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TEMPERATURE DEPENDENCE TUNING OF PHOTONIC BAND GAP OF A $BATIO_3$ /AIR PHOTONIC CRYSTAL

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ABSTRACT- The variation of dielectric constant of a ferroelectric crystal $BaTiO_3$ is studied for different temperatures experimentally. As in the literature, it is found that the dielectric constant becomes maximum at the transition temperature. The Photonic Band gap (PBG) of the photonic crystal consists of BaTiO3 and air is studied at various temperatures. By analyzing the transmission spectra of the photonic crystal, it is observed that there is a change in the PBG when the temperature increases.

Key Words- [Photonic crystal; Photonic band gap; $BaTiO_3$ /air]

1. INTRODUCTION

Research in the area of ferroelectrics is driven by the market potential of next generation memories and transducers. Thin films of ferroelectrics and dielectrics are rapidly emerging in the field of MENS applications. Barium Titanate is a dielectric ceramics used for capacitors. It is a piezoelectric material for microphones and other transducers. As a piezoelectric material, it was largely replaced by lead zirconate titnate, also known as PZT. Polycrystalline barium titanate displays positive temperature coefficient, making it a used material for thermistors and self-regulating electric heating systems. Barium titanate crystals find use in nonlinear optics. The material has high beam-coupling gain, and can be operated at visible and near infrared wavelengths. It has the highest reflectivity of the materials used for self-pumped phase conjugation (SPPC) applications. It can be used for continuous-wave four-wave mixing with milliwatt-range optical power. The pyroelectric and pyroelectric properties of Barium titanate are used in some types of uncooled sensors for thermal cameras. High purity Barium titanate powder is reported to be a key component of new Barium titanate capacitor energy storage systems for use in electric vehicles. This work on photonic crystal composed of barium titanate / Air photonic crystal indicates it is highly tunable and it has great potential as nano-optic switch [1].

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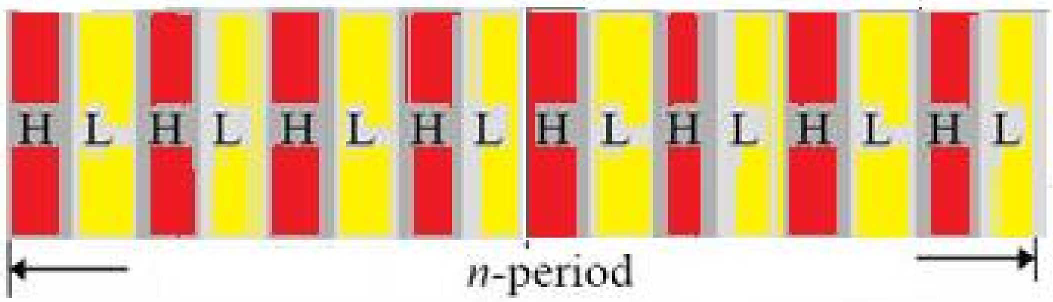

2. EXPERIMENTAL PROCEDURE FOR MEASURING DIELECTRIC CONSTANT

The dielectric constant of the sample ($BaTiO_3$) is measured from dielectric constant measuring instrument for various temperatures. The procedure is as follows:

1. Make top and bottom surfaces of the sample pellet conducting by applying silver paste and wait till it dries.
2. Put a small piece of aluminium foil on the base plate. Pull the spring loaded probes upward, insert the aluminium foil and let them rest on it. Put the sample on the foil. Again pull the top of one of the probe and insert the sample below it and let it rest on it gently. Now one of the probes should be in contact with the upper surface on the sample, while the other would be contact with the lower surface through aluminium foil.
3. Connect the probe leads to the capacitances meter.
4. Connect the oven to the main unit and keep the oven ON/OFF switch in OFF position.
5. Switch on the main unit and note the value of capacitances. It should be a stable reading and is obtained directly in pf.
6. Adjust the desired set temperature in the temperature controller.
7. Now switch ON the oven ON/OFF switch and let the controller slowly reach the desired temperature. Take the capacitance reading and continue the experiment by adjusting different temperature.

