Photonic Band Gap Measurements for Two Dimensional Photonic Crystals Employing Dielectric Rods of Alumina in Vacuum

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INTERODUCTION

Abstract

Photo Voltaic is the new technology that is being implemented for generating electricity with minimum cost. By 2010 solar photo voltaics will generate electricity in more than 80 countries and, while yet comprising a tiny fraction of the 4800 GW total global power-generating capacity from all sources, is the fastest growing power-generation technology in the world. In this assignment, with the help of CST software a new type of Photonic crystal is fabricated and its applications are discussed. The CST software will help the students understand the designing of Photonic crystal. Also the assignment highlights the advantages and disadvantages of using solar energy in daily life.

2. Introduction to Photo Voltaics

Photovoltaic is the new booming technology which is developing day by day and deals with the usage of photo voltaic cells which is the key component of a PV system. The cells used convert the energy from one form to another i.e. solar energy to electricity which is totally different then the other generating procedures. This is cleanest generating technique which is being used nowadays. Photovoltaic technology was first recognised in 1839[1] and its application began in early 1970's. This was the time when United States first used Photovoltaic technology in there space program. By the end of 1990 this technology was used in the small scale markets and large scale markets such as pocket calculators, electric power applications etc. As of 2010, solar Photovoltaic technology is generating electricity in more than 80 countries and, still covering a tiny fraction of the 4800 GW [2] total global power-generating capacity from all the other generating sources, is the fastest growing power-generation technology in the world.

Photovoltaic Technology is the best method for generating electricity through solar cells. The photovoltaic effect refers to photons of light knocking down the electrons into a higher state of energy to create electricity [1]. Solar cells produce a DC form of energy from sun light, which can be used to power equipment or can also be used to recharge a battery and an inverter is later used to convert the DC to AC form of electricity. The first practical application of Photovoltaics was to power the orbiting satellites and other spacecraft [1].

The capacity to generate electricity from sunrays is a relatively fresh and exciting technology that offers many new opportunities in generating 'green' electricity. This technology is called solar photovoltaics or more simply, PV. Also referred to as solar electric, PV offers the ability to generate electricity in a clean, quiet and renewable way. It makes use if the abundant energy from the sun, to generate electricity without the production of harmful carbon dioxide emissions, one of the main gases affecting climate change. It is one step towards the green technology which is important to use when the global warming is a important issue to handle.

_Many countries are trying their hands to advance PV technology through their own initiatives and practical implementations. Some countries such as Germany, Japan, Netherlands, Norway and the USA [3] have arranged programmes of government investment which is doing collaboration with various industries, which have lead to thousands of solar electric homes being built around the world [3].

But some countries such as Scotland and United Kingdom [3], do not have any large home market to display its skill in PV technology or the financial support to develop this market additionally.

These type of technology is reliable, simple to install and easy for maintenance. It can be noted that even with the expertise that exists in some developed countries, it is strange that PV technology is used minutely and does not plays a greater part in daily usage of human beings. This may be because of electric power generated from PV is expensive to compete in Scotland and the UK [3] due to the low prices of fossil-fuel, nuclear and even wind power.

Figure 1:- Application of Photovoltaic Technology [2]

In solar cells, a thin semiconductor layer operated as an electric field has two faces one side is positive and the other one negative. Nowadays the solar cells are mostly made from silicon, a special type of melted sand, which has two or more thin layers of semi conducting material; usually silicon [3].These layers have different charges.

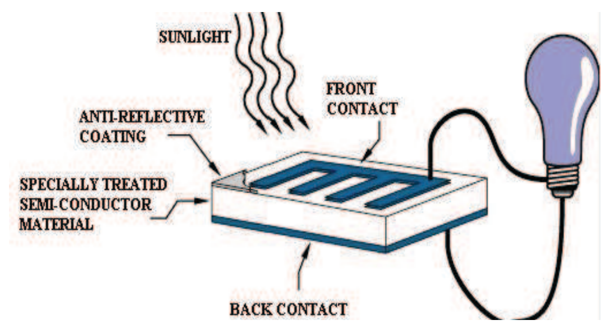


Figure 2:- Working of a PV system [3]

For the operation layers are given opposite charges one positive and one negative. When rays from sunlight strike the solar cell, electrons travelling along are knocked down resulting to make them loose from the bounding of atoms for a semiconductor material. In such a situation connecting two different conductors i.e. one at the positive and other at the negative side forms an electric circuit and thus the electrons can be captured in the form of an electric current that is, electricity. This electricity can then be used to power a load, such as a light or a tool.

