Controlling resonant surface modes by arbitrary light induced optical anisotropies

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Abstract. In this work the sensitivity of Bloch Surface Waves to laser-induced anisotropy of azo-polymeric thin layers is experimentally shown. The nanoscale reshaping of the films via thermal–Scanning Probe Lithography allows to couple light to circular photonic nanocavities, tailoring on-demand resonant BSW confined within the nanocavity.

1. Introduction

Azobenzene-containing polymers are known to exhibit interesting and peculiar properties when irradiated. Thanks to the azo bond present in the molecular structure, azobenzenes can switch between a *trans*- and a *cis*- form, involving a variation in both the steric hindrance and the polarizability of the molecule [1]. Upon a proper choice of the illumination wavelength, the photoisomerization process can be made cyclic, thus leading to macroscopic effects on azopolymeric films such as surface relief grating formation [2-3] and birefringence [4-5].

In this work, we show how such a light-controlled birefringence can be successfully exploited to tune the optical response of a resonant nano-photonic cavity coupled to Bloch Surface Waves (BSW). BSWs are surface defect modes sustained by one-dimensional photonic crystals (or planar multilayers) that are particularly sensitive to variations of the surface optical properties (e.g., refractive index or absorption). Here, we introduce an azo-doped polymer film deposited on top of a dielectric multilayer and use it as an arbitrarily-controlled anisotropic medium to tune some of the BSW properties. The azo-polymeric film birefringence is produced by controlling the polarization state of an external illumination laser beam. Two examples are addressed here, namely the spectral shift of a BSW propagating on a flat multilayer and a resonant BSW confined within a circular photonic nanocavity.

2. Results and discussion

2.1 Tailoring Bloch Surface Waves in flat Azo-doped layers

The dielectric one-dimensional photonic crystal is constituted by alternating layers of SiO_2 and Ta_2O_5 as described elsewhere [6]. Dispersed red 1-methacrylate (DR1M) is mixed with poly-phthalaldehyde (PPHA) (1:3 ratio) and then spun on the multilayer. The thickness of the polymeric layer is about 60 nm. We avoid the use of pure DR1M in order to improve the surface adhesion and the mechanical stability of the azopolymeric blend. In particular, we aim at avoiding strong morphological/topographical deformations that would occur with a pure DR1M structure upon irradiation with the excitation laser. More interestingly, the azopolymer-loaded PPHA layer can be patterned by means of a probe-assisted lithographic technique as will be described in the next section.

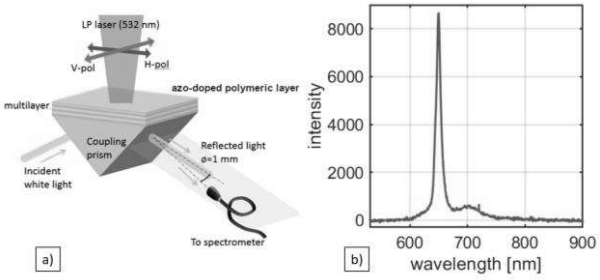

Fig. 1. a) Prism-coupling setup used for the detection of the BSW dispersion shift caused by the birefringence of the azopolymeric layer on top of the one-dimensional photonic crystal. b) Spectrum detected with a fibered spectrometer where the BSW peak is clearly evidenced.

A prism-coupling setup is used to interrogate the planar multilayer. Illumination is provided by a slightly focused white light beam. Differently from the conventional Kretschmann configuration, scattered light leaking in the substrate is detected instead of the reflected light. The zenithal collection angle is kept constant and the BSW signature is represented by a spectral peak

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Fig.1b). A 532 nm collimated laser beam is used to control the azopolymeric layer birefringence.

An increase/decrease of the BSW effective refractive index is detected as a red/blue-shift of the BSW spectral peak, because of the dielectric loading/unloading effect. In Fig. 2, the red and blue-shift of the BSW coupling wavelength are plotted over time, as the control laser polarization is varied from vertical, to circular and then horizontal (with respect to the BSW electric field orientation, which is oriented as V-pol in Fig. 1). The observations are consistent with the decrease of refractive index produced in DR1M films along the direction of polarization of the illuminating beam.

