REALIZATION OF SENSING APPLICATIONS IN NANOPHOTONIC WAVEGUIDE USING CyGEL^{TM} SOLUTION

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Abstract:

The vast increase in the amount of data transfer around the world each day, there has been a necessity for rapid development in optical communication technologies. Using an all optical scheme to replace the current electronic format shows promise in the next generation for optical communication. On viewing this, people from different areas are dong many works for the development for photonic circuits. Specific to the realm of photonics, there has been considerable effort to create wave guiding structures capable of sustaining high-density photonic integrated circuits. With demand for increased speed and bandwidth being the main impetus, innovative propagation mechanisms are necessary to supplant conventional techniques limited by the diffraction limit. In addition, there is propagation loss to contend with during guiding through passive components as well as wave dispersion at transmission bit rates approaching 40 Gbps and higher.

Keywords:

Nanophotonic, Waveguide,

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I.INTRODUCTION

With the vast increase in the amount of data transfer around the world each day, there has been a necessity for rapid development in optical communication technologies [1]. Using an all optical scheme to replace the current electronic format shows promise in the next generation for optical communication [2]. On viewing this, people from different areas are dong many works for the development for photonic circuits. Specific to the realm of photonics, there has been considerable effort to create wave guiding structures capable of sustaining high-density photonic integrated circuits[3]. With demand for increased speed and bandwidth being the main impetus, innovative propagation mechanisms are necessary to supplant conventional techniques limited by the diffraction limit[4]. In addition, there is propagation loss to contend with during guiding through passive components as well as wave dispersion at transmission bit rates approaching 40 Gbps and higher[5]. Although different types of waveguides are being considered now days to full fill the same, nanophotonic waveguide plays major role for the sake optical data transformations[6]. The concept of nanophotonic waveguide is briefly discussed in . Here also photonic crystal waveguide is also considered, where the strength of CyGEL^{TM} is measured. Which can be used in planer lighter wave circuits for sensing application The strength of CyGEL^{TM} is calculated using 2D photonic crystal structure based on the principle of photonic band gap.

This paper is organized as follows: in section 4.2, brief description of photonic crystal with CyGEL^{TM} solution is presented. In section 4.3, a brief idea about CyGEL^{TM} is given. and in section 4.3, simulation and discussion is made for the same.

II. PHOTONIC CRYSTAL WITH CYGEL^{TM}

Photonic crystals are special type of crystals, which have periodic optical nanostructures that are designed to affect the motion of photons in similar way that periodicity of a semiconductor crystal affects the motion of electrons [7]. It consists of separate high and low dielectric regions. The periodicity or spacing determines the relevant light frequencies. Depending on the periodicity of dielectric constants in different directions, one can construct 1D, 2D and 3D photonic crystals[8]. We have discussed 2D photonic crystal in this paper. Electromagnetic wave at a particular wavelength cannot propagate through the material in a similar way as electrons in a semiconductor are affected by periodic potential, which will give allowed and disallowed bands. The disallowed band of wavelengths in photonic band is called as photonic band gap (PBG)[9]. This band gap plays vital role for discussing photonic crystal structure. In this case we have considered a silicon semiconductor material having dielectric constant (eb) 11.7 and then a number of periodic holes are drilled on the surface of silicon. The schematic diagram of photonic crystal is shown in Figure 1.

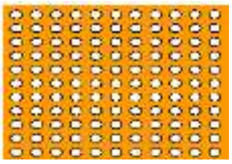

Figure 1 schematic diagram of 2D photonic crystal containing CyGEL™

The photonic band gap depends on the dielectric constants of holes, background, radius of holes and lattice spacing. If different materials are introduced in holes then the photonic band gap will change. Since different materials have different dielectric constants, the PBG will also change with respect to dielectric constant. Here we have taken CyGEL™ at different temperature, i.e., at 37^0C and 4^0C. The simulation studies are made for the photonic band gap of 2D photonic crystal structure containing different strengths of CyGEL™.

