Two dimension zero index materials design

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Abstract: We design a 2D photonic crystal structure with silicon pillar arrays. We set the pillar array to the pitch of 851nm and the radius of 171.3nm. Through experiment with Lumerical, we find its zero refractive index at around 1540nm. With Maxwell'sequation and properties of photonics crystals, we tests the validity of the outcome. We find this photonics crystal to be capable of achieving zero refractive index around 1540nm. This design can applies to other wavelength and optical region as well.

1. Introduction

Photonic crystals are periodically arranged structures that are designed specifically to trap and guide light. They have similar properties to semiconductors which enable the creation of electronic devices [1]. Semiconductors have band gaps so that no electrons can be found that have an energy in a certain range. Similarly, photonic crystals have band gaps to keep protons with frequencies fallen within the band gap from flowing inside. Light waves in the band gap that enter the lattice reflects off the boundaries between materials and cancel out incoming waves [2]. Thus, this light wave won't be able to propagate. Band gaps allows some wavelength of light to pass but not others. In this way, a photonic bandgap can guide or confine light by restricting it to certain layers. This property of photonic crystal presents up with the unprecedented control over behavior of light.

The idea of photonic crystal was first brought up by Eli Yablonovitch in 1987, who received the IOP's premier annual award and the Newton Medal and Prize for his contribution in photonic, specifically photonic crystal[3]. However, since the spacing between the lattices should be around half of the wavelength, it is very difficult to fabricate photonic crystals for waves like infrared, which require a lattice spacing of about 0.5 micrometer--1/100 the thickness of a human hair. Thus, photonic crystals was limited to microwave, with longer wavelength. Until 1996, Thomas Krauss borrowed techniques from the semiconductor industry and made the first photonic crystal that works with visible light [2].

Like electrons of 2D electron gas subjected to a strong magnetic field, photonic crystals also obtain the 'edge' states that characterize the quantum Hall effect. With certain techniques, we can confine photons to the edges of a 2D photonic crystal and restrict it to unidirectional propagation .

There is a wide range with the application of photonic crystals. The 2D photonic crystals we focused in this paper can be utilized to make photonic crystal fibre, a new class of optical fibre. The traditional optic fibre utilizes the difference in refractive indices to guide light, while the photonic crystal fibre utilizes the structural properties of the materials to reduce scale and increase the efficiency [1,4].

In this paper, we aim on designing a 2D photonic crystal which achieves zero refractive propagation in metamaterials. Firstly, we use the Lumerical FDTD to create out model, presented in Figure 1. We choose the laser resource as out input. After it cross the silicon photonic crystal structure, the

pillar array in out figure, we can measure the output light for transmission and refraction. According to Dirac Cone in the band structure, we can find the specific frequency that achieve zero refractive index.

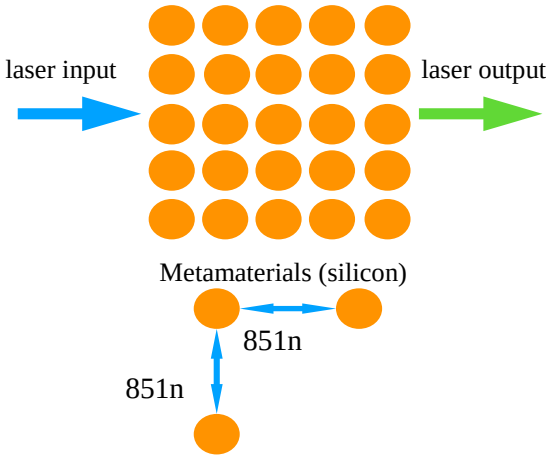


Figure 1: the blue arrow represent the laser resource input. The input light crosses the 5*5 silicon array in orange with the spacing of 851nm. The output light is represented by the green arrow. We use Lumerical FDTD to design and test zero index

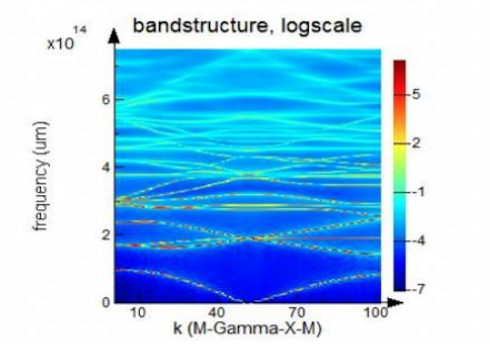
2. Design and Theory

According to the Maxwell equation,

$$\nabla^2\vec{E} - \frac{\mu\varepsilon}{c^2}\frac{\partial^2\vec{E}}{\partial t^2} = 0$$

we can figure out the two basic requirement for achieving zero index. First, the Dirac cone has to exist in the band structure. Second, the dielectric constant Ɛ and the magnetic conductivity μ have to be zero to achieve zero index.

