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Wavelength Conversion Via Refractive Index Tuning of A Hexagonal Photonic Crystal Cavity

Md Abu Jubair, Shu Jing, Zhou Xing-Ping

Abstract— Photonic crystals are consisting of a periodic dielectric medium that can affect the electromagnetic wave propagation by creating allowed and forbidden electronic energy bands. Bands of wavelengths which are not allowed are called photonic band gaps. An optical cavity can trap light at resonance frequencies and thus also be called as an optical resonator. By rapidly changing the cavity's resonance wavelength, it is possible to forcefully change the wavelength of photons captured in a cavity. It is achievable that the wavelength conversion of light across the simple dynamic refractive index tuning of a PC cavity. Our main purpose in this research is to find out which is the most beneficial material for optical converter. Applications like laser converters, coherent converters and opto-electronic converters are based on optically controlled gates are being highly researching for future use. The simulation process is done by FDTD solution method. This work aims at both developing highly nonlinear optical wavelength converter and demonstrating via cavity tuning through different types of material (silicon, GaAs, Germanium) at telecommunications wavelengths. We investigate the field intensity characteristics of wavelength-converted light. We used three different ways of cavity tuning and applied on three different material (Si, GaAs and Ge) to find out which one shows more better response. According to our result there is no noticeable peak at the original wavelength. After the simulation process, tuned through the cavity it shows that 100% wavelength conversion occurs in this process. Our results indicate that this wavelength conversion process can be noticed in clear eye. The significance of this research project is that it shows us a path to choose dielectric medium for future use.

Keywords— two-dimensional photonic crystal, hexagonal cavity, refractive index tuning, wavelength conversion.

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*Shu Jing: corresponding author

First Author: [1,2] Ministerial Key Laboratory of JGMT, jubair207@yahoo.com, [1,2] Nanjing University of Science and Technology, Nanjing, 210094, China, +8615651983161
Second Author: jingshu@njust.edu.cn,
Third Author: School of Physics and National Laboratory of Solid State Microstructures, njustzhouxingping@gmail.com, Nanjing University, Nanjing 210093, China

I. Introduction

To meet up with the increasing levels of bandwidth and capacity requirements, technology forces us to the optical communications industry to produce new products that are faster, more powerful and more efficient. Especially, optical conversions in Wavelength Division Multiplexing (WDM) mechanisms prevent higher data transfer speeds and create a serious tailback for optical communications. Due to the Wavelength converters of WDMs, these changes happen and therefore, all-optical wavelength conversion methods have become enormously important. PC cavities are very promising to strongly limiting light inside cavities of wavelengths [1-3]. This strong imprisonment of light is very efficient for the improvement of nonlinear optical phenomena [4] such as two-photon absorption [5], up–down wavelength conversion [6], Raman scattering [7] and the Kerr effect [8]. For various optical engineering technologies, the wavelength conversion of light can be applied. For example, information processing in wavelength division multiplexing (WDM) communication. Semiconductor-based PC nanocavities can show inherent nonlinear coefficients so these materials have been studied intensively and can be used in other optoelectronic apparatuses [9]. Wavelength conversions, such as sum frequency generation (SFG) and second harmonic generation (SHG), in PC nanocavities, have been established experimentally by using semiconductors made of gallium silicon carbide (SiC) [10,11], phosphide (GaP) [12] and gallium arsenide (GaAs) [13]. This type of wavelength conversion has focused mostly on the use of a single nanocavity mode. Which results in a high *Q* factor and small modal volume. Using two resonant modes wavelength conversion in the PC cavity has been established recently [11], but wavelength conversions—using hexagonal PC tuned cavity has not been confirmed yet. Where higher-order polarization generates new frequency components, there we normally operate a nonlinear optical process (e.g. $y = x^2$) to convert wavelength [14]. It is necessary to use highly nonlinear crystals for this conversion and the conversion proficiency depends on light roaming distance, the input light strength, and phase-matching condition. Hence, it is usually tough to realize high efficiency for a little light in a small sample. It is discovered recently that the light wavelength properties can be improved by dynamic processes in the photonic crystal. Reed *et al* showed that a light pulse traveling in a PC, reflected by a shockwave front, exhibits a large wavelength shift and spectral compression [15]. Later, Yanik *et al* showed that light propagation can be stopped if the refractive index of a coupled-resonator waveguide-implemented in a PC is forcefully changed [16,17]. The most significant parts of their methods are that the pulse spectral width is dynamically compressed. These results indicate that by controlling the dispersion characteristics of the material or waveguide, we can dynamically control the wavelength properties of a light pulse. Even though, there has been no complete research of such wavelength controllability. In this condition, we inspect a simpler way to clarify how the dynamic process can affect the wavelength properties of light in a single cavity. In comparison with conservative wavelength conversion, we explore the physical mechanism of this phenomenon and discuss if we can execute such effects practically to discover wavelength conversion in realistic form.

