PES UNIVERSITY

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Course: Chip Level Photonics

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Project on:

Simulation of Photonic Crystal Directional Coupler Switch

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1.Abstract:

In this project, we attempt to design a directional coupler switch based on photonic crystals, implement and the linear state has been analyzed and simulated. Then, the principles of nonlinear optics are used to perform optical switching while using ANSYS Lumerical 2020 R2.4 and the FDTD electromagnetic simulator.

2.Introduction:

Photonic crystals (PC) are periodic structures made from dielectric or metal that can affect the direction of the electromagnetic wave just as semiconductor crystals do with electrons.

[fig 1] shows the structure of the photonic crystal directional coupler switch and is the basic design of our implementation in the project. The Working principle, specifications of the crystals and dimensions will be discussed further in the report.

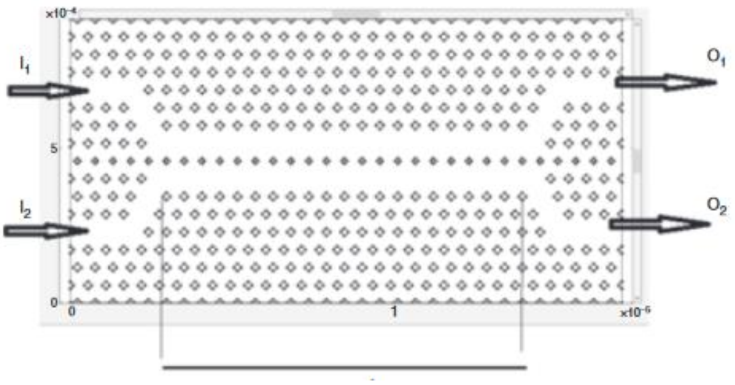


Fig 1 : Structure of photonic crystal directional coupler

2.1 The Kerr effect:

[2] Non linear optical phenomena include Self phase modulation or cross phase modulation. These are mostly used to develop compact and ultra fast optical integrated circuits. The main reason photonic crystal waveguides are used is because light can strongly be confined in the waveguide. This can be achieved vertically by Total internal reflection and horizontally by photonic band gaps.

Taking these effects into account, the structure of the waveguide is derived as shown in fig 1. The optical Kerr effect is a nonlinear optical phenomenon where the refractive index of a material change in response to the intensity of the light passing through it. When high intensity light passes through a nonlinear optical material, the refractive index *n* of the material changes according to this equation given in fig 2.

$$n = n_0 + \Delta n$$

Fig 2: change in refractive index

Where n0 is the refractive index in the linear state and has a constant value, whereas Δn is the refractive index change and is linearly proportional to the intensity of the pump signal in the optical Kerr effect. Aluminium Gallium Arsenide is used as the material to make PC rods which are used along with air for substrate in the simulation. The material is chosen to avoid non-linear absorption due to Two photon absorption in the same wavelength region. A gaussian source of 1550 nm wavelength is used with an lattice constant calculated as ∝=500 nm fig 3.

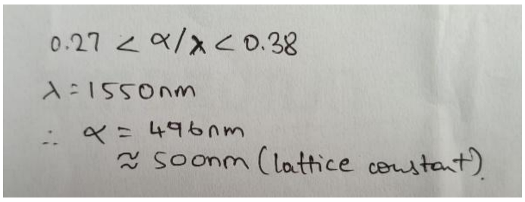


Fig 3: calculation of lattice constant (∝)

The optical switching is observed when the phase between 2 sources is π.By increasing Δn, the output power ratio increases, meaning that the optical power is transferred from the output port (O_1) to the output port (O_2).

In this project, we use the Kerr effect to be able to bend light by simulating the nonlinear state of light. This occurs by applying Δn = 0.43 to the central dielectric rods.

3.Implementation:

The Ansys Lumerical tools enable the design of photonic components, circuits and systems. FDTD is a simulator within the Lumerical's suite. [fig 4] shows the layout of the interface.

