Bloch-surface-waves based photonic devices studied by leakage radiation microscopy

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Abstract. The Bloch-surface-wave photonic devices were for the first time manufactured by the two-photon polymerization lithography. Bloch-surface-wave modes excitation and propagation were visualized by the leakage radiation microscopy. The mode structure of the guided light was characterized by the back-focal-plane imaging. It was demonstrated that the photonic devices are able to guide light in multimode regime.

INTRODUCTION

Bloch-surface-wave (BSWs) in 1D photonic crystals (PC) is an electromagnetic wave, propagating along and exponentially decaying away from the PC surface [1]. It is analogous of well-known surface plasmon polaritons (SPP). BSWs are advantageous over the SPPs due to lower losses and longer propagation length (order of 1 mm for BSW versus 10-100 μm for SPP) associated with the absence of the Ohmic losses [2]. It is also possible to control the BSWs dispersion law changing the parameters of photonic crystals. Their narrow resonances only several nanometers wide make them very attractive in the fields of optical switching and sensing. Because of strong sensitivity of BSW to the geometrical parameters of BSW-supporting photonic structure one should carefully choose the structuring method. Two-photon absorption induced polymerization lithography (2PP) is based on nonlinear absorbtion in a focal volume of tightly focused infrared laser radiation [3]. It guarantees precise control over geometrical shape of manufactured structures and surface roughness of less than 15 nm. This method is an excellent candidate to be utilized for BSW-supporting photonic devices. In our work we demonstrate, for the first time, a BSW photonic device manufactured by 2PP.

EXPERIMENTUL TECHIQUE AND DATA

In our experiments we used a home-built 2PP setup with a femtosecond laser source (80 MHz, 800 nm, 60 fs). The detailed description of the setup may be found in our previous work [4]. The simplest photonic device for BSW is a waveguide a thin dielectric stripe on the surface of PC, guiding a highly confined BSW waveguide mode. Also the more complicated photonic devices such as splitters and interferometers have been fabricated and its optical properties have been studied by leakage radiation microscopy. To control the square form of waveguide crossection we worked in overexposure regime in thin polymer films with 200 nm thickness (SU-8 2015 Microchem).

Due to the in-plane wave vector matching condition of incident radiation and BSW it cannot be directly excited from the air. Either prism schemes or diffraction gratings can be used to couple incident radiation to the BSW. Bulky prism scheme is incompatible with the densely packed photonic integrated circuitry for compact high speed optical data links or miniature sensors. Hence we have chosen diffraction grating method. Thus the photonic device was a waveguide with entrance and exit diffraction gratings. Focusing and defocusing triangles were added to increase the coupling efficiency of BSW and incident radiation (fig. 1). The photonic devices were manufactured on the top layer of the PC composed of 10 pairs of Ta_2O_5/SiO_2 quarter-wavelength-thick layers with the photonic band gap center

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spectral position of 810 nm. To monitor the quality and the geometrical parameters of the structures we used scanning electron microscopy (SEM), atomic force microscopy (AFM) and optical microscopy. The results are presented in figure 1.

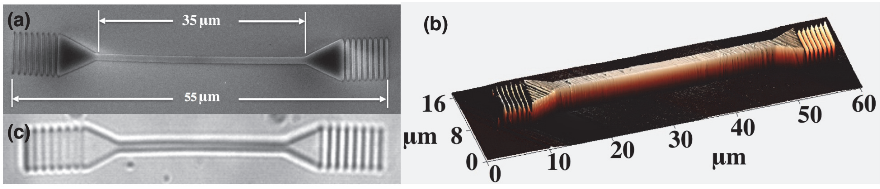

FIGURE 1. (a) SEM image, (b) AFM image, (c) Optical image.

The light propagation in waveguide structure was visualized by the leakage radiation (LR) microscopy (fig. 2). In order to prove that the guided mode that we observed was a BSW we utilized back focal plane imaging (BFP). BFP allows to obtain Fourier space image and to calculate effective refractive indices of propagating modes.