Figure 2: This illustration shows that three optic bands for a dirac cone around the Gamma point, allowing us to find the specific frequency for zero refractive index.



Then we can adjust our parameters to find the band structure as well as the frequency of which the dielectric constant and magnetic conductivity both have the value of zero.

In Lumerical FDTD, we set the pillar array to the pitch of 851nm and the radius of 171.3nm. After the test, we get Figure 3 and find the frequency around 1450nm shows zero refractive index.

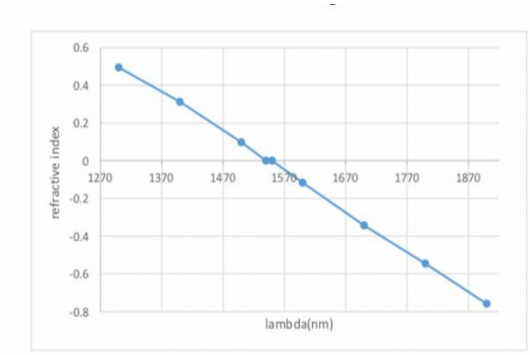


Figure 3: refractive index vs. wavelength

This chart show the change in refractive index based on change in wavelength. Zero index appears around 1540nm. The system appears positive index before that and negative after.

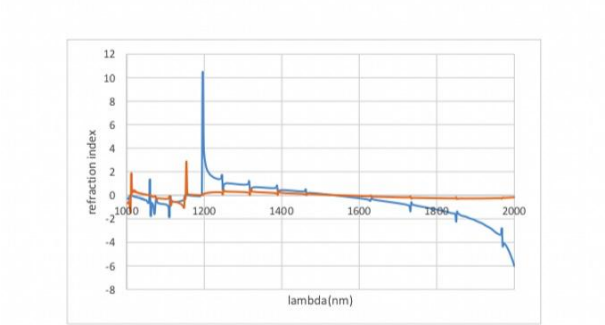


Figure 4: Permitivity and permeability

Based on Maxwell equation, the dielectric constant and wave vector have to be zero at the same frequency to find the wavelength of zero index. We can see that around 1540nm, both dielectric constant and wave vector are zero at the point of zero index.

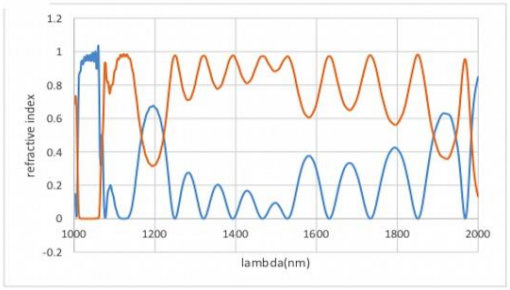


Figure 5: Transmission and Reflection

The blue line represents the transmission, and the orange line represents the reflection of the system. Around 1550nm, the sum of transmission and reflection becomes 1.

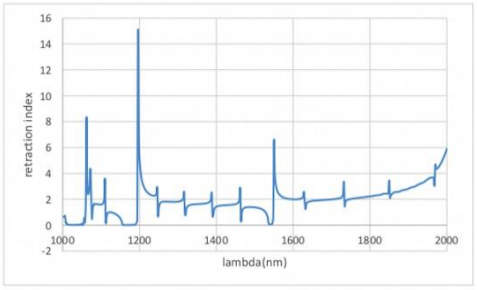


Figure 6: Impedance

We would also need to check the impedance. The impedance around 1550nm is not too high, so the light can cross the system successfully.

Conclusion

Using Lumerical, we design a photonics crystal and tests the wavelength for zero refractive index. By adjusting the pitch to 851nm and the radius to 171.3nm, we found the wavelength of zero index at around

1540nm. We then tests several other properties to ensure the validity of our photonic crystals.

Reference

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