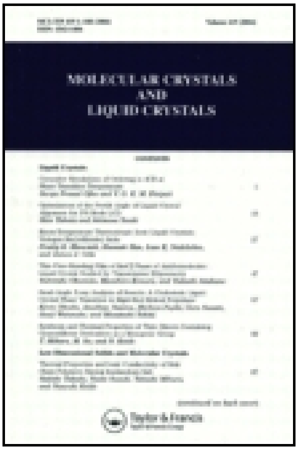


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

# Realization of an Optical Filter Using POLICRYPS Holographic Gratings on Glass Waveguides

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Version of record first published: 22 Sep 2010

*Mol. Cryst. Liq. Cryst.*, Vol. 486, pp. 31/[1073]–37/[1079], 2008

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400801916603



# Realization of an Optical Filter Using POLICRYPS Holographic Gratings on Glass Waveguides

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*In this paper an optical filter is presented using a hybrid fabrication approach. The filter is made of a glass channel single mode optical waveguide covered by a POLICRYPS holographic grating. The fabrication process of the device is described and preliminary optical characterization is presented. The optical response of the filter is reported showing the capability of the device to filter wavelengths typically used in optical communication systems.*

**Keywords:** glass waveguide; holographic gratings; liquid-crystalline composite materials; optical filter

## INTRODUCTION

The development of holographic and diffractive optical devices has become of great interest in fields like integrated optics, optical interconnections and remote sensing [1,2]. In many applications it is needed to control the diffraction efficiency but, up to few years ago, available Liquid Crystals (LC) based devices made use of polarized light, and a cumbersome preparation procedure was required [3]. Later on, attempts have been made to exploit the electro-optical properties of Polymer Dispersed

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Liquid Crystals (PDLC) [4] and their utilization for the realization of electrically switchable diffraction gratings has become one item of great interest [5,6]. Since a sharp and uniform fringe morphology is required, a technique has been also utilized, consisting of an electromagnetic curing of the liquid crystal – monomer mixture (pre-syrup), thus allowing for a direct formation of the grating during the curing process [7]. It has been observed, however, that the resulting electro-optical characteristics of recorded gratings are affected by the scattering of the impinging light, due to the small size of LC droplets dispersed in the polymeric matrix. A real improvement has been recently achieved when the same curing technique has been exploited to realize gratings with a layered structure, referred to as POLICRYPS, in which pure polymer slices are alternated to pure liquid crystal films [8–12]. The high application-oriented interest strongly encouraged to plan the study of further electro-optical applications of POLICRYPS gratings, with a particular attention for the fabrication of devices in which such structures could be directly cured on an optical waveguide.

In this paper, after reviewing the "recipe" for fabrication of POLICRYPS gratings, we illustrate the first preliminary results obtained when a POLICRYPS grating is fabricated on an optical waveguide and used as a Bragg filter.

## EXPERIMENTAL

The basic idea for POLICRYPS fabrication is to avoid the formation of the nematic phase during the curing process. In this way, an almost complete re-distribution of nematic LC (NLC) and monomer molecules inside the sample is induced, by exploiting the high diffusion which NLC molecules can undergo only when they are in the isotropic state.

The standard procedure consists of the following steps:

- The heating of a syrup of photo-initiator – monomer – NLC mixture up to a temperature which is above the Nematic-Isotropic transition point of the NLC component. This step prevents the appearance of a nematic phase during the curing process;
- The illumination of the sample with the interference pattern of a curing UV radiation;
- The slow cooling (down to room temperature) of the sample below the Isotropic-Nematic transition point after the curing UV radiation has been switched off and the polymerization process has come to an end.

The experimental set-up used both for the UV curing and the DE measurements is presented in Figure 1. A single mode beam from an

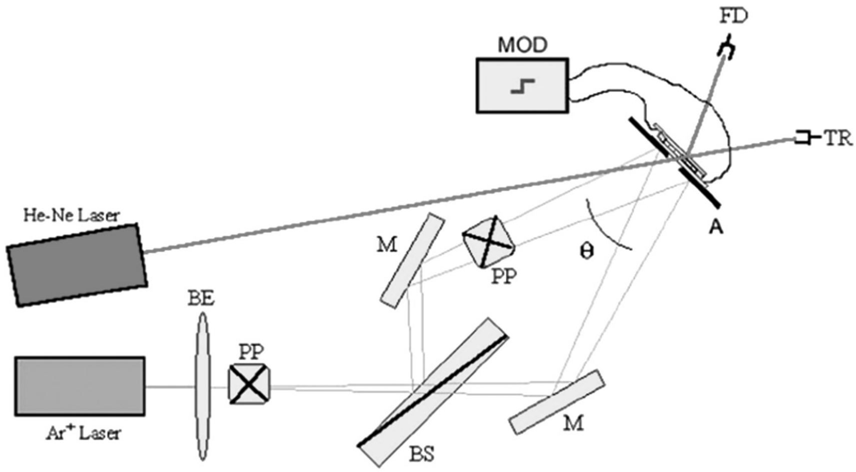



**FIGURE 1** Sketch of the experimental set-up. BE = Beam Expander; BS = Beam Splitter; M = Mirror; PP = Half Wave Plate and Polarizer; MOD = bipolar bipolar square wave supplier; A = aperture; FD = First Diffracted beam photodetector; TR = Transmitted beam photodetector; $\theta$ = Interfering Beams Angle.



