Numerical Assessment of Bloch Surface Wave 1D-PhC Sensor using $Ba_2NaNb_5O_{15}$ Defect Layer

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***ABSTRACT*: In this paper, a top defective layer of Barium sodium niobate ($Ba_2NaNb_5O_{15}$) material of nanometer range thickness is used to confine Bloch surface mode at the upper interface of the proposed structure. For a 1275 nm operating wavelength, the structural characteristics are intended to stimulate a BSW at the top interface. Wavelength interrogation, angle interrogation, and a surface electric field profile are used to confirm mode confinement. It has been demonstrated that $Ba_2NaNb_5O_{15}$ is an excellent material for electro-optic and nonlinear optics applications. The impact of $Ba_2NaNb_5O_{15}$ on the top interface of the photonic crystal on sensing performance is investigated in depth. At a wavelength of 1275 nm, the BSW reflectance curve was obtained by comparing different thickness layers of $Ba_2NaNb_5O_{15}$ ranging from 45 nm to 85 nm.**

Index Term- Bloch surface wave, Photonic crystal, $Ba_2NaNb_5O_{15}$, Defect layer, Electric field, Reflectance

I. INTRODUCTION

Based on the previous study, sensing techniques based upon surface plasmon Resonance (SPR) and Bloch surface wave (BSW) are being used in various sensing applications, including chemical, gaseous, and biological sensors. [1]. Metal dielectric free electrons get to interact with light in SPR sensors, [2] and as a result, changes in the refractive index of a very thin layer on the sensor surface are exceedingly sensitive. Without double refraction, barium sodium niobate can be phase-matched; its nonlinear coefficients are nearly double those of lithium niobate. $Ba_2NaNb_5O_{15}$ large nonlinear coefficients and lack of "optical degradation"[3]. Sensors based on BSW resonances, like sensors based on SPR, can function in the angle or spectral domain. The angular spectrum shows a dramatic dip in the angular domain. A dip in the reflection spectrum can also be seen in the spectral domain [4]. Optical Tamm States (OTS) or Bloch Surface Waves (BSW) is plasmonic-like resonance modes that are excited at the interface of a defect layer and one-dimensional photonic crystals (1D-PhC) [5]. Without a metallic layer, Tamm Plasmon Polariton cannot be excited; nevertheless, dielectric materials can be used to excite the optically Tamm mode and the Bloch surface mode. [6]. The Bloch wave vector at the top interface is a complicated variable that causes both surface modes and evanescent waves. The transfer matrix approach is used to do structure improvements and sensing analyses (TMM) [7]. Layer thicknesses, refractive index contrast, and stack count have all been optimized to provide the highest possible sensitivity [8].

II. DEVICE PARAMETERS AND METHODOLOGY

The creation of the BSW at the resonance frequency is responsible for the decrease in light speed in the defect mode of the multilayer. Before being transmitted, the light is temporarily held on the multilayer's surface in the form of the BSW. [8]. BSW in reflection maps is characterized by narrow dips, which result in a localized electric field at the surface of the structure. The suggested design's sensing capabilities are evaluated using both angular and wavelength interrogation. In the structure, N-pairs of TiO_2/SiO_2 layers with thicknesses of 151 nm & 246 nm are arranged in a Bragg stack arrangement, and another essential characteristic is provided in Table I. Fig. 1 shows an operating structure of 1D-PhC-based BSW sensor with defect layer $Ba_2NaNb_5O_{15}$, and Fig. 2(a) shows that intensity of the electric field distribution, and in Fig. 2(b) it can be seen that the spatial distribution of normalized electric field at 1275 nm BSW resonance at thickness 55 nm and angle 42.7 degrees. The structure is periodic in the one direction i.e., 'y' direction, having a defect layer 'D' at the interface for BSW confinement. A quarter wavelength Bragg stack is used to design the structure. The suggested design's reflected electric field profile can be computed by adding the total of both backward and forward propagating fields.