Graph is drawn between temperature and dielectric constant Ɛ, from the graph we can find the curie temperature (T_c).

The refractive index of the $BaTiO_3$ is given by

$n_h = \sqrt{\varepsilon}$

Where $\varepsilon = \frac{c}{c_o}$

$c_o = \frac{\varepsilon_o A}{t}$

Where

C = capacitance using the material as the dielectric in the capacitor

C_o =capacitance using vacuum as the dielectric (461.350×10^{-3} F)

ε_o =permittivity of the free space (8.85×10^{-12} F/m)

A =area of the sample (55.2577×10^{-6} m)

t =thickness of the sample (1.06×10^{-3} m)

3. THEORY

For TE wave, the characteristics matrix for a single period is given by [2]

$$M = \begin{vmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{vmatrix} = \prod_{j=1}^{N} M_j$$

If the j^{th} layer is characteristics by refractive index, n_j , the extinction coefficient, k_j, and the thickness d_j, then the individual transfer matrix M_j is given by

$$M_j = \begin{pmatrix} \cos\left(\frac{2\pi}{\lambda} p_j d_j\right) & i\frac{1}{p_j}\sin\left(\frac{2\pi}{\lambda} p_j d_j\right) \\ i p_j \sin\left(\frac{2\pi}{\lambda} p_j d_j\right) & \cos\left(\frac{2\pi}{\lambda} p_j d_j\right) \end{pmatrix}$$

Where $p_j = N_j \cos\Theta_j$

$N_j = n_j + ik_j$ is the complex refractive index of the j^{th} layer, and Θ_j is the angle of incidence for the j^{th} layer. Here we analysed the photonic band gap by suitable absorbtion mechanism. A saturable absorption-based photonic crystal is described by $(n_h/n_1)^n$.

To compute the transmission spectra, we employ the transfer matrix method (TMM). The transmission coefficient for tuning through such a structure given by [2].

$$t = \frac{4}{(m_{11}+m_{22})^2+(m_{12}+m_{21})^2}$$

4. RESULT AND DISCUSSION

Fig.1 explains the change in dielectric constant of $BaTiO_3$ with increasing temperature. The dielectric constant increase and reaches a maximum and get a sudden decreases. It is due to the curie temperature (T_c). When the temperature reaches T_c the ferroelectric behaviour changes to paraelectric nature. The dielectric constant values are noted at room temperature (30^0 C) and at a high temperature (140^0C). The photonic crystal is designed theoretically by taking $BaTiO_3$ as high refractive index material and air as low refractive index material. The refractive index is calculated from above equations and the photonic band gap is determined for both the temperature.

The transmission spectrum of the photonic crystal in the visible region at room temperature and at the temperature 140^0 C is shown in Fig 2&3 respectively. It is observed that there is an increase in the number of PBG with temperature. Additional modes occur with temperature in the PBG region. This work on photonic crystal composed of barium titanate/Air photonic crystal indicates it is highly tuneable and it has great potential as a nano-optic swith and signal processing.

S.NO	TEMPERTURE (^{0}C)	CAPACITANCE (pf)	DIELECTRIC CONSTANT (ϵ)
1	30	624	1352
2	40	612	1326
3	50	609	1320
4	60	613	1328
5	70	615	1333
6	80	625	1354
7	90	641	1389
8	100	671	1452
9	110	717	1554
10	120	801	1736
11	130	979	2122
12	140	1158	2510
13	150	1138	2466

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14	160	1029	2230
15	170	891	1931
16	180	791	1712
17	190	698	1512
18	200	618	1339
19	210	589	1277

