Selective reflection in two-dimensional hybrid photonic structures of Si-ZnO

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***Abstract*— Two-dimensional photonic structures have been patterned using the focused ion beam method on a ZnO thin film deposited on silicon substrate. Reflectance spectra measured shows this structure is suited to reflect near infra-red radiation.**

***Keywords*— Photonic crystals; Transparent conductive coating; Zinc oxide; Wavelength filtering device**

I. INTRODUCTION

Photonic structure (PhS) interest is growing incredibly in these days, many applications are being suited to photonic structures such as band pass filters, electro-optical sensors, switches, power splitters and light extraction on LEDs [1-5] to mention just some of them. These applications are playing a very important role in new advances to develop ultimate technology. In the literature it has been reported reflectance measurements on several PhS, which have drive in antireflective coatings [8] and light filtering applications [10].

In this work a two-dimensional hybrid Phs consisting of a ZnO thin film deposited on a silicon wafer with square lattice is fabricated by the focused ion beam (FIB) method. It has been found a great selectivity on specular reflectance for specific wavelengths when light impinges the PhS on its top surface. In fact, we have observed a shift of reflectance spectra of our PhS to long wavelength in the Near Infra-Red (NIR) range.

II. EXPERIMENTAL DETAILS

A PhS was milled over a ZnO thin film of about 170 nm deposited on a substrate of silicon wafer by the Aerosol Assisted Chemical Vapour Deposition Method (AACVD). Structure sculpted on the substrate is a square lattice with lattice constant a = 1 μm, and holes with diameter about of 500 nm. This sctructure was fabricated using a Focused Ion Beam JEOL JEM 9320-FIB. ZnO thin film deposited on Si wafer and the photonic structure are shown in Fig. 1 and Fig. 2 respectively. Figure 1 shows a micrograph of ZnO thin film obtained by field emission SEM using a JEOL JSM-7401F operated at 2 kV. In this figure the thin film thickness can be seen. The photonic structure sample dimension is 80 × 80 μm^2. As it can be observed from Fig. 2 some material eroded by FIB fabrication method is redeposited on the holes surroundings making a rough surface on sample. As it is well known this redepostion could be prevented using a sacrifical layer to be removed after milling the structure [6] or a carrier gas could help to remove material eroded before it is redeposited while milling [7].

We have measured the reflectance on PhS sample tailored, using a He-Ne laser at 633 nm wavelength and a multichannel fiber couple laser source, which emits 850 nm, 1310 nm and 1550 nm wavelengths to cover from red visible to near infra-red range. Reflectance measurements were taken at normal angle [8] for all wavelengths using a Newport power meter 4832 for visible 633 nm wavelength, and ARITSU MS9740A Spectrum analyzer for NIR range.

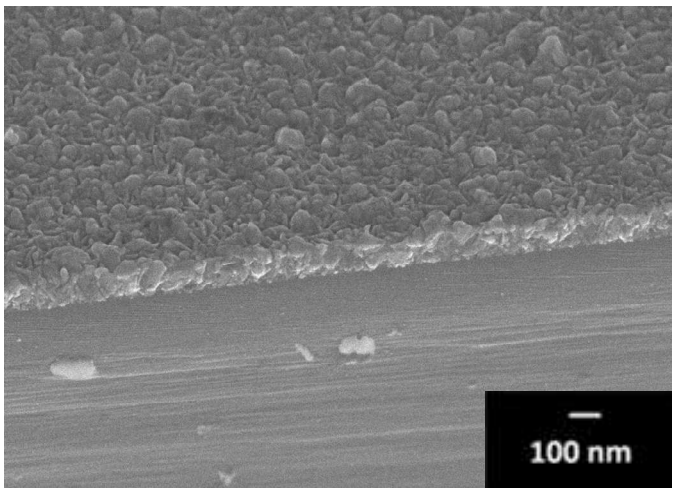

Figure 1. Secondary electron SEM micrograph of ZnO thin film deposited on Si wafer.