II. SIMULATIONS SETUP

To find out the characteristics of this photonic crystal cavity we can assume below simulation setup in figure 1. Where we going to need some necessary components like laser source, our proposed photonic crystal with the hexagonal cavity, one spectrometer. The simulation process is done in the temperature of 300K. Photonic crystal plate is made of Si, Ge, GaAs. Wavelength of the source light is 100-400 micro meter. This 2D photonic crystal of dielectric column has lattice constant of 0.2 micron and radius of 0.07 micron.

III. RESULTS AND ANALYSIS

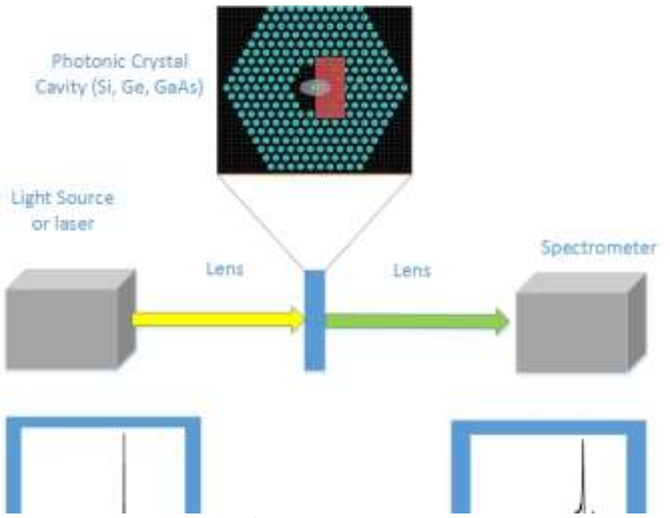

Figure 1. Schematic diagram for the optical experimental setup to find out the wavelength conversion feature of photonic crystal hexagonal cavity.

We numerically demonstrate the wavelength conversions in a two-dimensional (2D) hexagonal air hole PC cavity by imposing the nonlinear optical characteristics. Compara to those of other nonlinear semiconductors [19] the hexagonal SiC has second-order nonlinear optical coefficients [18] and is an interesting material for realizing nonlinear photonic devices without optical absorption [20]. The heterostructure PC cavity has several resonant modes, including the nanocavity mode and Fabry-Pérot (FP) modes, with considerable mode overlaps and high *Q* factors that enable multiple-channel wavelength conversions. Besides, we studied the polarization characteristics of the SFG light to classify the contributing modes and compared these with the calculated results. We study the dynamic effect using a simple 2D model with the finite-difference time domain FDTD method [20]. The model cavity is shown in Fig. 1(a), which has a resonant mode at λ_1 =255 nm for *H* polarization. *H* is perpendicular to the 2D plane. Such index tunng can be accepted in various ways. For example, recently demonstrated index tuning in a similar Si PC cavity system because of the optical nonlinear effect [22-24]. Figure 1(b) shows calculated wavelength spectra of the electromagnetic field in the cavity without index tuning. We used tuning times t = 10000 fs. We later consider the effect of the tuning rate.

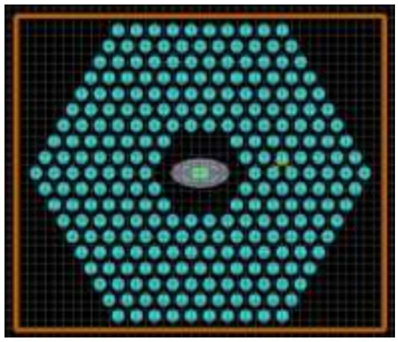

Figure 2(a)

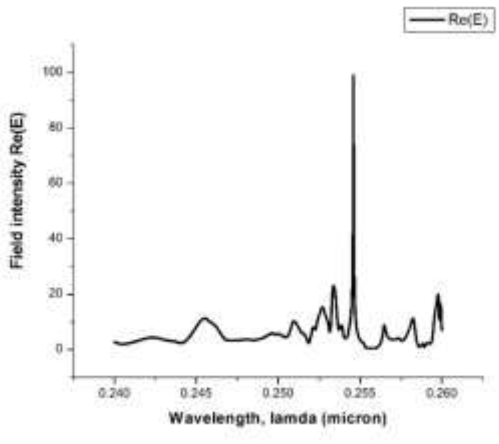

Figure 2(b)

Figure 2: Actual wavelength without tuning in a hexagonal PC cavity. (a) Schematic of the cavity in a 2D hexagonal air hole PC slab. The lattice constant *a*=200 nm, the hole radius *r*=0.70 nm, the index of the center black region is 1(without tuned). (b) Wavelength spectra without the index tuning calculated by 2D FDTD. Which has a resonant mode at λ_1 =255 nm for *H* polarization.