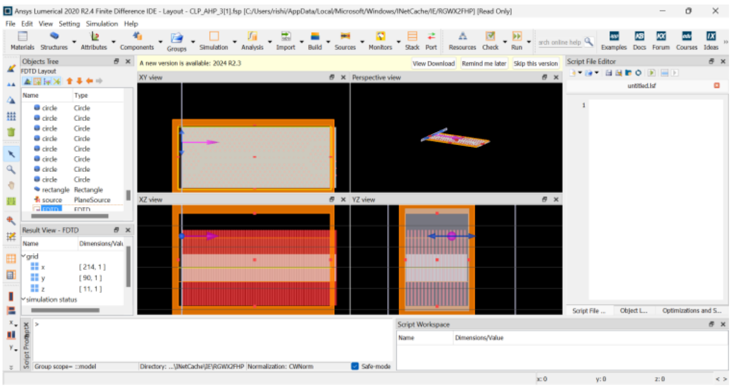
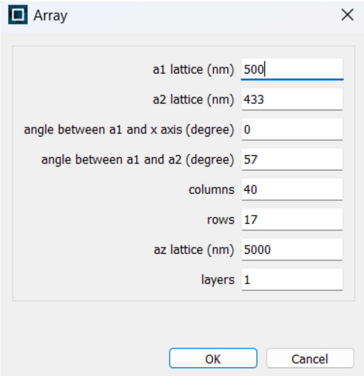


Fig 4 : interface of Lumerical FDTD

3.1 Steps involved in the implementation:

1. Open a new Lumerical FDTD project.
2. Import the refractive index file for the crystal rod material, in this case Aluminium Gallium Arsenide (AlGaAs) rod was used.
3. Add the file to the materials [3]. Name it AlGaAs.
4. Reduce the dimensions to nanometres.
5. Select the circle structure and change the radius to 0.2a => 100nm, change the material to AlGaAs.
6. Create an array with the parameters in [fig 5] to create a (31x17) array or PC.
7. Edit the structure as shown in [fig 4].

8. The radius of the central rods must be set to 0.14a.
9. For the non-linear simulation change the refractive index to an additional 0.43 appropriately.
10. The gaussian source with a wavelength of 1550nm is chosen as the input light source.
11. Change the phase of the source from 0 to 180.
12. Add the simulation region and mesh with DFT monitor to finish the structure [fig7].
13. Run the program and evaluate the results (Linear structure).
14. Change radii of centre rods for evaluation of power vs Δn graphs.
15. For non linear simulation, change the refractive index of the central rod by 0.43.