The PV cells used are normally designed as pn junction or even the Schottky barrier device [4]. When the cell gets the sunlight on its surface pairing of electrons and holes takes place which is done due to the interaction of incident photons in sunlight and atoms that are present in the cells. This causes the electrons and photons to drift making them to change their region. The I-V characteristic for a PV cell can be written as

$$I = I_l - I_o\left[e^{\frac{qv}{kT}} - 1\right] \text{ [4]}$$

Where, I_l is the cell current due to photons

q= $1.6*10^{-19}$ coulombs

k= $1.38*10^{-23}$ j/K and T is the temperature in Kelvin.

The electrical output of solar cell is establishes at Standard Test Conditions (STC), where the irradiance is 1000W/m2 and at a cell temperature of 25°C [3]. With the cell operating at these conditions the open circuit voltage (Voc), short circuit current (Isc), voltage at maximum power point (V max) and current at maximum power point (Imax) are obtained. From this the maximum power delivered by the cell can be calculated as well as the fill factor (FF) – the cell conversion efficiency. [4]

$$Formfactor = \frac{V\max * \mathrm{Im}ax}{Voc * Isc}$$

$$P\max = Voc * Isc * Formfactor$$

In many countries people turn only to PV technology as a last resort, usually in rural areas or locations where it is difficult to access the electricity or where the cost of connection to the grid is expensive. Countries such as India, Africa have this kind of issues in the rural areas, but due to plenty of sunlight available here the PV technology can be beneficial. In these locations stand-alone systems are already proving economically viable. Such systems are independent of the grid and any excess energy produced would usually be stored in a battery.

It will be beneficial to use the solar cells or the PV cells by connecting them in series and creating a PV module. This kind of designing makes the chances of achieving adequate amount of voltage at the output. Normally a multiple of 12 volts operation is used or designed.

Figure 3:- Various dimensions of Photonic crystals [6]

The Photonic crystals are the material that has a band gap in which the photons of certain energy level cannot propagate through the crystal. These photonic crystals are divided in three parts which are dielectric constant, lattice topology and spatial period [6] and when significant parameters of this are considered a gap can be created where the electromagnetic rays can be prohibited. Thus a photonic band gap is created. The photonic crystals can be designed in three different dimension schemes which are one, two and three. In the two-dimensional photonic crystals all derivatives with respect to z coordinate vanish and the study is restricted to the propagation along the cross-section plane of the crystal, i.e. the xy plane. [6]. When a layer of different dielectric constant is used one dimensional photonic crystal is achieved. The figure below shows the one, two and three dimensional photonic crystals.

3. Designing of Photovoltaic Crystals

In this chapter the designing of Photo Voltaic crystal is discussed. For the designing of such cell software such as CST microwave studio. This kind of software is known for the 3D EM simulation of high frequency components. CST MWS enables gives the user fast and accurate analysis of high frequency (HF) devices such as antennas, filters, couplers, planar and multi-layer structures and SI and EMC effects [5].

In this process of designing, dielectric rods used are of alumina which has an epsilon value of 9.9 [6] which is in vacuum lattice.