III. Brief idea about CyGEL™:

CyGEL™ is a novel thermoreversible gel that is compatible with LIVE cells. It can be used to immobilise non-adherent cells and beads by simple warming, and conversely allowing their recovery by simple cooling. CyGEL™ is unusual in that it is a liquid when cold and a gel when warmed[10]
The first reference to CyGEL™ was published in 2007 enabling novel research on anokis. The research was done in the laboratory of Dr Andrew P Gilmore, University of Manchester, UK.The following subsections describe an important properties of CyGEL™. An application note developed by GE Health care Biosciences to support use of their in cell Analyser 1000 demonstrates the use of Cygel and fluroscent microspheres to improve z-sectioning and spatial resolution. This was demonstated with zebrafish embryos[11].
Sciencestists in the laboratories of Professor Debbie smith at the University of York have validated Cygel for live parasite imaging using leishmania and trypanosomes. They also showed cygel to be an excellent carrier for fluroscent viability and organelle probes. Organisms could be imaged for up to 2 hours before being recovered from CyGEL[12].

General features:

It is a novel hydrogel compatible with LIVE cells. controllable and rapid transition from liquid to gel. Optically clear with low autofluorescence .convenient immobilisation of non-adherent cells and beads .compatible with GFP and "in gel" fluorescent probes including DRAQ5™ [13].

Recommendations:

Mounting LIVE de-adhered / non-adherent cells for microscopy (Upton et al, 2007)mounting LIVE *C. elegans* and parasites (e.g. leishmania, trypanosomes) which can be recovered thereafter (Price, Maclean, et al. 2009)immobilization of LIVE *Danio rerio* for micro-injections / microsurgery (Alvarez et al, 2009)mounting FIXED *Danio rerio* (zebrafish) embryos and other fixed tissues[14].

Advantages

CyGEL™ allows rapid preparation of LIVE cells for gel mounting. It permits temporal analysis of non-adherent cells and acts as a support matrix for cells, tissues & beads. It also permits sterile, low temperature recovery of cells from gel. CyGEL™ give multiple assay formats and applications including apoptosis detection[15].

Key benefits

CyGEL™ is an optically clear with low auto fluorescence. It is controllable and rapid transition from liquid to gel. And it also convenient immobilization of non-adherent cells and beads .This is compatible with GFP and "in gel" fluorescent probes including DRAQ5™ [16]

Applications:

CyGEL™ has many applications in imaging, flow cytometry and cell-based screening. It is compatible with LIVE cells, usefully allowing their immobilization for analysis and subsequent release for ongoing experimentation.

Imaging:

CyGEL™ Sustain make it possible to immobilize live zebra-fish embryos for high quality crisp imaging [18]: It has following characteristics such as

- Live fish can be kept anaesthetised in CyGEL™ Sustain™
- Live fish can be recovered to grow on after more than an hour in CyGEL Sustain™- remarkable!
- Immobilising live embryos permits other techniques like tissue-specific micro-injections and micro-surgery
- Fixed embryos can be held still for high resolution imaging, needed for HCS applications -

Flow Cytometry:

Flow cytometry is the technique of choice to reliably analyze cell phenotype and is a workhorse technique in immunology and hematology, research and clinical analysis. It is based on the ability to analyse cells in a population one-by-one, for light scatter properties that gives information on both cell size and granularity. The additional detection of fluorochrome-labelled antibodies can be used to identify and quantify cell surface and internal markers. Fluorescent nuclear stains can be used to discriminate nucleated from anucleated cells, provide information on cell cycle status, ploidy, apoptosis and proliferation.

Cell-based screening:

High Throughput Screening and High Content Screening are the workhorses of the pharmaceutical industry's search for new compound activities and new druggable targets.Where cell-based assays are used there is usually the need to localise the nucleus. This can be used to allow

- Automated recording of translocation and redistribution events in the cell
- Relative quantitation of changed expression or turnover of a tagged protein
- Measurement of the cell cycle position or ploidy of a cell / population

Immobilization

The time-lapse pictures below‡ illustrate how fluorescent beads are effectively immobilized using CyGEL™, allowing for the simple and accurate calibration of optical instrumentation in X, Y and Z orientations. The same can be achieved with cells.

