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NEAR-FIELD CHARACTERIZATION OF SOI PHOTONIC CRYSTALS STRUCTURES

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Key words: SNOM, photonic crystals, SOI

Abstract. *Photonic bandgap structures are very promising for the integration of optical functions at the nanoscale level and particularly two-dimensional structures perforated in a slab waveguide. The light can be guided in these structures by creating a linear defect, i.e. by omitting a row of holes. Near-field optical microscopy, used in collection mode, allows us to access in a non-destructive way to the electromagnetic field map in the guiding structure. In this article, we show evidence of the guided light in simple devices on Silicon On Insulator (SOI), working in telecom wavelengths. Bloch waves were observed in a straight W1 waveguide and in a 60°-bended W1 waveguide.*

1 INTRODUCTION

In recent years, photonic crystals (PC) have attracted a lot of interest due to their ability to control the flow of light [1,2]. Such devices, which are composed of a periodic lattice of air holes in a dielectric slab, appear as attractive candidates for the miniaturization of integrated optical circuits. Indeed, the periodic variation of their refractive index leads to the apparition of photonic band gaps (PBG) within which the propagation of light is prohibited. Defects modes can be created in the PBG by introducing a linear defect (one missing row of holes) called W1 in the PC. Thus, the linear defect behaves like a waveguide. Moreover, two-dimensional PC are relatively easy to fabricate and can be conveniently integrated into conventional devices.

But the characterization methods by classical far-field microscopy are not adapted to the study of photonic crystals because of their lack of resolution due to diffraction. Scanning Near-field Optical Microscopy (SNOM) is therefore a unique way of characterization since it allows a local mapping of the electromagnetic field of a component under working conditions, at a sub wavelength resolution.

In this paper, we analyse the guided light within the basic building blocks of PC-based optical circuits on SOI: a straight W1 waveguide and a 60°- bended W1 waveguide.

2 SNOM DEVICE

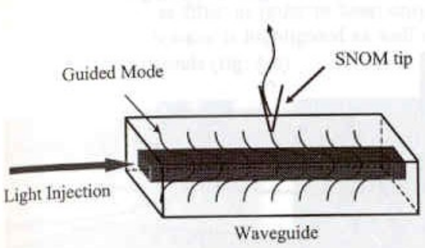

Figure 1 : Experimental setup

Our apparatus is a commercial instrument of Omicron trademark. The setup presents a configuration especially adapted for the study of waveguides. Indeed, the injection in the guides is made with a monomode IR lensed fiber whose displacements are controlled with an accuracy of 10 nm by a piezo-electric platform. The evanescent field on the surface of the waveguide is collected by a SNOM tip which is scanning the sample's surface.

The SNOM tip is a non-metallized tapered optical fiber obtained by chemical attack in hydrofluorhydric acid [3]. The apex radius is approximately 100 nm. The feedback controlling the position of the fiber is of shear-force type and makes it possible to obtain simultaneously the topographic image and the optical image. The field mapping is done using constant distance mode.

3 STRAIGHT WI WAVEGUIDE

The SOI used for our structures is composed of a 0.22 µm layer of monocrystalline Silicon, stuck on a 1 µm layer of silica. Patterns were fabricated by deep-UV lithography (248 nm) followed by an Inductive Coupled Plasma (ICP) etching, with a chemistry based on Cl_2 /$HBr/He/O_2$ [4]. The air holes of radius R = 0.16 µm are laid out according to a hexagonal lattice of period a = 0.5 µm.

The first structure presented here is a waveguide constituted of a linear defect W1 in the ΓK direction (fig. 2-a). The light injection in the guide is made within the telecom wavelength range of 1.2-1.6 µm, with TE polarization (electric field E in the plane of the structures). SNOM images with various wavelengths were recorded between 1.5 and 1.6 µm.