TABLE: 1

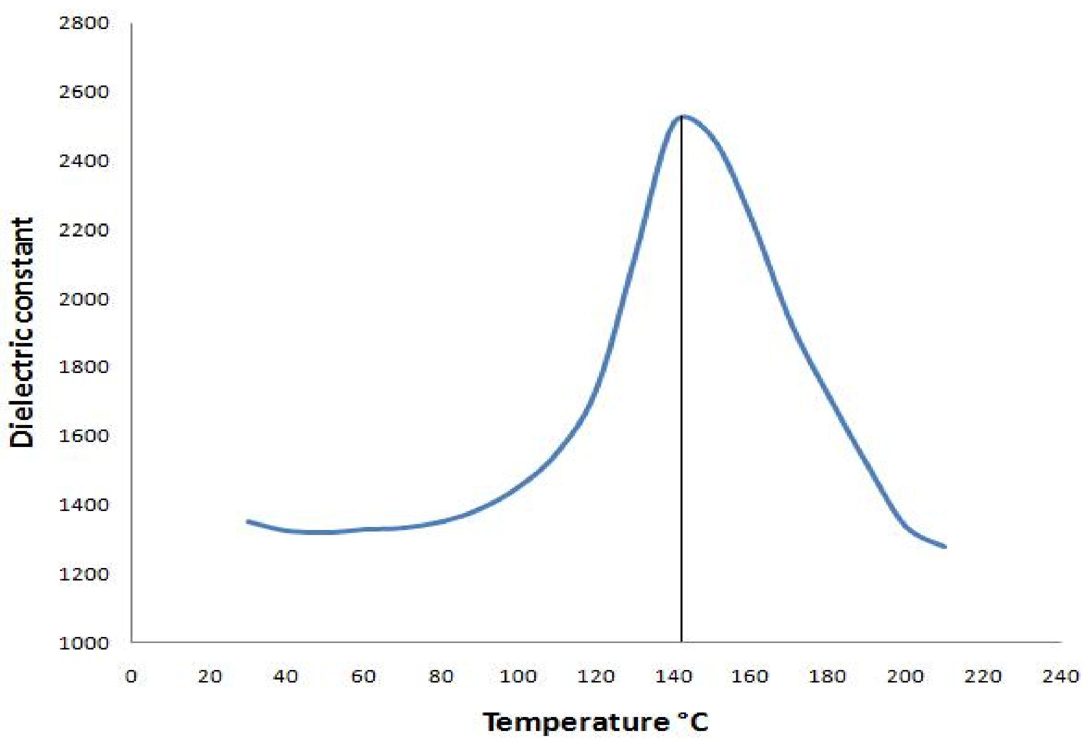

Figure 1- Temperature Vs Dielectric constant

Volume 3, Special Issue - Available Online: http://ijrset.in/Volume3,Special-Issue-I.php Pages: 27-32