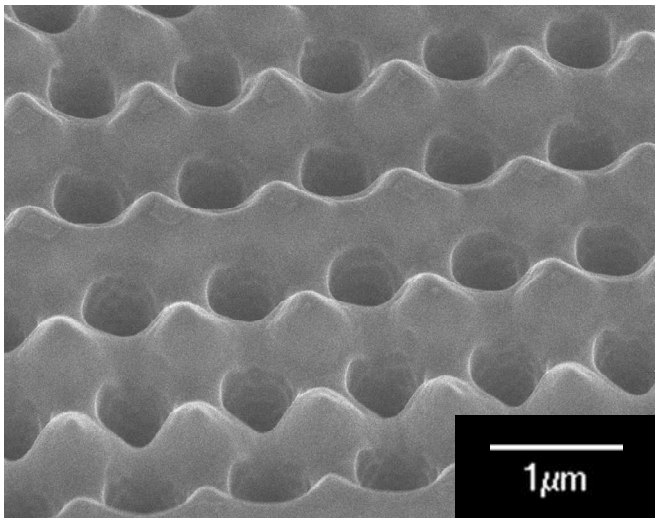

Figure 2. Secondary electron micrographs of surface of photonic structure structure on Si wafer coated with ZnO thin film

III. Results and Discussion

First measurements performed at 633 nm wavelength, allowed us determining PhS width employing a systematic method depicted in Fig. 3. Power reflected was measured on ZnO thin film and on the PhS, being the last the one showing a higher reflectance on the whole substrate.

Once knowing values of reflectance for both ZnO thin film and the photonic structure we were able to measure PhS width by moving the probe wavelength spot position on x-axis direction on a 10 μm step basis. Measurements across all the PhS capturing power reflected for each step were performed as described in Fig. 3 (insets and graph). PhS width is now visible in a reflectance vs distance on x-axis direction graphic. Difference on width measurement and real width of PhS (80μm in this particular case) could be derived by the spot diameter. Whether it is large, then a major error will be induced, on the other hand, if spot is small then high accuracy on measurement is achieved.

Reflectance spectra was built by performing reflectance measurements at red (λ=633nm) and near infra-red wavelengths 850 nm, 1310 nm and 1550 nm on PhS. Fig. 4 reveals PhC behavior on suggested discret spectra, showing a higher reflectance response at λ=1550 nm than the rest of measured wavelenghts. This shift of the reflectance spectra could be attributed to PhS hole diameter and the length of lattice constant *a*. This situation denotes the PhS selectivity for specific wavelengths in reflectance measurement, property which can be projected for filter coatings in future.

IV. Conclusions

A noticeable increment on reflectance in the NIR range as wavelength is increased was observed for the two-dimensional hybrid photonic structure of Si-ZnO with square lattice fabricated by focused ion beam method.

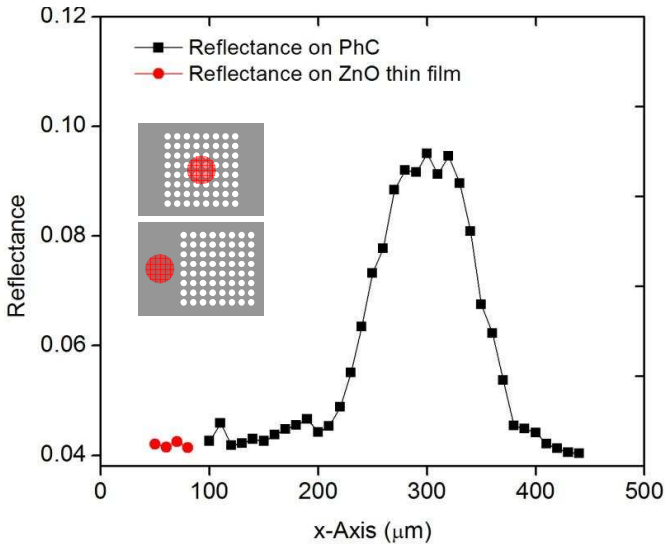

Figure 3. Reflectance on photonic crystal (squares) and on ZnO thin film in the PhC neighborhood (dots). Insets describe how the measurement was performed to obatin PhC width

From our optical measurements performed on the PhS built and described in this work, we have found a reflectance level increment as wavelength is increased. We think this behavior is derived from the interaction between silicon and ZnO film. Although, the dimensions of the PhS characteristics, i. e. holes diameters and lattice constant *a*, are necessarily involved in this behavior. This photonic structure property may be used to fabricate Infra-Red reflective coatings for technological applications.