Only the image corresponding to λ = 1.55 µm (fig. 2-b) is presented here. This SNOM image makes it possible to see that a part of the light is reflected back at the level of the junction between the W1 guide and the output guide, leading to the apparition of a standing wave of period 1.36 µm. We can also clearly see that another wave with a smaller period exists. A profile along the W1 axis (fig. 2-c) allows to measure this period which is equal to 0.5 µm. This period matches the lattice period so it can be deduced that those waves are Bloch waves.

The period of the standing wave varies with the wavelength [5]. It decreases when λ increases. For wavelengths between 1.2 and 1.5 µm, as the period of the standing wave was much bigger, a linear IR camera was used for the measurements instead of the SNOM. The evaluation of this period allows us to deduce the propagation constant k of the mode in the guide. The theoretical projected dispersion diagram was calculated by the Plane Wave

Expansion method (PWE), using a 2D-model and an effective index n=2.83 (fig. 2-d). Then, our experimental points were transferred to the theoretical diagram. Our experimental results are in good agreement with simulations.

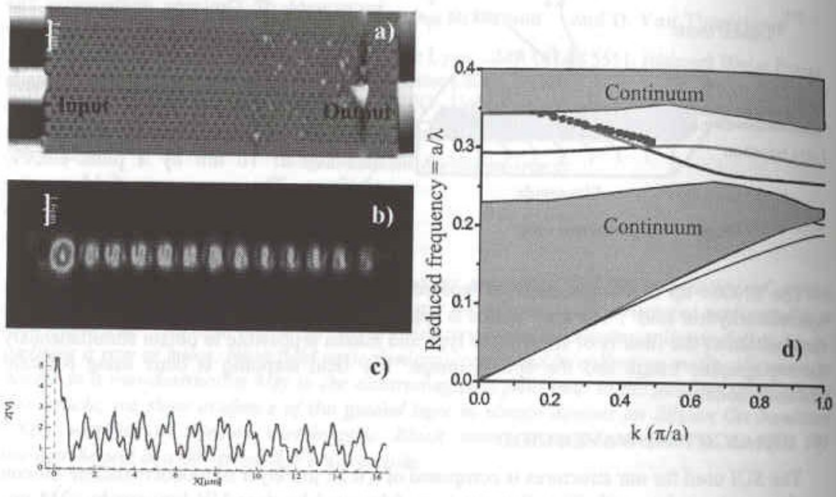

Figure 2: a) Topography b) Optical image at 1.55 µm c) Profile along the W1 axis d) Projected dispersion diagram (experimental points with squares)

4 W1 BENDS

Let us now consider a structure made of a W1 guide having two successive bends at 60° (fig. 3-a). The structure is excited at λ =1.52 µm. Like for the W1 waveguide, one still observes a standing wave pattern (fig. 3-b and 3-c). This was foreseeable since the transmission is relatively weak within the corners and a great part of the signal is reflected back. A more adapted design of the holes located at the level of the bends would make it possible to minimize this phenomenon. One can also notice that there are very important losses at the level of the bends. These losses are not estimable since the detector gets saturated at the first bend.

This time, the Bloch wave cannot be obviously seemed. This is probably because a very important part of the light is reflected back at the bends and at the end of the photonic crystal, so the Bloch wave signal completely disappears behind the standing wave signal. To go further in our analysis, we carried out a Fourier transform (FFT) of the optical image (fig. 3-d). The FFT shows a series of oblique lines, each one corresponding to a given space frequency. Some of the lines correspond to the period of the standing wave (1.65 µm) but others correspond to a period of 0.5 µm. This oscillation at a period of 0.5 µm renders once again the presence of Bloch waves, which are propagating into the W1 guide. Then, we applied a high-pass filter in order to keep only the highest frequencies relating to the finest details. The Bloch wave is highlighted as well as concentric rings corresponding to the losses coming from the bends (fig. 3-e).