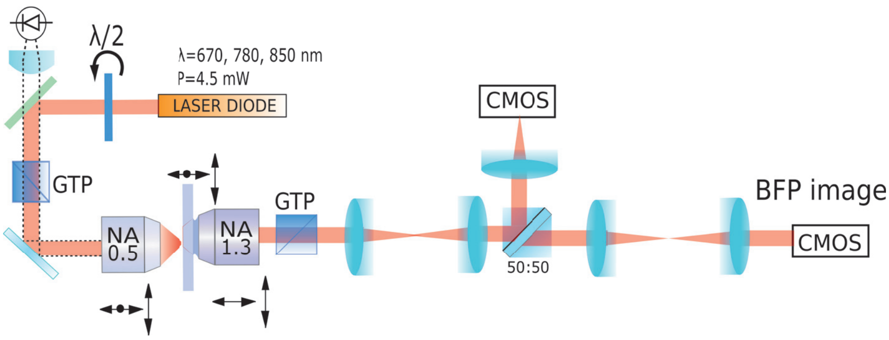

FIGURE 2. Leakage radiation microscopy setup.

Laser diodes (wavelengths of 670, 780 and 850 nm) were used as light sources. We varied the wavelength of the laser source as well as the diffraction grating period to find the best excitation conditions for BSW. The power and polarization of the incident radiation were controlled by a system of Glan-Taylor prism (GTP) and half-wave plate. The polarization of the incident radiation should have been matched to the grating orientation (TE polarization). The laser radiation was focused by the objective (NA=0.5) into the entrance grating. The LR transmitted through the photonic crystal and was collected by the oil-immersion objective (NA=1.3). The polarization of collected light was conrolled by the second Glan-Taylor prism and then it was split into two channels: direct and BFP

The BFP image (fig. 2) shows three bright vertical lines (highlighted by dashed lines), that correspond to three BSW waveguide modes. Our photonic devices support TE_{00}, TE_{01} and TE_{02} modes with the effective refractive indices of 1.12, 1.07 and 1.02, respectively. TE_{00} mode has the largest value of the wave vector, TE_{02} – the smallest one. Experimental results are in a good agreement with FDTD simulations.

FINAL KEY POINTS TO CONSIDER (FIRST LEVEL HEADING)

- The BSW-supporting photonic devices have been fabricated by the method of two-photon polymerization lithography
- The mode structure of transmittance light was visualized by leakage radiation microscopy and back focal imaging microscopy
- Three BSW (TE_{00}, TE_{01} and TE_{02}) modes supports by the fabricated photonic devices.

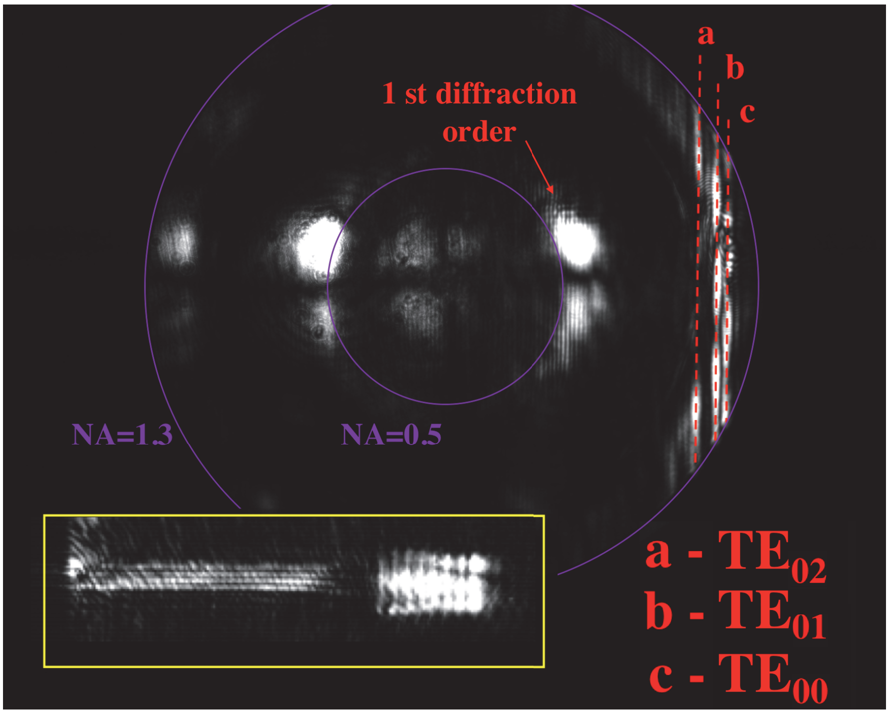

FIGURE 3. BFP image. Red dashed lines correspond to TE_{00}, TE_{01} and TE_{02} BSW modes. Yellow inset: Propagation of light in the waveguide structure.

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