IV. Simulation results and discussion:

Simulations are made for phtonic band gap of 2D photonic crystal structure having air holes, where holes are are infiltrated with CyGEL™ at different temperature. This simulation is done using plane wave expansion method; which is described thoroughly in paper, section 4 For the same , we have used different input parameters, such as types of lattice , radius of air holes, lattice constant, temperature, refractive indices of core and cladding etc. Choosing proper input parameters, the simulations are carried out for 37 ^{0}C and 4 ^{0}C. The simulation parameters for both temperatures are same except permittivity. Table 1 shows the design parameters of 2D photonic crystal structure.

Table 1. Design input parameters for 2D photonic crystal structure Simulations for photonic band gap at temperature 37 0C

2D Photonic Crystal Structure	
Lattice Type	Square lattice
Radius of air holes	0.4µm
Lattice constant	1 µm
Background materials	Silicon (Si)
Permittivity of Background materials (eb)	11.7

To find out the photonic band gap of 2D photonic crystal structure having CyGEL™ in air holes, the choosing input parameters are shown in Table 1 [16].

Table 2 Variation of dielectric constant of CyGEL™ with respect to their strengths at temperature 37^{0}C .

Temperature	CygelTM (st.) in %	Dielectric constant (ea)
37^{0}C	85	1.853
	100	1.865
	115	1.873
	130	1.879
	145	1.883

Using data from Table.1 and 2, simulations are made by using plane wave expansion method to compute the photonic band gap of 2D photonic crystal structure having different strength of CyGEL™ at 37^{0}C. The simulation results for strength 85%, 100%,115%,130% and 145% are shown in the figure 2, 3, 4, 5 and 6 for temperature 37^{0}C.

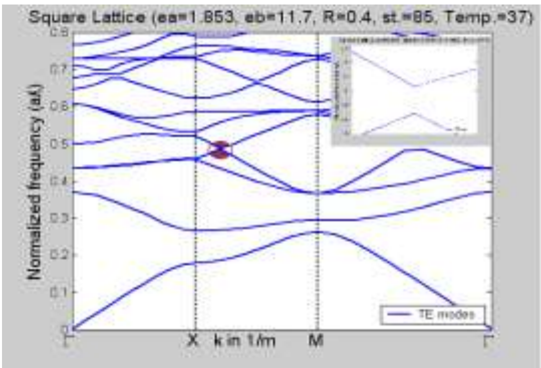

Figure 2 Simulated dispersion diagram for 85% at 37^{0}C

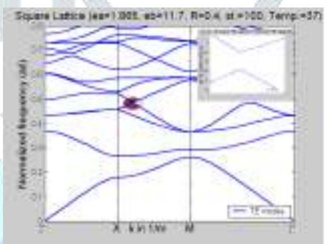

Figure 3 Simulated dispersion diagram for 100% at 37^{0}C

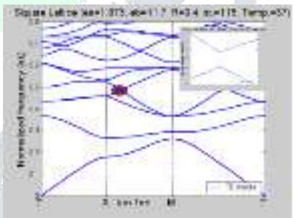

Figure 4 Simulated dispersion diagram for 115% at 37^{0}C

Temperature	Strength of CyGEL™ (st.) in %	Dielectric constant (ea)
4^{0}C	85	1.871
	100	1.885
	115	1.894
	130	1.900
	145	1.904

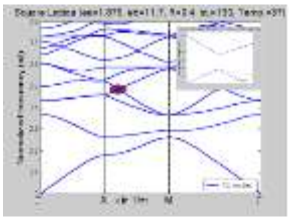

Figure 5 Simulated dispersion diagram for 130% at 37^{0}C In these graphs the wave vector k in m^{-1} is taken along x- axis and the normalized frequency (a/λ) is taken along y-axis, where 'a' is lattice spacing. The top of these diagrams are represented 'type of lattice', permittivity of CyGEL^{TM}, permittivity of background material, strength of CyGEL^{TM} and temperature.

