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

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Version of record first published: 22 Feb 2010

Mol. Cryst. Liq. Cryst., Vol. 516: pp. 152–158, 2010

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400903408400

Integration and Characterization of LC/Polymer Gratings on Glass and Silicon Platform

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In this paper we present two practical technological approaches to demonstrate that liquid crystals and composite materials can be employed to make low cost integrated optic devices with the specifications of fibre optic systems. In a first approach active properties are conferred to passive glass waveguides, by means of LC-based composite holographic grating cladding: this grating presents a specific morphology called POLICRYPS (POlymer LIquid CRYstal Polymer Slices). It can be electrically addressed, so that a tunable integrated optical filter has been achieved. In this paper we present the electro-optical characterization. In a second approach SiO_2/Si V-grooves are filled with composite materials to produce a high performance integrated optical filter with the same POLICRYPS morphology. A first passive prototype of such optical filter is presented hereafter.

Both prototypes have been characterized in terms of spectral response.

Keywords composite materials; diffraction gratings; integrated optical filter; silicon photonics

Introduction

In the last years a noticeable interest has risen concerning application-oriented studies of diffractive devices based on soft matter. In particular, great attention has been devoted to liquid crystals (LC) and polymer composites [1], since LC have an efficient electro-optic effect.

A considerable progress in the state of art has been recently obtained with the fabrication of diffraction gratings known as POLICRYPS [2]. This grating consists

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of polymer slices alternated with films of nematic liquid crystal whose director orientation is perpendicular to the polymer stripes in the absence of external applied voltage. By applying an external voltage, the LC director orientation can be varied; therefore POLICRYPS represents a solution for efficient electro-optic Bragg gratings. We aim at integrating POLICRYPS-based tunable gratings in waveguided devices indeed LC tunable diffractive devices [3–5] have strong implications on the application side: namely in optical filtering and switching for wavelength division multiplexing and low-power consuming optical communications systems. However, while diffraction gratings based on composite materials have been studied in a free-space configuration [6–9], their use in integrated optics requires additional and specific control of LC alignment conditions, encapsulation, specific electrical driving and optical interconnects solutions.

In a previous paper [10] we have reported the design, structure, fabrication steps and principle of working of an integrated optic filter made of glass waveguides and POLICRYPS holographic gratings. In this paper we focus on the experimental characterization [11] of two optical filter solutions based on POLICRYPS grating on different photonic platforms: glass and silicon.

A Guided Wave Tunable Filter using POLICRYPS Grating on Glass

Figure 1 shows a schematic of an integrated optical filter with POLICRYPS morphology: an optical channel waveguide is fabricated by double ion-exchange in borosilicate BK7 glass [12]. On top of this substrate, a composite POLICRYPS grating is used as overlayer. This holographic Bragg grating presents a periodic modulation of the refractive index and acts as a perturbation element of the waveguided light, thus producing optical phase modulation.

Glasses are excellent optical materials, already used in LC cell manufacturing. Glass waveguide technology is simple, reliable and mature, able to yield low loss high optical quality and low cost waveguides. Therefore the implementation of glass waveguides coupled with LC/polymer gratings will yield typical low-cost, application-specific devices.

This device demonstrates the development of a technology where the electro-optical control of LC affects only the conditions of a waveguide cladding. The main advantage of this approach is to confer active properties to passive glass waveguides, by LC-based grating cladding.

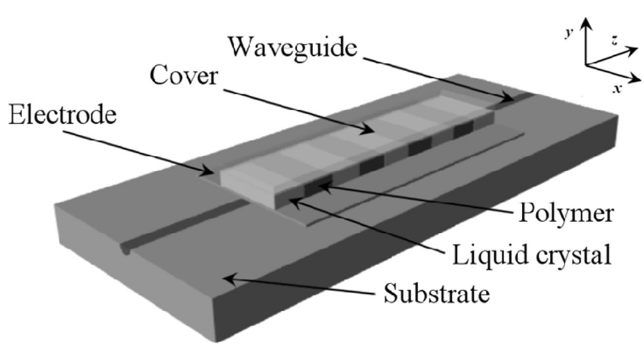

Figure 1. Schematic of the integrated optical filter with POLICRYPS morphology.