Step 1:- Creating the slab cube of 1*1

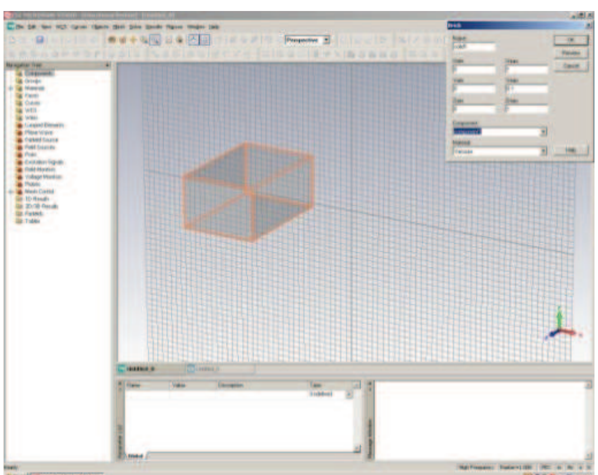


Figure 4:- Creating a slab

Xmin = 0 Ymin = 0 Zmin = 0

Xmax = 1 Ymax = 0.1 Zmax = 1

Material = Vacuum

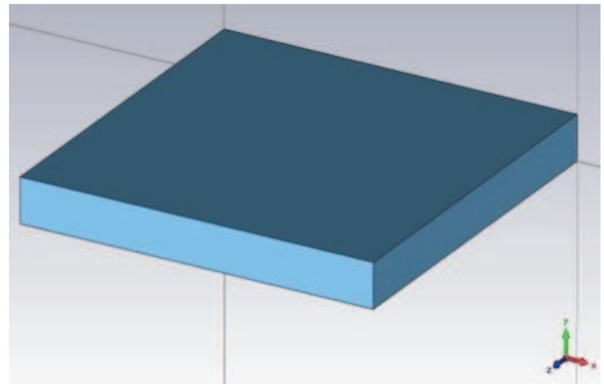


Figure 5:- Final a slab

Step 2:- Creating the cylinder

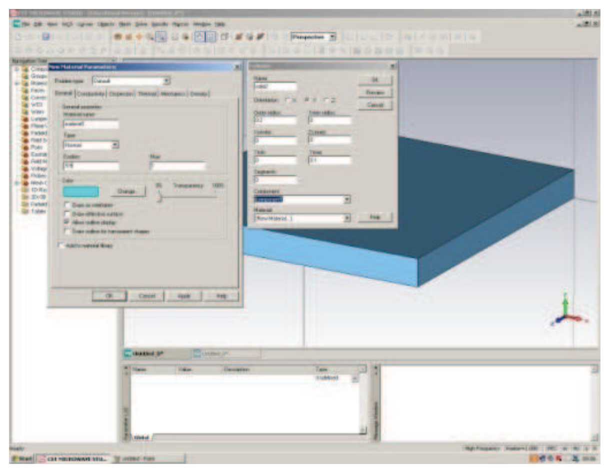


Figure 6:- Creating cylinder

Orientation = Y axis

Outer Radius = 0.2 Inner Radius = 0

X center = 0 Z center = 0

Ymin = 0 Ymax = 0.1

Now for cylinder new material is used and that is alumina. For alumina used in this assignment its epsilon value is taken as 9.9.

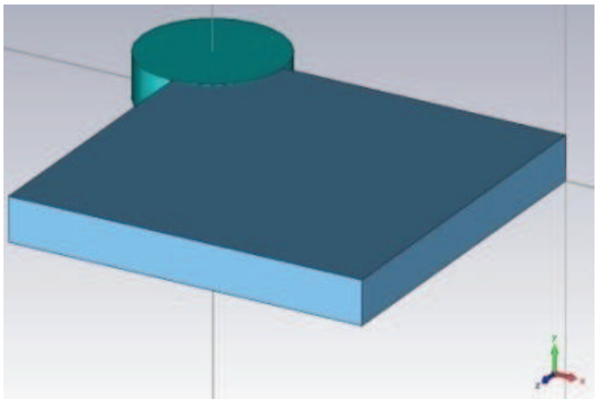


Figure 7:- Cylinder rod at one corner

After designing cylinder at one corner, the designed cylinder is transformed on other 3 corners which is shown in the figure below.