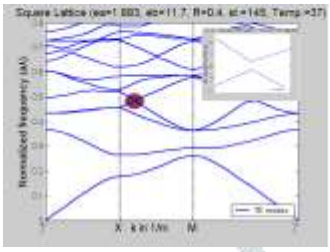

Figure 6 Simulated dispersion diagram for 145% at 37^{0}C

The photonic band gap is obtained from the figures 2, 3, 4, 5 and 6 with respect to their corresponding strengths at temperature 37^{0}C, where circles are shown. Photonic bandgap indicated within the circle is zoomed and shown in the inset in each simulation results. The photonic band gap is calculated from each dispersion diagram with respect to their corresponding strengths and these calculated values are shown in Table 3.

Table 3. Calculated photonic band gap with respect to strength of Cygel^{TM} at 37^{0}C

Temperature	Strength of CyGEL^{TM} (%)	Photonic band gap in eV
37^{0}C	85	0.0047
	100	0.0045
	115	0.0044
	130	0.0043
	145	0.0042

It is found from the above results that the photonic band gap decreases from 0.0047 eV to 0.0042 eV with respect to increase of CyGEL^{TM} from 85 % to 145 % (permittivities are increase from 1.883 to 1.853) at temperature 37^{0}C. Using data from Table 3, a graph is plotted between photonic band gap in eV along y-axis and CyGEL^{TM} in % along x-axis. This is shown in figure 7.

Table 4 Variation of dielectric constant of CyGEL^{TM} with respect to their strengths at temperature 4^{0}C

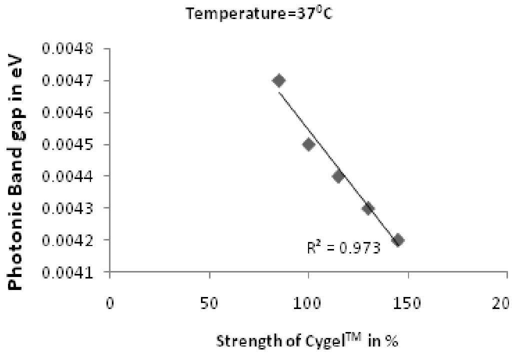

Figure 7 Variation of P.B.G. with strength (85% to 145%) of Cygel^{TM} at 37^{0}C

From this above graph, it is found that the photonic band gap varies almost linear (R^2=0.973) with respect to the strength of CyGEL^{TM} , which varies from 85 % to 145%. Apart from this, an excellent linear variations (R^2=1) of photonic band gap is found with respect to CyGEL^{TM} , which varies from 100 % to 145 %, which is shown in Figure 8.

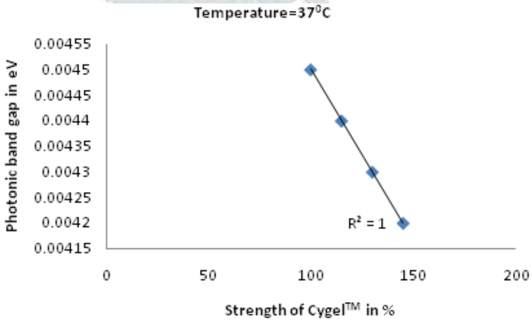

Figure 8 Variation of P.B.G. with strength (100% to 145%) of Cygel^{TM} at 37^{0}C

This excellent linear relationship gives sensing application to determine the Cygel^{TM} strength between 100% to 145% at temperature 37^{0}C by using two dimensional photonic crystal structures.

Simulations for photonic band gap at temperature 4 ^{0}**C**

To find out the photonic band gap of 2D photonic crystal structure having CyGEL^{TM} in air holes, the choosing input parameters are shown in Table 1 and 4.

Using data from Table.1 and 4, simulations are made by using plane wave expansion method to compute the photonic band gap of 2D photonic crystal structure having different strength of CyGEL^{TM} at 4^{0}C. The simulation results for strength 85%, 100%, 115%, 130% and 145% are shown in the figure 9, 10, 11, 12 and 13 at temperature 4^{0}C.