Such a structure forms an integrated optical filter for signals travelling in the optical glass waveguide. The device structure also includes coplanar electrodes in order to reorient the LC molecules and subsequently to tune the filter.

Characterization of POLICRYPS Filter on Glass Platform

Figure 2 shows the optical set-up used to investigate the optical propagation through the filter and to measure its transmission and reflection spectral responses.

The broadband light source used for coupling light into the POLICRYPS filter (device) is an Erbium-Doped-Fiber-Amplifier (model EBS-4015/EFA, from MPB technologies Inc.). It is based on amplified spontaneous emission (ASE) from diode-pumped Erbium-doped fibre and utilizes a cleverly-conceived spectral-shaping scheme to produce more than 15 dBm of unpolarized output centered at 1548 nm and with a near flat-top spectrum; maximum ripple does not exceed 2.0 dB over most of the spectrum, namely 39-nm, while 3-dB bandwidth is larger than 40 nm. The transmission response of the filter can therefore be measured in the 1530–1565 nm band.

The broadband light source is connected to a polarization controller. At the device output, an optical spectrum analyzer is used to visualize the transmission response of the filter. The optical filter is butt-coupled both at the input and at the output. Before coupling the cleaved fibre with the optical filter, the state of light polarization injected into the sample is calibrated by means of a linear polarizer. In this paper, the sample presents a grating pitch of about 2.5 μm, a thickness of 4.5 μm and a length of 11 mm.

Figure 3 shows a typical transmission response of this novel optical filter: at the designed Bragg wavelength of 1552 nm, the signal is suppressed by 20 dB.

An optical circulator is added to the previous set-up in order to detect the reflection response of the filter. By applying a square wave voltage of 1 kHz to the filter electrodes, continuous tuning of the optical response is observed as voltage is varied. Figure 4 shows the reflection optical response of the filter tuned by 4 nm when a square wave of about 40 V of amplitude is applied. One of the appealing features of the fabricated optical device is the low power consumption, which is in the sub-mW range. As a perspective of this work, the development of chirped and apodized grating structure will lead to a filter spectral response optimization. By means of a proper electrode configuration, it will be possible to achieve a polarization insensitive device. At last, different POLICRYPS materials and working grating orders will be investigated in order to reduce the optical losses and to improve the tuning capability of the filter.

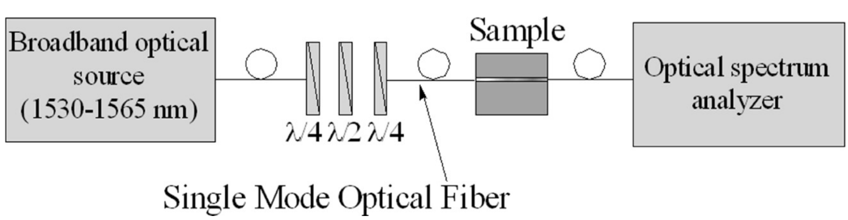

Figure 2. Set-up for the transmission response of the POLICRYPS filter.

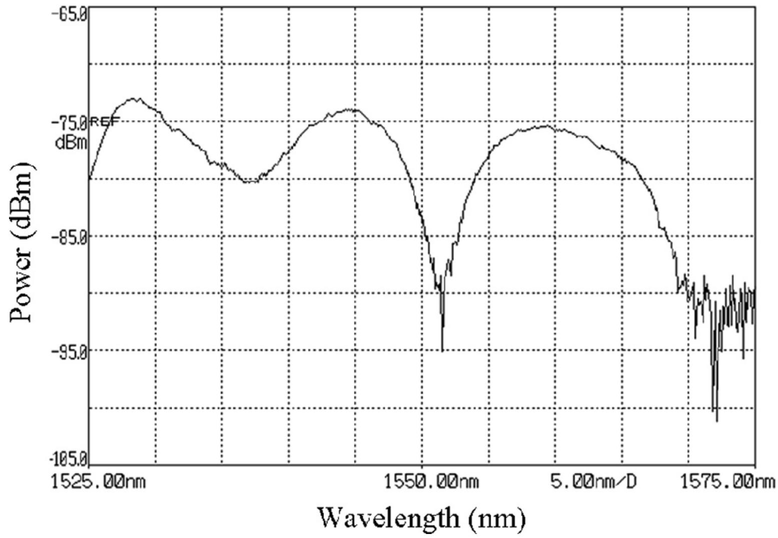

Figure 3. Filter optical transmittance measured by means of an optical spectrum analyzer.