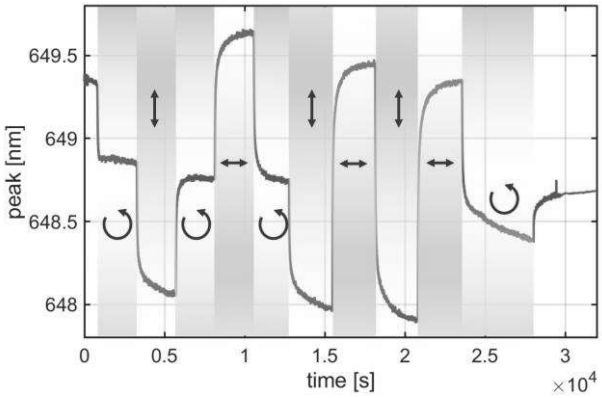

Fig. 2. Time evolution of the BSW peak position detected at a fixed leakage angle, upon variation of the laser polarization state. The overall downward drift of the BSW is likely due to heating effects.

2.2 Tailoring Bloch Surface Waves in photonic nanocavities

Resonant nanophotonic cavities have been engineered at the surface. The use of the novel thermal-Scanning Probe Lithography (t-SPL [7]) has enabled high-resolution nanopatterning of the Azo-doped thin film (PPHA-DR1M) as nanograting cavities. The cavity is constituted by a circular Distributed Bragg reflector (DBR), and it is designed to resonate at a frequency outside of the absorption spectrum of the azopolymer. An additional annular grating encircles the cavity for coupling free-space radiation to the BSW [8], and is shown in Fig.3a-b.

Spectroscopic measurements are based on a modified inverted microscope, with oil-immersion collection optics. The illumination is provided through the condenser. The collected light is Fourier-filtered with a beam blocker in order to let only light propagating at large angles to reach the image plane. In Fig. 3b the optical image of a cavity and outcoupler structure is shown, with the central spot representing the scattered light associated to the cavity resonant mode. The entrance slit of the spectrometer is aligned with the cavity centre, resulting in the spectrum shown in Fig. 3c, where the peaks associated to the cavity modes are highlighted.

A 532 nm laser beam is focused through the condenser over the cavity in order to excite the azopolymer. In Fig.3d the red and blue shift of one of the cavity resonant modes is shown. The shift is similar to the one described in Fig. 2, suggesting an active way to modulate the spectral response of the cavity in the nanometre range.

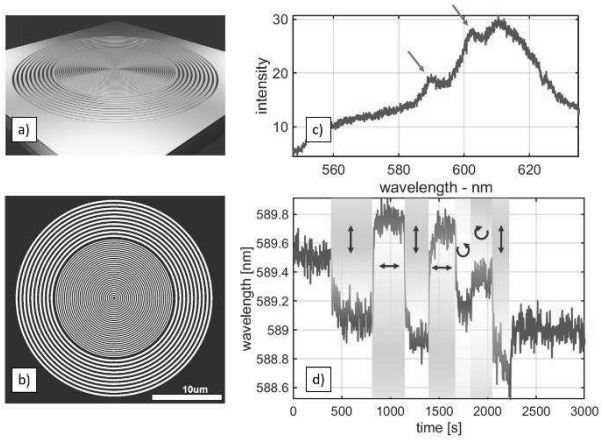

Fig. 3. DBR circular cavity fabricated by means of a probe-assisted indentation technique. a) 3D CAD image of the cavity. b) Image of the cavity obtained by Fourier-filtering the illumination beam. c) Spectrum measured at the centre of the cavity where two resonances are highlighted. d) Time evolution of the left most resonance peak upon variation of the laser polarization state.

3. Concluding remarks

In this work we successfully exploited the photo-induced birefringence of an azopolymer blend in order to tune Bloch Surface Waves. We have shown the capability to optically control the resonant response of photonic nanocavities engineered via thermal nanolithography. In perspective, the proposed approach can be used in luminescent cavities to finely tune resonant emission peaks.

References

1. C. Barrett, A. Natansohn, & P. Rochon, Macromolecules **27**, 4781–4786 (1994).
2. K. Sumaru, T. Yamanaka, T. Fukuda, & H. Matsuda, Appl. Phys. Lett. **75**, 1878–1880 (1999).
3. J. Neumann, K. S. Wieking, & D. Kip, Appl. Opt., AO **38**, 5418–5421 (1999).
4. D. S. Dos Santos et al., Polymer **43**, 4385–4390 (2002).
5. A. Kozanecka-Szmigiel et al., Dyes and Pigments **114**, 151–157 (2015).
6. A. Angelini et al., Sci Rep **4**, 5428 (2015).
7. E. Albisetti et al., E. Riedo, *Nat. Rev. Methods Primer* **2022**, *2*, 32.
8. U. Stella, L. Boarino, N. De Leo, P. Munzert, & E. Descrovi, ACS Photonics **6**, 2073–2082 (2019).