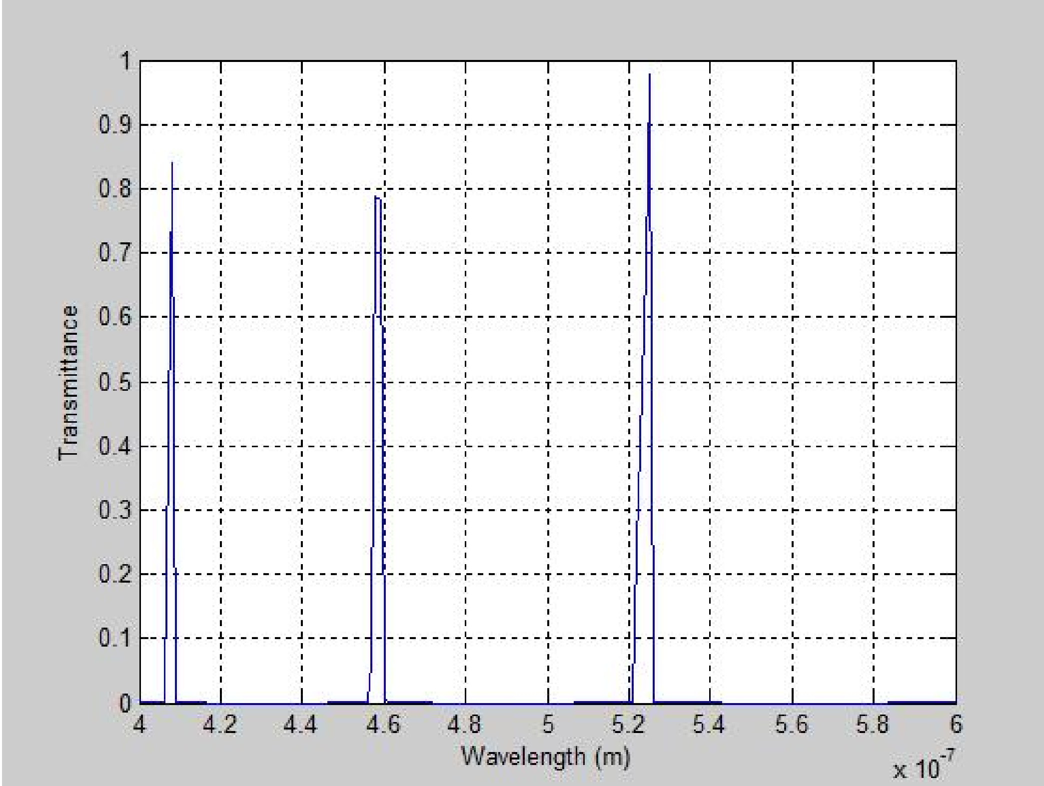

Figure 2- Transmission spectrum of PC at Room temperature (30°C)

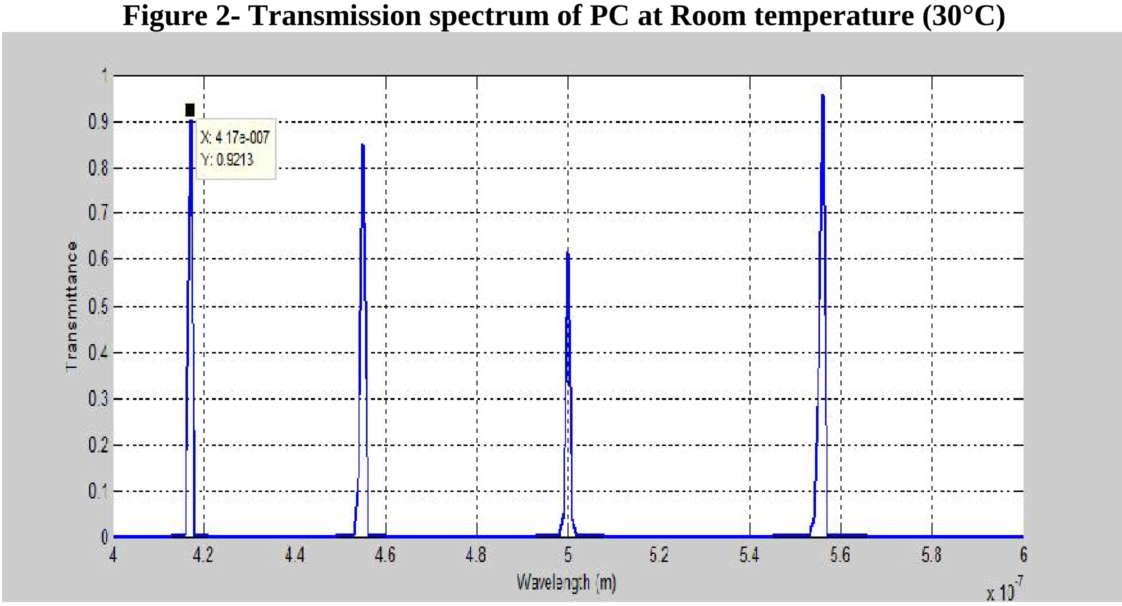

Figure 3- Transmission spectrum of PC at temperature (140°C)

CONCLUSION

The variation of dielectric constant of a ferroelectric crystal, $BaTiO_3$, is studied for different temperatures experimentally by using **DIELECTRIC CONSTANT MEASURING** (Model: DEC 600). It is found that the dielectric constant become maximum at the transition temperature (140^0C). The Photonic Band gap (PBG) of the photonic crystal ($BaTiO_3$/Air) is studied using Transfer Matrix method at various temperatures. The transmission spectra of the photonic crystal is analysed and it is observed that the number of PBGs increases with temperature.

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