Optical Channel Periodic Waveguide on Silicon

The second configuration presented is a SiO_2/Si V-groove filled with a mixture of UV curable polymer (NOA-61 by Norland) and nematic liquid crystal (E7 by Merck), in order to holographically write a POLICRYPS grating right inside the core of the groove. Such a technique provides an alternative approach to the POLICRYPS filter on glass: indeed light here propagates directly inside the holographically-written periodic waveguide.

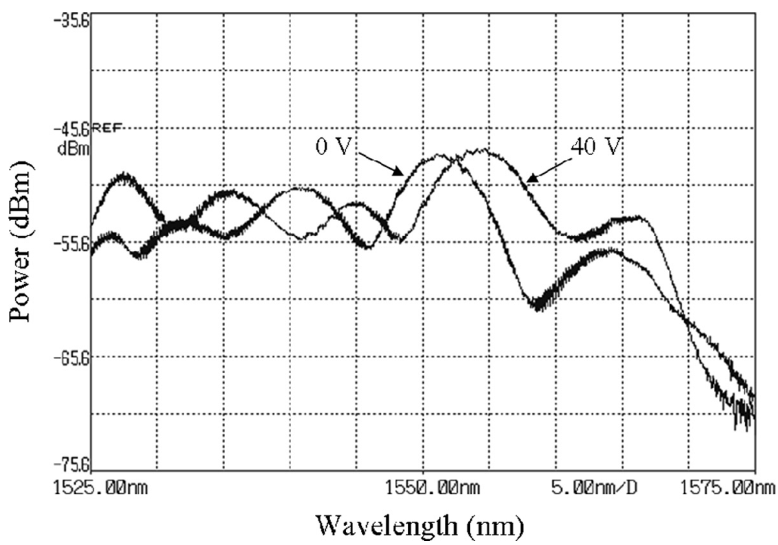

Figure 4. Tuning of the filter reflection response.

As a first step in the assessment of grooved structures, we have designed and fabricated a configuration of LC-only channel waveguide in silica-coated silicon grooves. Preliminary results of passive [13–16] and active [17] structures have been reported: they concern the simulation, fabrication and optical characterization of LC channel waveguide in SiO_2/Si V-grooves.

Integrated optics based on LC or composite as waveguide core material requires to shape very accurately the LC optical channel and to have compatible optical claddings and interfaces. Silicon can actually provide this more ambitious platform: it can bring together the LC encapsulation, via microfluidic techniques, the optical integration and the electrical driving.

The micromachining technology, widely used for microsystems, is used for the fabrication of this novel device.

The Figure 5 shows a schematic of this novel periodic waveguide whose core is constituted by a POLICRYPS grating. In order to emphasize the grating structure in the groove, the glass cover is not shown in the figure, but it is present in the realized device. In the sample characterized in this paper, the glass cover does not present neither a layer of mechanical rubbed Nylon 6 nor a patterned electrode.

An adequate packaging has been developed to permit the fibre coupling. Indeed before filling the groove with the POLICRYPS mixture, the UV-curable adhesive NOA 61 is used to achieve input and output solid interfaces for fibre butt-coupling [18]. The filling procedure is quite simple and is based on capillary forces acting on the mixture inside the cell. A small drop of the mixture is placed at the side of the glass until the cell is completely filled. After filling, the cell is exposed to an interferometric pattern by UV laser. The grating pitch is controlled by the angle formed by the two incident UV beams; for this first prototype it is about 1.52 μm. The length of the grating structure is about 1 cm.