Ar-Ion laser operating at the wavelength $\lambda_B = 0.351\,\mu m$ is broadened by the beam expander BE up to a diameter of about 25 mm; further, it is divided into two beams of nearly the same intensity by the beam splitter BS. These two beams intersect at the entrance plane of the sample cell, giving rise to an interference pattern whose spatial period depends on the interference angle and can be varied in the range $\Lambda = 0.3 \sim 15\,\mu m$. An aperture A (3 mm in diameter) placed before the sample entrance provides a uniform intensity of the curing beam all over the exposed part of the cell. The temperature of the sample is monitored by a thermo-controller. Figure 2a shows the morphology of a POLICRYPS grating as seen under a polarizing microscope and Figure 2b refers to another POLICRYPS grating observed by using a Scanning Electron Microscope (SEM).

Such gratings were fabricated by using one glass substrate containing a channel waveguide so that the structure sketched in Figure 3 was obtained. The channel waveguide is single mode, obtained by using $K^+$–$Na^+$/$Ag^+$–$Na^+$ double ion-exchange in BK7 glass, with less than 1 dB/cm propagation loss. The filter structure can include coplanar electrodes, which allow in-plane reorientation of the NLC molecules between the polymer slices by applying an electric field; this reorientation makes TE guided light to "see" a refractive index modulation of the overlaying composite cladding. A suitable control voltage

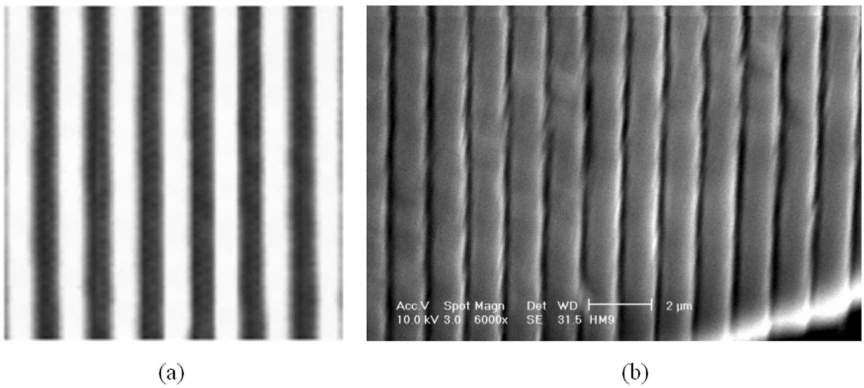



**FIGURE 2** Typical morphology of a POLICRYPS grating. (a) $\Lambda = 3.6\,\mu m$, $C_N = 26.0\%$, image taken by Polarization Optical Microscope, fringes aligned $45^\circ$ with respect to light polarization; the widths of NLC films and polymer slices seem to be comparable due to diffraction and to the poor resolution of the optical microscope. (b) $\Lambda = 1.3\,\mu m$, $C_N = 29.0\%$, image taken by Scanning Electron Microscope (SEM).

(applied in order to obtain the requested tilt of the NLC molecules) induces therefore a corresponding profile of the refractive index of the grating, thus determining the Bragg wavelength of the optical guided wave to be filtered.