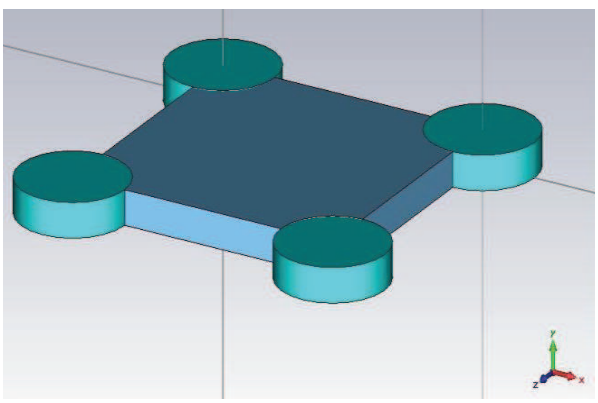


Figure 8:- Cylinder rod at all corners of lattice

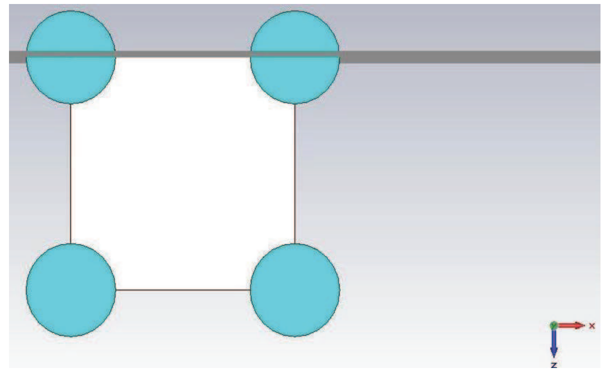


Figure 9:- Cylinder rod at all corners top view

Step 3:- Chopping the Cylinder to make it symmetrical with the lattice

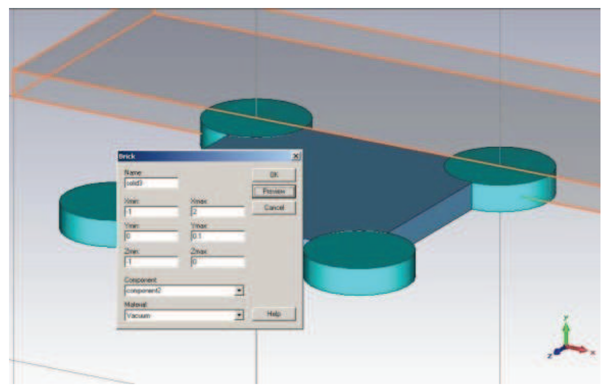


Figure 10:- Chopping the cylinder

A] Xmin = -1   Xmax = 2
Ymin = 0   Ymax = 0.1
Zmin = 1   Zmax = 0

B] Xmin = 1   Xmax = 2
Ymin = 0   Ymax = 0.1
Zmin = -1   Zmax = 2

C] Xmin = -1   Xmax = 0
Ymin = 0   Ymax = 0.1
Zmin = -1   Zmax = 2

D] Xmin = 1   Xmax = 0
Ymin = 0   Ymax = 0.1
Zmin = -1   Zmax = 2

By using the above stated configurations, the cylinder will be chopped off and will align with the rectangular slab. This final cell after chopping is shown in the figure below