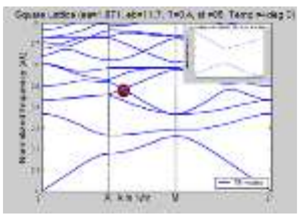

Figure 9 Simulated dispersion diagram for 85% at 4^{0}C

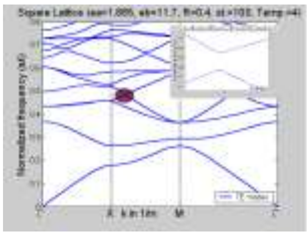

Fig 10 Simulated dispersion diagram for 100% at 4⁰C

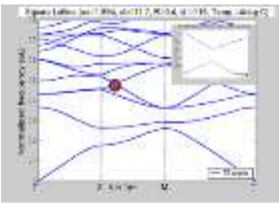

Figure 11 Simulated dispersion diagram for 115% at 4⁰C

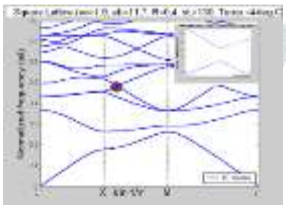

Figure 12 Simulated dispersion diagram for 130% at 4⁰C

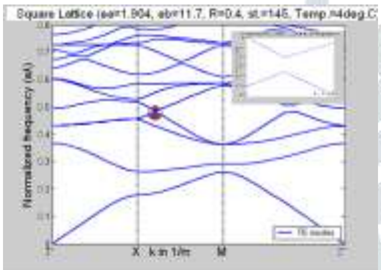

Figure 13 Simulated dispersion diagram for 145% at 4⁰C

In these graphs the wave vector k in m^{-1} is taken along x- axis and the normalized frequency (a/λ) is taken along y-axis , where 'a' is lattice spacing. The top of these diagrams are represented 'type of lattice', permittivity of CyGEL™ ,permittivity of background material, strength of CyGEL™ and temperature. The photonic band gap is obtained from the figures 2, 3, 4, 5 and 6 with respect to their corresponding strengths at temperature 4⁰C, where circles are shown. Photonic band gap indicated within the circle is zoomed and shown in the inset in each simulation results. The photonic band gap is calculated from each dispersion diagram with respect to their corresponding strengths and these calculated values are shown in Table 5.

Table 5. Calculated photonic band gap with respect to strength of CyGEL™ at 4⁰C

It is found from the above results that the photonic band gap decreases from 0.0044 eV to 0.0038 eV with respect to increase of CyGEL™ from 85 % to 145 % (permittivities are increase from 1.871 to 1.904) at temperature 4⁰C. Using data from Table 6.5, a graph is plotted between photonic band gap in eV along y-axis and CyGEL™ in % along x-axis. This is shown in figure 14.

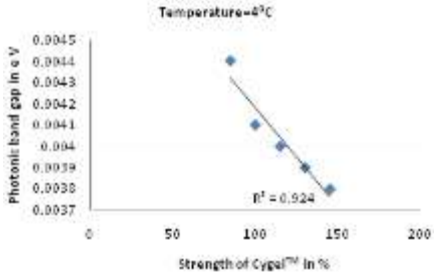

Figure 14 Variation of P.B.G. with strength (85% to 145%) of CyGEL™ at 4⁰C

From this above graph , it is found that the photonic band gap varies almost linear (R^2=0.924) with respect to the strength of CyGEL™ , which varies from 85 % to 145%. Apart from this, an excellent linear variations (R^2=1) of photonic band gap is found with respect to CyGEL™ , which varies from 100 % to 145 %, which is shown in figure 6.15.

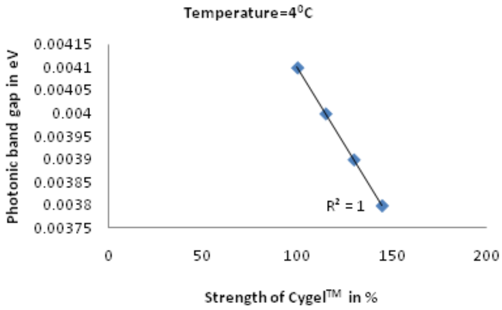

Figure 15 Variation of PBG. with strength (100% to 145%) of CyGEL™ at 4⁰C

V. Conclusions

This excellent linear relationship gives sensing application to determine the CyGEL™ strength between 100% to 145% at temperature 4⁰C by using two dimensional photonic crystal structures.

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