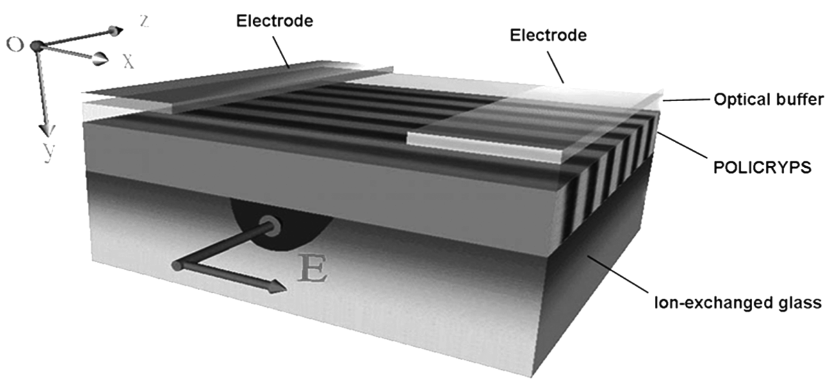
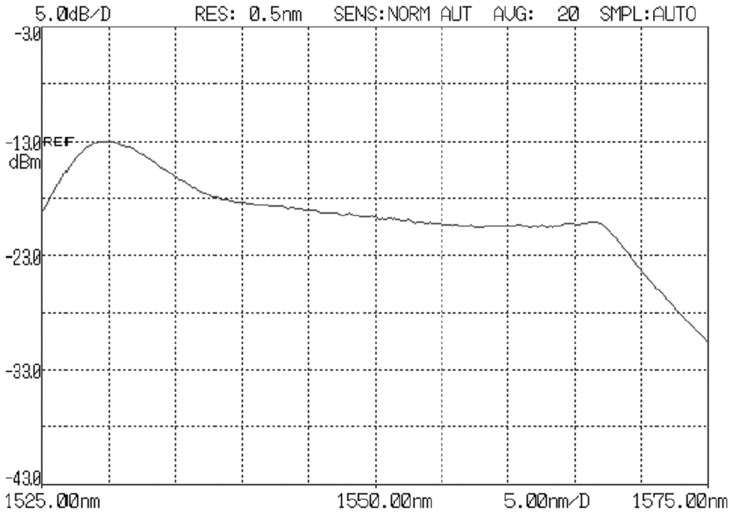
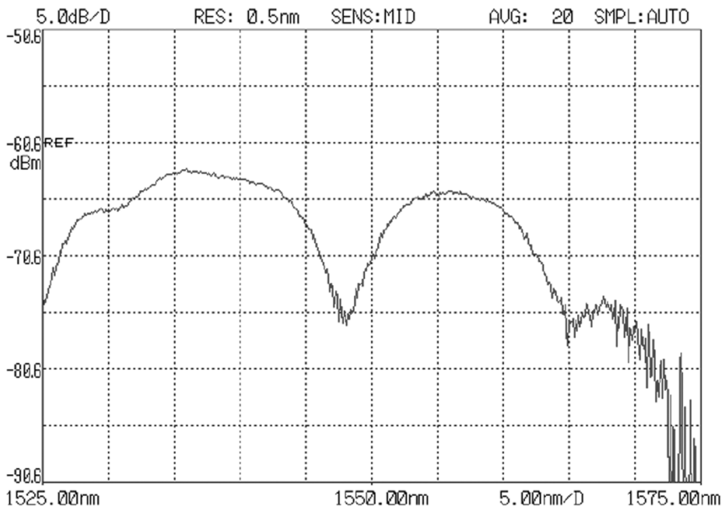



**FIGURE 3** Sketch of an integrated optical filter formed by a POLICRYPS grating on top of a glass optical waveguide on BK7 glass. The orientation of the input optical electric field is also reported. Coplanar electrodes serve to control LC orientation in the grating.




(a)




(b)

**FIGURE 4** Input (a) and output (b) spectra of the optical filter using a POLICRYPS grating with period of 2.5 μm.

A sample was fabricated by using a POLICRYPS grating made of E7 liquid crystal in combination with the UV curable prepolymer NOA61 by Norland on top of a 6 μm wide waveguide. The grating period of about 2.5 μm has been designed to obtain the working Bragg wavelength at the center of the used broadband source, at about 1.55 μm, in absence of an external control voltage, due the mismatch between the refractive indices of the polymer and the NLC.

A preliminary measurement of the optical filter characteristics was performed by launching the broadband source output light consisting of a spontaneous emission of an erbium-doped fiber amplifier whose spectrum, reported in Figure 4a, ranges from 1.530 μm to 1.565 μm. At these optical wavelengths the waveguide is singlemode. Figure 4b shows the spectrum collected by an optical spectrum analyser at the output of the filter. As expected, the notch in the spectrum at the wavelength 1.547 μm is due to the filtered retro-reflected wavelength. An applied electric field would tune the refractive index modulation of the grating inducing a change of the filter properties [13].



## CONCLUSIONS

By curing at high temperature a homogeneous mixture of monomer and NLC with a UV interference pattern of suitable intensity, we are able to fabricate a structure, called POLICRYPS, in which homogeneously aligned NLC films are separated by uniform polymer slices. Due to its sharp and uniform morphology, this structure can become a Bragg filter if used as the overlayer of a single mode optical channel waveguide, obtained by using $K^+$–$Na^+$/$Ag^+$–$Na^+$ double ion-exchange in BK7 glass. A preliminary prototype was fabricated by using a POLICRYPS grating made of NLC E7 and the UV curable polymer NOA65 by Norland with a period of about 2.5 μm. The device operates by filtering the optical wavelength of 1.547 μm. This optical filter is the demonstration of a simple and inexpensive technology to make integrated optical functional components on glass and can result of high interest in wavelength division, multiplexing, optical communication systems and in optical sensor systems.

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