This first prototype has been characterized in terms of transmission spectral response. The optical set-up used to investigate the optical propagation through the filter is the same as the one described in the previous paragraph. Figure 6 shows a typical transmission response of this novel optical filter on silicon demonstrating a very deep notch profile.

With respect to the prior art, this work reports the first demonstration of light confinement and filtering in such novel channel structures. We are moving towards

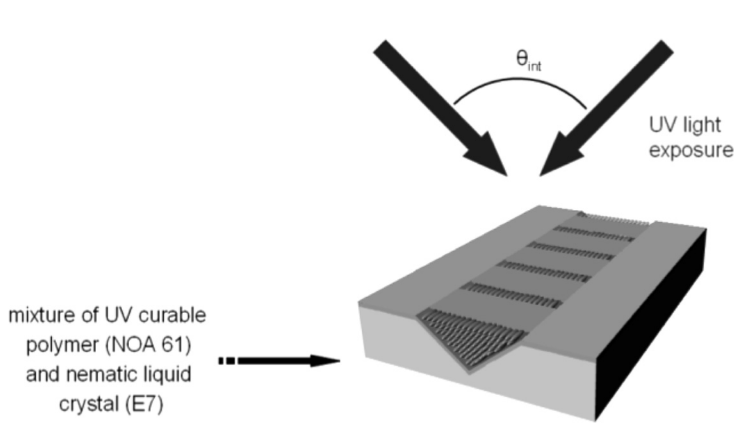

Figure 5. Sketch of the grating writing inside the SiO_2/Si V-groove.

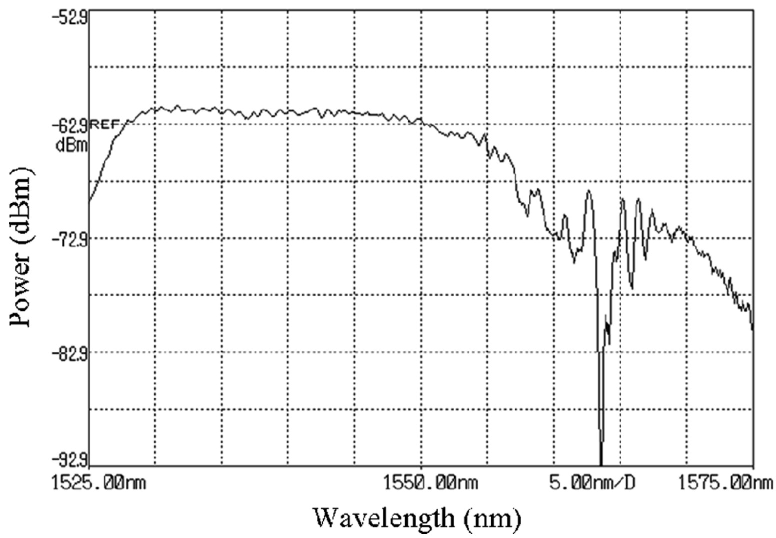

Figure 6. Filter optical transmittance measured by means of an optical spectrum analyzer.

the fabrication of a new generation of low-power active linear and non-linear integrated optical devices on silicon compatible with CMOS process.

Conclusions

In this paper we have reported the preliminary experimental results of two novel filtering devices based on POLICRYPS holographic gratings. We have demonstrated a hybrid Bragg integrated optical filter on glass substrate. This device demonstrates a simple and inexpensive technology to make high performance integrated optic functional components on glass. The experimental characterization of this integrated optical filter shows low power consumption, the suppression of optical signals by 20 dB and a tuning range of about 4 nm.

The second configuration of the optical filter reported in this paper uses a silicon platflorm as substrate and a LC-polymer mixture as propagation medium. The objective is to benefit from the CMOS technology and to be compatible with already developed silicon photonic devices. The integration of LC/composite diffractive devices on silicon substrate will allow optical functions to be efficiently coupled to electronic functions.

The potential application fields of this kind of optical filters are optical communication systems and fibre optic sensor systems.

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