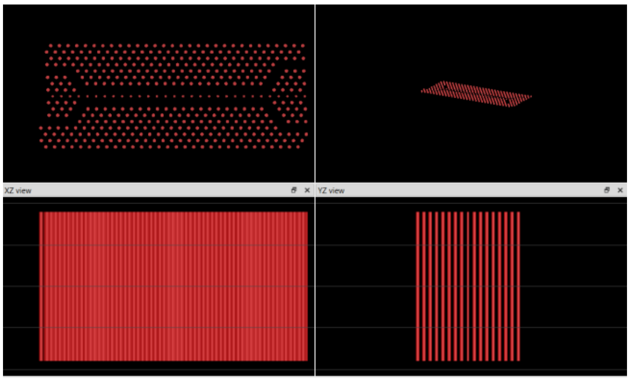


Fig 5 : parameters of array

Fig 6 : layout of the structure

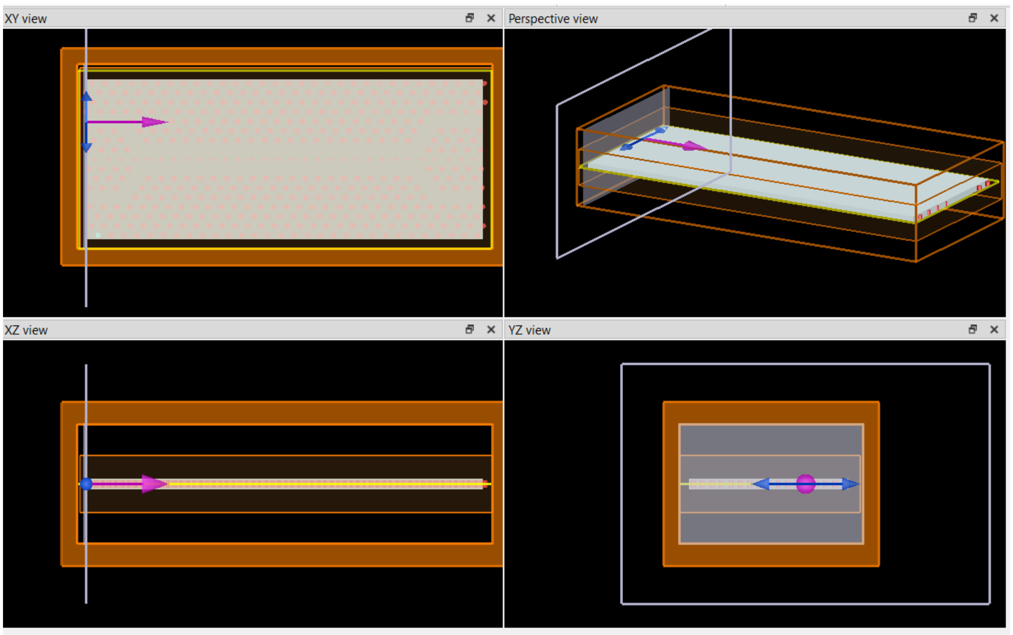


Fig 7 : finished structure of the switch

4.Simulation results and Analysis:

Simulations are carried out on Ansys Lumerical 2020 R2.4 with an Intel core i7-12650H CPU and Nvidia GeForce RTX 3050 Laptop GPU. [4] was used for debugging and to resolve runtime errors.[1], [5] and [6] were reffered for simulation constraints.

First we run the linear simulation with the refractive index of the central rods as that of AlGaAs. [fig 8] describes the plot of the electromagnetic field intensity or how energy is travelling though the structure.

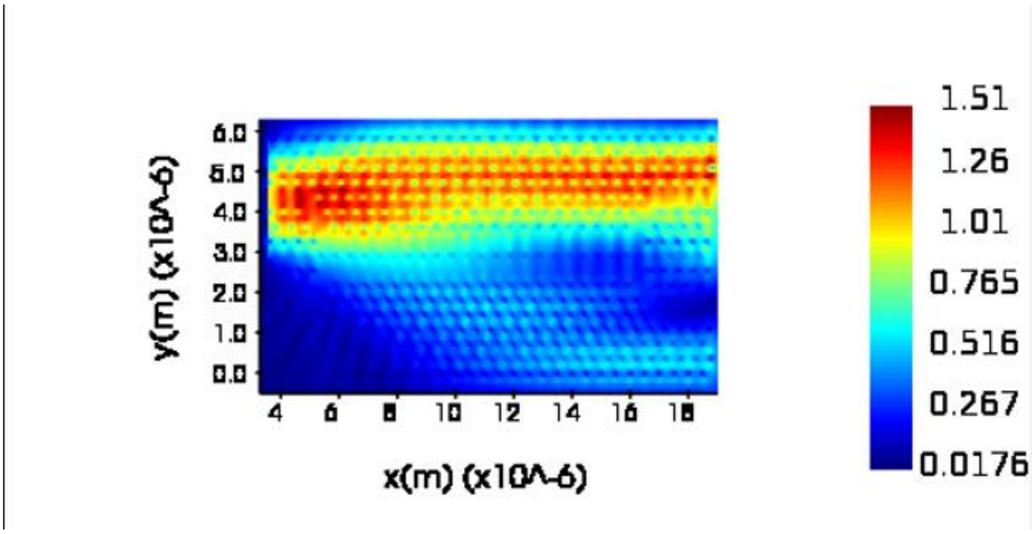


Fig 8 : electromagnetic field distribution graph for linear condition

In a directional coupler switch, the coupling depends on the change in the refractive index between the 2 media within a photonic crystal structure. The path of light is seen to propagate along the path expected (bending in same side), as there is no change In n and the mode represents the same.