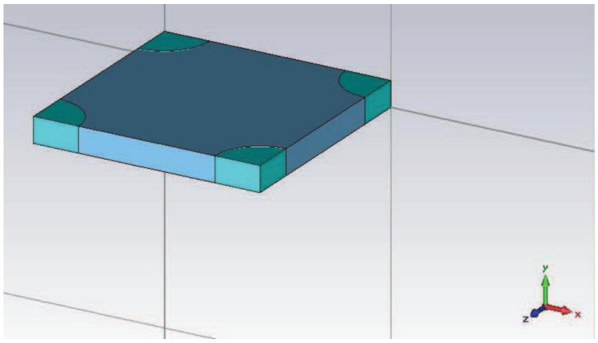


Figure 11:- Final Photonic Crystal

Step 4:- Dimension Units

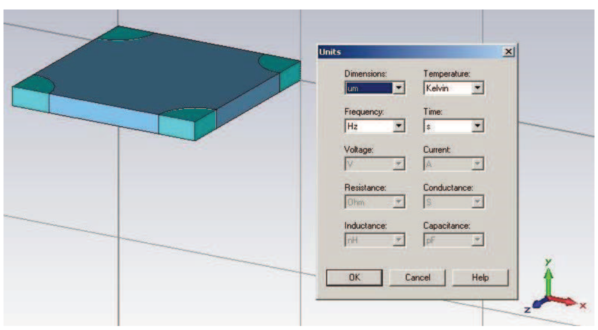


Figure 12:- Final Photonic Crystal

Dimensions = um

Frequency = Hz

Step 5:-Setting the Frequency

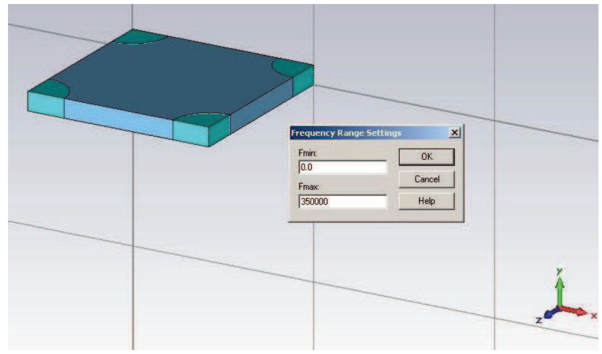


Figure 13:- Frequency setting

Fmin = 0.0 Hz

Fmax = 3500000 Hz

Step 6:- Setting the Boundary Condition for Photonic crystal

In this step, Xmin, Xmax, Zmin and Zmax are made periodic and Ymin, Ymax is made 0 to get the magnetic property at the output for the designed Photonic crystal. Now in this step also it is important to fix the Phase shift or the scan angle. This is shown below

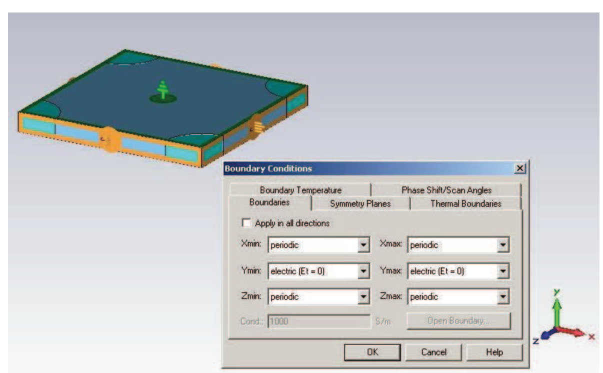


Figure 14:- Setting Boundary Condition

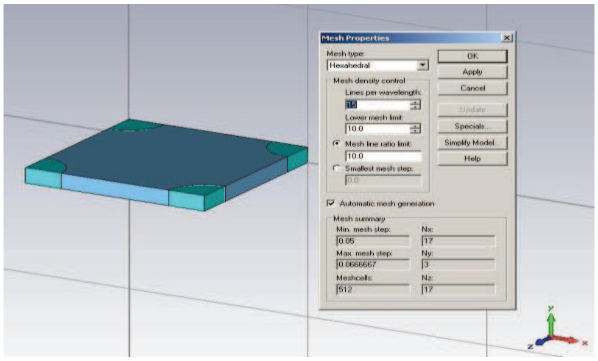


Figure 15:- Setting Phase Shift

This phase shift is changed to get the output graph for the crystal. These settings are mentioned below.

X = phase (defined as 180 degree) Z = 0
X = 180 Z = phase
X = phase Z = Phase

Step 7:- Setting the Mesh

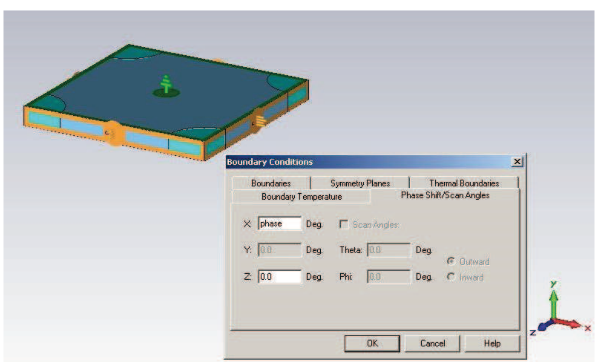


Figure 16:- Setting the Mesh

Line per wavelength = 15

Step 8:- Eigen Mode Solver

Name = phase

From = 0 to 180
Samples = 10
Also while doing that, adding two new frequency modes.

