7th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics – Metamaterials 2013
Bordeaux, France, 16-21 September 2013

Guided Wave Metamaterial Configurations for Application in the Near IR Domain

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Abstract – **We address the potential of a metamaterials in a guided wave configuration for applications in the near IR domain. We consider a hybrid type structure made of 2D metamaterial array over a high index slab waveguide, as for instance silicon our case. The experimental and modeling results show that effective index and loss level in such hybrid waveguides can be carefully controlled by the engineering of metamaterial resonances. The investigated approach may constitute a promising alternative to the bulk multi-layers metamaterial structures.**

I. INTRODUCTION

The sustained interest generated by the advent of metamaterials (MMs) during the past decade is strongly driven by their ability for an efficient tailoring of electromagnetic waves propagation in such artificial composite media effective index leading to a range of intriguing and unusual properties which are not encountered in natural media [1,2]. Among the most fascinating applications we can note the invisibility cloak [3-6], concentrators [7], rotators [8], wormholes [9].

For the time being most of the experimental demonstrations for the transformation optics applications using metallic MMs were performed in the microwave domain [3-5]. Demonstrations in the optical domains are essentially limited to all dielectric MMs [9-12]. The two essential factors preventing the use of metallic MMs in the optical domain are related to the planar technology limitations for the number of MMs layers in the stack [13-15] and the losses due to the absorption of the metal resonator elements.

To circumvent these issues of metallic MMs, we considered a hybrid type photonic structures in which metallic parts are coupled with dielectric (and almost lossless) waveguides (Fig. 1). In this configuration, useful functionalities are obtained by allowing just enough light to interact with the metallic parts of the system. The experimental validation of the technological feasibility and operation of the MMs in a guided wave configuration in the spectral domain around 1.5µm is the aim of the present work.

II. DESIGN AND FABRICATION

Here we discuss the potential of hybrid MMs waveguides for guided optics applications. We consider the case of a composite guiding structure made of a single film of metamaterial over a high index waveguide, such as Silicon in the present case. For our experiments we considered a 2D array of gold cut wires (CWs) with 10 periods along the propagation direction, placed on the top of a 10µm wide and 200nm thick silicon on insulator (SOI) waveguide (Fig. 1).

In order to obtain the resonance frequency around 200THz, which corresponds to 1.5µm wavelength, we fix the CWs dimensions to 200×50×50nm [16,17]. The separation of two adjacent cut wires along the longitudinal axis, which is perpendicular to the light propagation direction, is set to 100nm. The separation distance D between two adjacent elements along the light propagation direction is set for different samples to either 50, 100 or 150nm. The tapered transitions from a 3µm wide input waveguide down to 0.6µm wide single mode waveguide, then to the 10µm wide output waveguide are used to insure fundamental mode propagation. This point is especially critical since at a 10µm width the waveguide is intrinsically multimode.

Fig. 1b shows a scanning electron microscope (SEM) view of the fabricated device. The precision of the waveguide alignment with respect to the MMs array is of the order of one hundred nanometers. Such a precision is far sufficient in our case where the waveguide width is 10µm and the MMs array extent across the waveguide is 9µm.

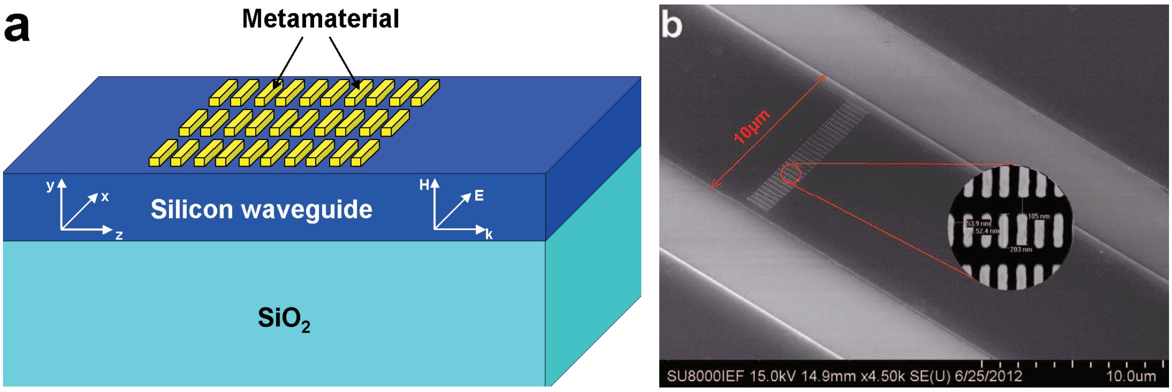

Fig. 1. a) Sketch of the slab waveguide with an array of MMs on the top. Light propagation direction along Z axis. The E field is parallel to the X axis. b) SEM view of a 10µm wide SOI waveguide with MM area (inset)

III. EXPERIMENT AND RESULTS

The experimental characterization is based on a end-fire coupling setup in the spectral range between 1250 and 1640nm with a resolution of 2pm. Figure 2 shows the TE- polarization transmission spectra for a tapered waveguide with a separation distance D between adjacent CWs either 50, 100 or 150nm. The measurements are not corrected for the coupling losses. As seen from Fig. 2, a marked dip in transmission is observed. No such a dip in transmission was observed for TM polarized light, i.e. when the electric filed is perpendicular to the layers interface and the orientation of the cut wires. This result confirm the efficient excitation of the MMs resonance in a guided wave configuration for TE polarization.