The refractive index is now changed to Δn and the simulation results in [fig 9]

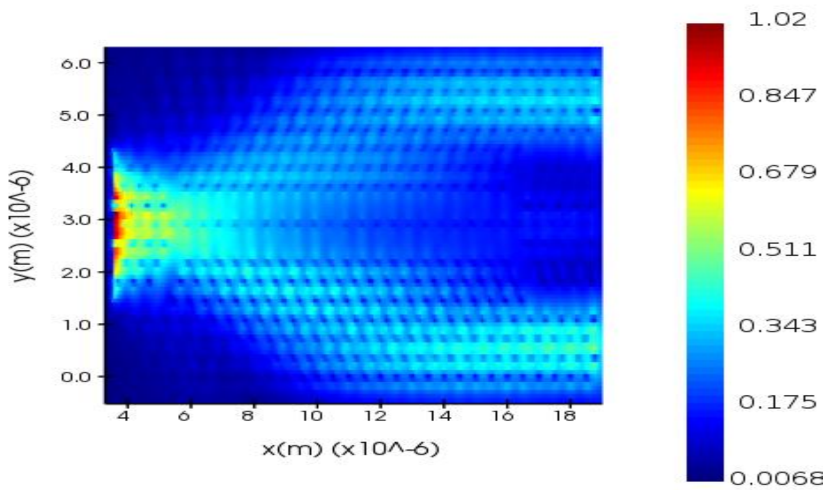


Fig 9 : electromagnetic field intensity graph for non linear condition

The path of light is not completely seen to bend towards the desired output gate but we can observe a higher intensity on the required output gate and this was the best output we could achieve. A major reason could be explained as the limits to which we can change the refractive index without hindering the working of the structure did not produce accurate results.

Comparing the normalised power outputs at the port O2 against the different radii of central rods, the simulation resulted in the plots as described for a radius of 0.14∝ (70nm)[fig 10], 0.15∝ (75nm)[fig 11] and 0.16∝ (80nm)[fig12]. As radius of the central rod increases the output power is observed to increase as well. Due to smaller dimensions the results are not evident.

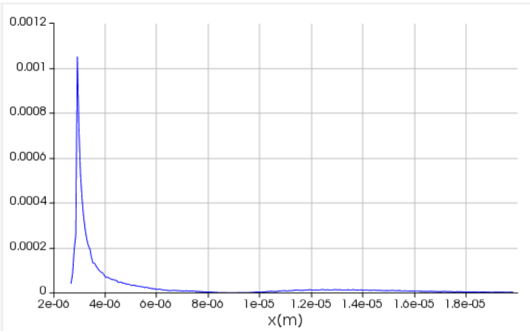


Fig 10 : radius of 0.14a

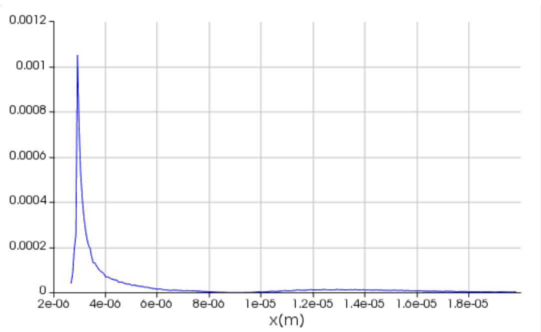


Fig 11: radius of 0.15a

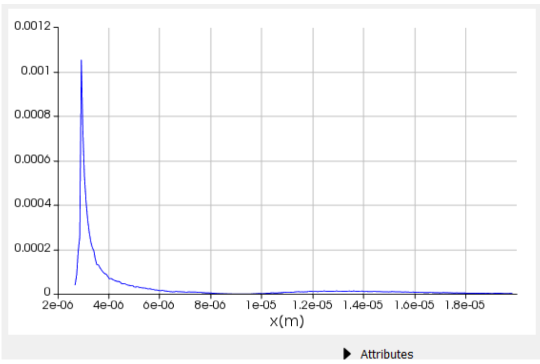


Fig 12 : radius of 0.16a

The Output power ratio against refractive index change (Δn) is visualised in[fig 13]