TABLE I: BASIC PARAMETERS USING TO DESIGN 1D-PHOTONIC CRYSTAL STRUCTURE IN COMSOL MULTIPHYSICS

NAME	VALUE	DESCRIPTION
n_s	1.5007	prism
n_{TiO2}	2.15	High Index layer
n_{SiO2}	1.44	low index layer
n_a	1	R.I. of Analyte
t_h	151nm	High Index layer thickness
t_l	246nm	low Index layer thickness
t_d	45,50,55,60,65,70,75 ,80 &85 nm	Defect layer thickness

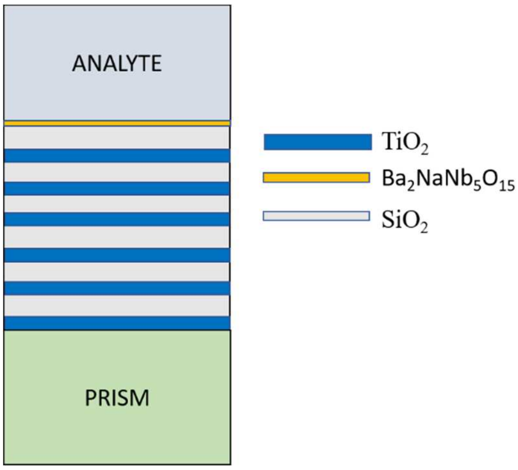

Fig. 1 Bloch Surface Waves Sensor to proposed 1D-PhC based sensor having $Ba_2NaNb_5O_{15}$ Film.

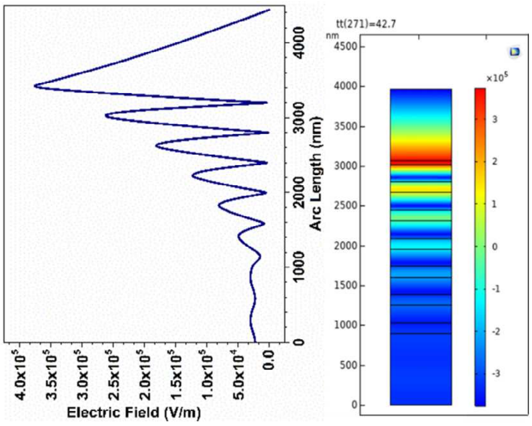

Fig. 2 Normalized electric field profile at 1275 nm BSW resonance at thickness 55 nm and angle 42.7 degrees (a) Intensity of the electric field and (b) Variation in Electric field intensity w.r.t. length in proposed optimised structure.

III. Results and Discussion

This research paper found that at incident angle is lesser than required critical angle of total reflection, 41.90°, light absorption for this device is tends to zero, implying that Bloch mode cannot occur. It can be formed at a specific angle and wavelength when the incidence angle crosses the critical angle, resulting in maximum absorption hence is BSW generated at upper most layer of device.

The BSW was generated at an incidence angle of 42.7 degrees for an effective defect layer thickness of 55 nm for 6 stacked 1D-PhC structure, and wavelength interrogation was conducted in Fig. 3(a) & (b). Fig. 4(a) indicates the incidence angle versus reflection graph of a basic dielectric mirror with a defect layer thickness of 45 nm. As a result, no BSW mode is produced, and all incident light is reflected. At operating wavelength 1275 nm, the confinement of BSW at incident angles of 41.90 degrees, 42.70 degrees, 43.51 degrees, 44.35 degrees, 45.19 degrees, 46.03 degrees, 46.84 degrees, and 47.62 degrees at defect layer thicknesses of 45 nm, 50 nm, 55 nm, 60 nm, 65 nm, 70 nm, 75 nm, 80 nm, and 85 nm, as shown in Fig. 4(b). It is found that as defect layer thickness increases the reflectance value decreases, also peak’s sharpness and depth reduce.