One important feature that can be observed from the spectra in Fig. 2 is that the transmission level strongly depends of the separation distance D between adjacent elements. For the same amount of CWs, the transmission level drops by almost 20dB when separation distance D varies from 50 to 150nm. This is related to the increasing contribution of the Bragg reflection interference effects for a larger separation distance. The obtained results can be described by a simple plane waves model for a stratified homogeneous layers with a Lorentz dispersion low properties. The reflection and transmission obtained using HFSS numerical simulations and plane wave modeling (Fig. 3) are in a good agreement with experimental results.

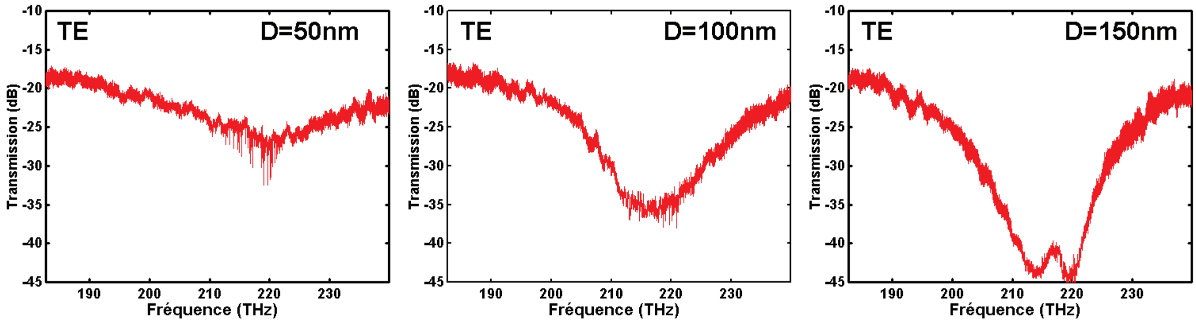

Fig. 2. a) Transmission spectra of a 10µm wide waveguide with an array of MMs on the top.

The composite waveguide effective index determined from the modeling and experimental results show an important variation in the vicinity of the MM resonance. The ability for the local engineering of the effective index based on the interaction of the evanescent tail with the MMs layer and control in such a way the light flow in a guiding slab layer constitutes a real opportunity to design a novel class of photonic devices. It may constitute a promising alternative to the bulk multi-layers metamaterial structures.

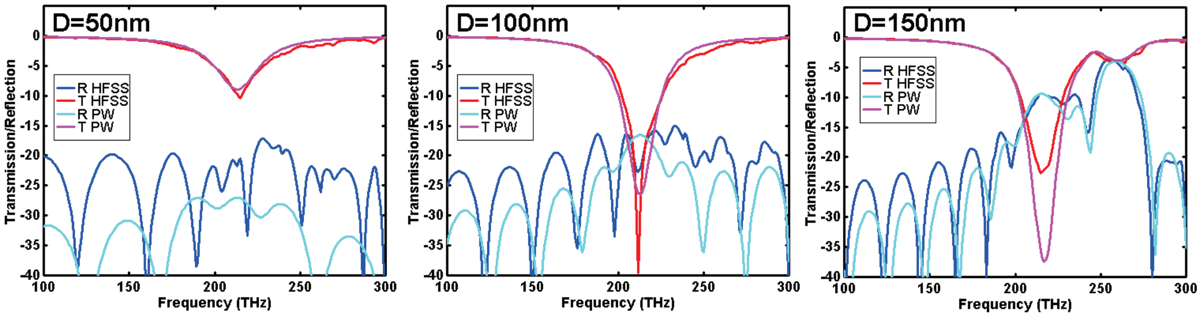

Fig. 3. a) HFSS numerical simulation and plane wave modeling results for hybrid MM/SOI waveguide.

IV. CONCLUSION

We report experimental and modeling results for a hybrid guiding structure made of metamaterial layer over a SOI waveguide. It is demonstrated that the effective index and the loss level in such hybrid waveguides can be carefully controlled with such planar metallo-dielectric MMs.

ACKNOWLEDGEMENT

This work was supported by the French National Research Agency (ANR Metaphotonique, contract number 7452RA09) and the Champagne-Ardenne region.

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