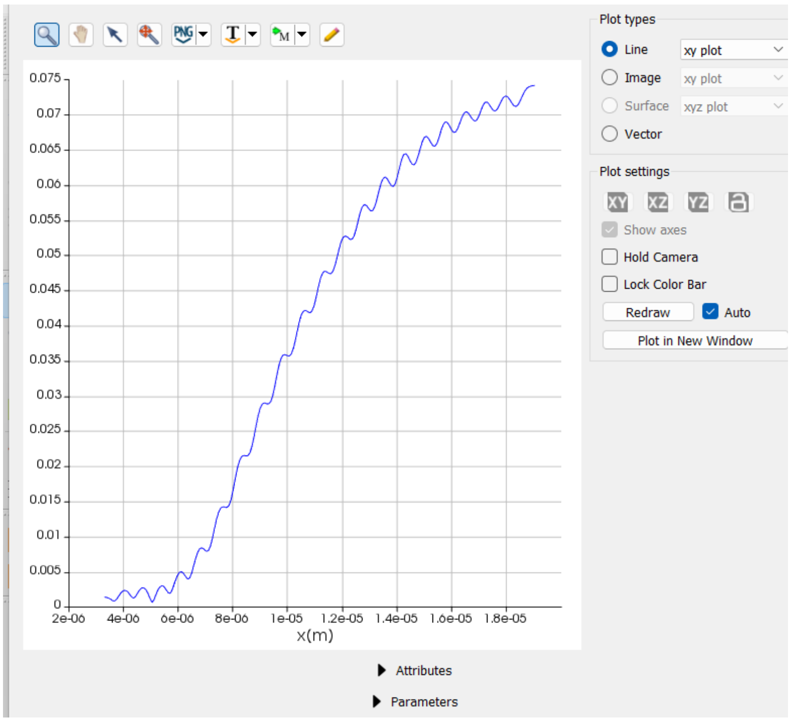


Fig 13 : Output power ratio against refractive index change Δn

From this graph we can infer that by increasing Δn, the output power ratio increases, meaning that the optical power is transferred from the output port (O1) to the output port (O2).

5.Conclusion:

The optical switch is one of the key devices in today's optical networks and processing systems.

In this project we were able to fairly able to design a directional coupler switch based on photonic crystals, and compare them on the various parameters mentioned.

The structure can guide an optical pump power in the central path to induce the required refractive index change. Linear and nonlinear states of the switch have been simulated.

We have also illustrated that the required refractive index change and therefore the needed optical pump power are modified by increasing the nonlinear material in the structure so that the effect of optical nonlinearity on the switching performance is enhanced.

6.References:

[1] S. Maktoobi and S. Bahadori-Haghighi, "Investigation and simulation of photonic crystal directional coupler switch," *Electronics Letters*, vol. 51, no. 13, pp. 1016–1018, Jul. 2015.

[2] H. Oda, A. Yamanaka, N. Ikeda, Y. Sugimoto and K. Asakawa, "All-optical swicthing by optical Kerr effect in AlGaAs photonic crystal slab waveguide," *CLEO/QELS: 2010 Laser Science to Photonic Applications*, San Jose, CA, USA, 2010, pp. 1-2, doi: 10.1364/CLEO.2010.JThE37

[3] https://refractiveindex.info/?shelf=other&book=AlAs-GaAs&page=Aspnes-0

[4] https://optics.ansys.com/hc/en-us/articles/11277217507603-Troubleshooting-diverging-simulations-in-FDTD

[5] T. Nagai and K. Hane, "A Silicon Photonic MEMS Matrix Switch Using Directional Couplers in Comparison with that Using Adiabatic Couplers," *2019 20th International Conference on Solid-State Sensors, Actuators and Microsystems & Eurosensors XXXIII (TRANSDUCERS & EUROSENSORS XXXIII)*, Berlin, Germany, 2019, pp. 1533-1536, doi: 10.1109/TRANSDUCERS.2019.8808766

[6] Chip Level Photonics- course materials