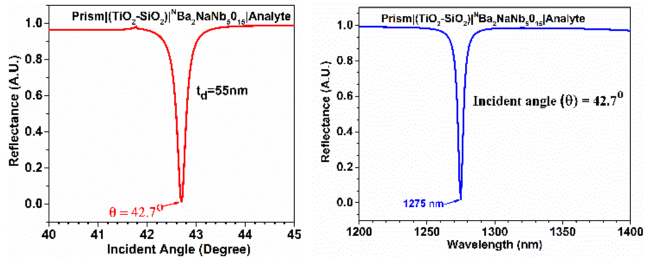

Fig. 3 BSW excitation evaluation at 42.70 degrees incidence angle for infrared wavelength 1275 nm utilising (a) angular evaluation and (b) wavelength interrogation.

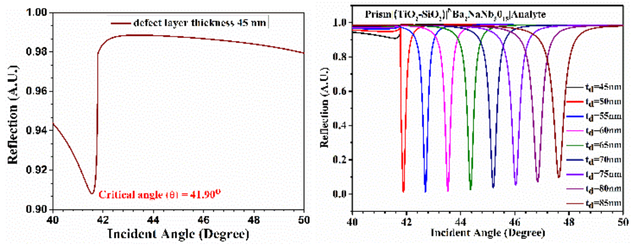

Fig. 4 Effect of incident angle on refection spectrum for (a) a $Ba_2NaNb_5O_{15}$ film having thickness 45 nm and, (b) a $Ba_2NaNb_5O_{15}$ film with different thicknesses.

IV. Conclusion

BSW has been detected at upper most layer of proposed structure taken as defective layer of $Ba_2NaNb_5O_{15}$ material of nano meter range thickness, for operating wavelength 1275 nm with varying defect layer thickness from 45 nm to 85 nm. Wavelength, Angular interrogation along with electric field profile at surface has been confirmed mode confinement. At thickness 45 nm, critical angle confirmed no BSW at the upper most interface of proposed structure. At a $Ba_2NaNb_5O_{15}$ film thickness of 55 nm, a maximum electric field of 377195.177 V/m was measured, confirming BSW at the top layer and analyte.

References

[1] M. U. Khan and B. Corbett, “Bloch surface wave structures for high sensitivity detection and compact waveguiding,” *Sci. Technol. Adv. Mater.*, vol. 17, no. 1, pp. 398–409, 2016, doi: 10.1080/14686996.2016.1202082.

[2] M. Gryga, D. Ciprian, and P. Hlubina, “Bloch Surface Wave Resonance Based Sensors as an Alternative to Surface Plasmon Resonance Sensors,” 2020, doi: 10.3390/s20185119.

[3] J. E. Geusic, H. J. Levinstein, J. J. Rubin, S. Singh, and L. G. Van Uitert, “The nonlinear optical properties of Ba2NaNb5O 15,” *Appl. Phys. Lett.*, vol. 11, no. 9, pp. 269–271, 1967, doi: 10.1063/1.1755129.

[4] A. K. Goyal and J. Saini, “Performance analysis of Bloch surface wave-based sensor using transition metal dichalcogenides,” *Appl. Nanosci.*, vol. 10, no. 11, pp. 4307–4313, 2020, doi: 10.1007/s13204-020-01538-0.

[5] P. Yeh, A. Yariv, C. Hong, and I. Introduction, “<YEHjosa77.pdf>,” vol. 91125, no. November 1976, pp. 423–438, 1977.

[6] P. Yeh, A. Yariv, and A. Y. Cho, “Optical surface waves in periodic layered media,” *Appl. Phys. Lett.*, vol. 32, no. 2, pp. 104–105, 1978, doi: 10.1063/1.89953.

[7] A. K. Goyal and A. Kumar, “Recent advances and progresses in photonic devices for passive radiative cooling application: a review,” *J. Nanophotonics*, vol. 14, no. 03, pp. 1–20, 2020, doi: 10.1117/1.jnp.14.030901.

[8] A. K. Goyal and A. Kumar, “Thermal Stability Analysis of Surface Wave Assisted Bio-Photonic Sensor,” 2022.