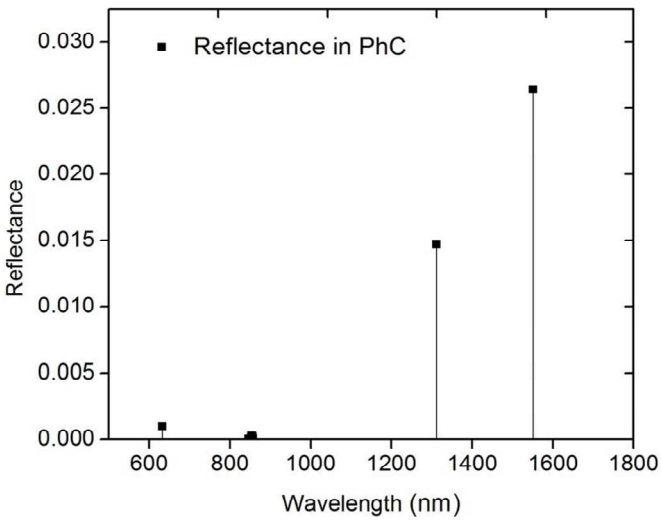

Figure 4. Photonic structure reflectance spectra as a function of wavelenght from 633 nm to 1550 nm.

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REFERENCES

[1] S. Robinson, R. Nakkeeran, "Investigation on two dimensional photonic crystal resonant cavity based bandpass filter," Optik 123, 451– 457, 2012.

[2] D. Yanga, H. Tiana, Y. Ji, "The properties of lattice-shifted microcavity in photonic crystal slab and its applications for electro-optical sensor," Sensors and Actuators A 171, 146– 151, 2011.

[3] A. Esmaieli, R. Ghayour, 'Magneto-optical photonic crystal 1 x 3 switchable power divider," Photonics and Nanostructures – Fundamentals and Applications 10, 131–139, 2012.

[4] A.I. Zhmakin, "Enhancement of light extraction from light emitting diodes," Physics Reports 498, 189–241, 2011.

[5] A. T. Rahmati, N. Granpayeh, "Kerr nonlinear switch based on ultra-compact photonic crystal directional coupler," Optik 122, 502–505, 2011.

[6] D. Freeman, S. Madden and B. Luther-Davies, "Fabrication of planar photonic crystals in a chalcogenide glass using a focused ion beam," Opt Express 13, 30079-3086, 2005.

[7] S. Cabrini, A. Carpentiero, R. Kumar, L. Businaro, P. Candeloro, M. Prasciolu, A. Gosparini, C. Andreani, M. De Vittorio, T. Stomeo, E. Di Fabrizio, "Focused ion beam lithography for two dimensional array structures for photonic applications," Microelectronic Engineering 78–79, 11–15, 2005.

[8] W. C. Stumpf, T. Asano, T. Kojima, M. Fujita, Y. Tanaka, and S. Noda, Reflectance measurement of two-dimensional photonic crystal nanocavities with embedded quantum dots, Physical Review B 82, 075119, 2010

[9] S. Domínguez, O. García, M. Ezquer, M.J. Rodríguez, A.R. Lagunas, J. Pérez-Conde, J. Bravo, "Optimization of 1D photonic crystals to minimize the reflectance of silicon solar cells," Photonics and Nanostructures - Fundamentals and Applications 10, 46-53, 2012.

[10] A. A. Miskevich, V. A. Loiko, "Two-dimensional planar photonic crystals: Calculation of coherent transmittance and reflectance at normal illumination under the quasicrystalline approximation," Journal of Quantitative Spectroscopy and Radiative Transfer 112, 1082-1089 , 2011.