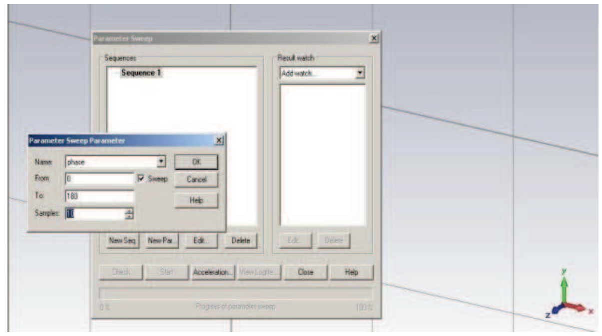


Figure 17:- Creating new sequence

After following all the above-mentioned steps, the simulation is started and following type of graphs for photonic crystal is obtained.

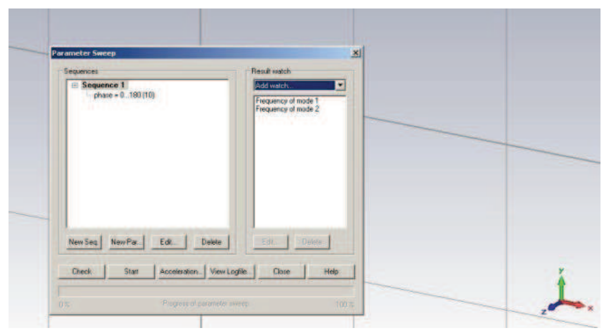
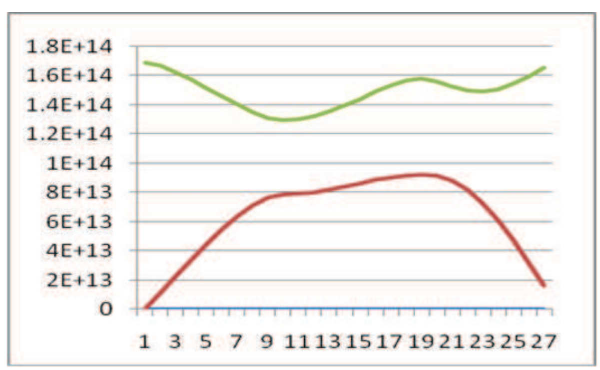
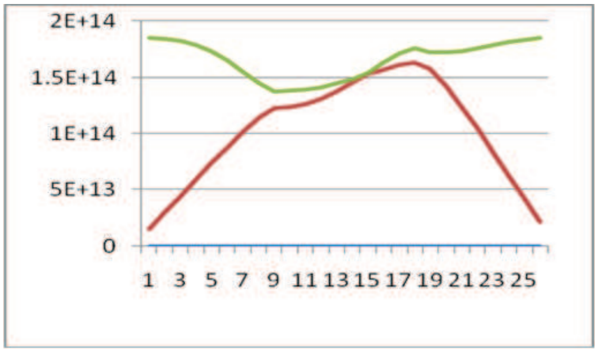


Figure 18:- adding the frequency mode



Graph 1:- Output with frequency mode 1 and 2 when Et = 0



Graph 2:- Output with frequency mode 1 and 2 when Ht = 0

The magnetic and electrical output property for the designed photonic crystal is shown above. It can be seen that the photonic crystal used in this experiment has got a band gap in which the photons of certain energy level cannot propagate through the crystal.

Also when the value of epsilon is changed i.e. if the material is changed the band gap will increase and for higher value of epsilon band gap will increase. This also results in increase in the refractive index for the used material.

4. Conclusion

Thus from analysis it was seen that with different type of material for the manufacturing of photonic crystal a band gap can be achieved which allows a certain energy range of photons not to propagate through it. So it can be said that the crystal becomes more promising for holding the photons in it for a much longer time. With materials of high value for epsilon, the band gap increase, which leads to increase in the refractive index for the used material. But it will be not feasible to use a material with high epsilon value because it may lead to increase in the cost of manufacturing the crystal.

The CST software helps students to understand the designing of photonic crystals in a very simple way other then the practical method used in companies. It also helps the students to design a number of different type of crystals with different material used in it.

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