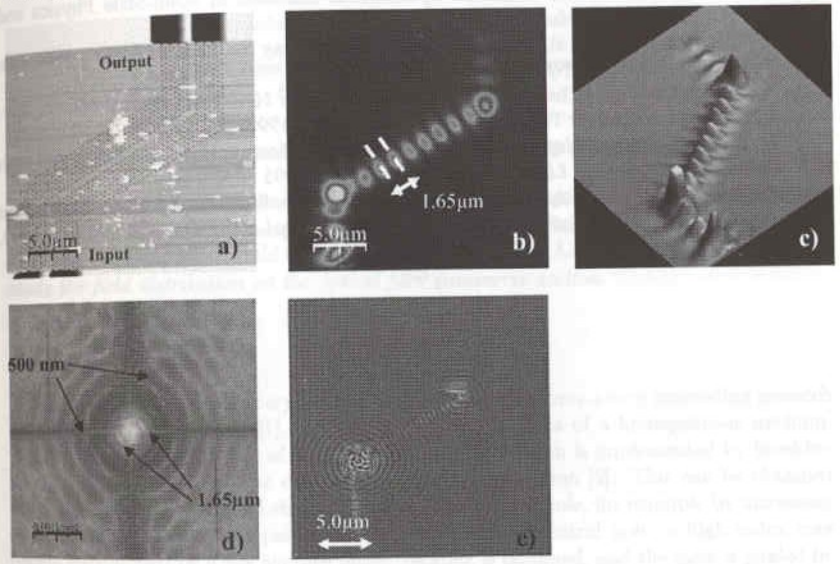

Fig. 3: a) Topography b) Optical image in 2D c) Optical image in 3D d) FFT e) Filtered optical image

6 CONCLUSION

In this article, SNOM measurements in two-dimensional PC were achieved at telecom wavelengths and Bloch waves propagating in the structures were evidenced. We have shown that SNOM is a valuable tool for the study of components for the integrated optics because it allows us to understand the intrinsic working of those devices. Particularly, the achievement of the field map at a resolution less than the wavelength is well adapted to the cartography of photonic crystals structures.

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EFFECTIVE AREA MEASUREMENT OF PHOTONIC CRYSTAL FIBERS THROUGH SCANNING NEAR-FIELD OPTICAL MICROSCOPE

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Key words: near-field optical microscopy, photonic crystal fiber, effective area.

Abstract. *The effective area of the fundamental mode guided by a photonic crystal fiber has been experimentally investigated through a near-field based technique. A spectrally resolving Scanning Near-Field Optical Microscope (SNOM) has been developed in order to study the field distribution on the optical fiber transverse section.*

INTRODUCTION

In the last years photonic crystal fibers (*PCFs*) have become a very interesting research field in optical technology [1]. This kind of fibers consists of a homogeneous medium, usually silica, with a lattice of air-holes. The guiding region is implemented by breaking the lattice periodicity at the center of the fiber cross-section [2]. This can be obtained by changing the geometrical characteristics of the central hole, for example by increasing or reducing its radius. In particular, by removing the central hole, a high index core region surrounded by a low average index cladding is obtained, and the light is guided by modified total internal reflection. The guiding properties in this kind of fibers are strongly influenced by the geometric parameters, that is the air-hole diameter and the hole-to-hole spacing. This aspect has been investigated both theoretically and experimentally resulting in *PCF* design for a huge variety of functionalities, such as dispersion compensation, amplification and non-linearity enhancement [3], [4]. The effective area is an important parameter to characterize optical fibers being used to define, for example, non-linear coefficient γ, Raman gain coefficient γ_R, coupling losses [5], [6], [7]. Its values can be numerically obtained by modeling the fiber cross-section and the field displacement on the cross-section itself, as well as by the experimental analysis of the beam profile of the propagating field.

This paper deals with the application of a recently developed technique for investigating samples on a nanometric scale, called Scanning Near-field Optical Microscopy (*SNOM*),