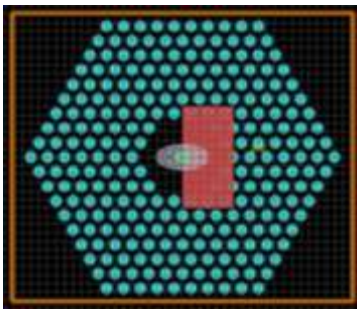

Figure 3(a)

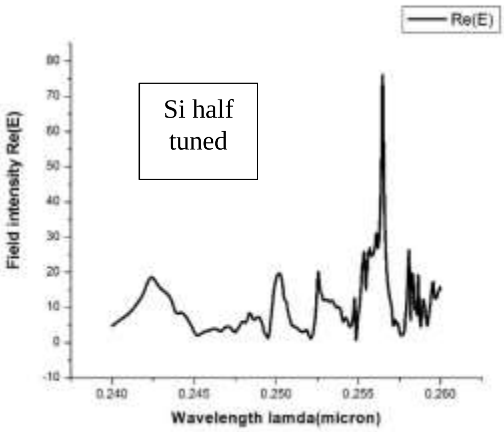

Figure 3(b)

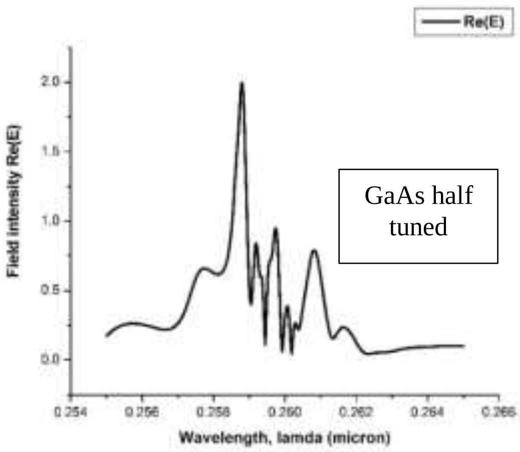

Figure 3(c)

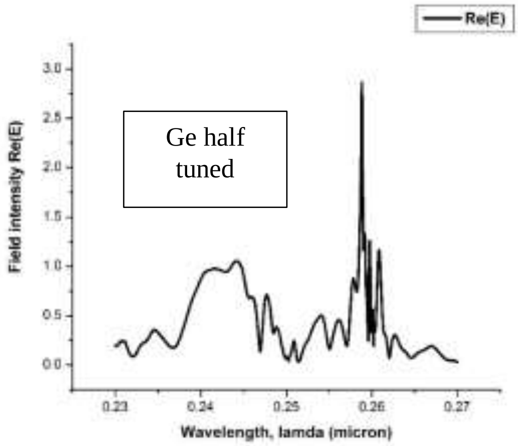

Figure 2(d)

Figure 3: 3(a)Wavelength conversion in a half tuned (red area) hexagonal PC cavity. The lattice constant and radius are same. Schematic of the cavity in a 2D hexagonal air hole PC slab. Wavelength spectra with the index tuning are show in graph. 3(b) The refractive index of the center red region is 3.4 for silicon. Which has a resonant mode at 256 nm for *H* polarization. 3(c) The refractive index of the tuned medium is 3.9 for GaAs. Which has a resonant mode at 259 nm for *H* polarization. But the resonant amplitude is not so high and effective. 3(d) The refractive index of the tuned medium is 4 for Germanium. Which has resonant mode at 260 nm for *H* polarization. But the resonant amplitude is very low.

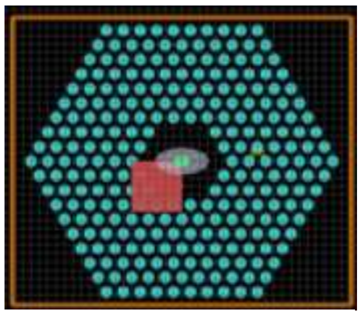

Figure 4(a)

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Figure 4: 4(a)Wavelength conversion in a quarterly tuned (red area) hexagonal PC cavity. The lattice constant and radius are same. Schematic of the cavity in a 2D hexagonal air hole PC slab. Wavelength spectra with the index tuning are show in graph. 4(b) The refractive index of the center red region is 3.4 for silicon. Which has a resonant mode at 259 nm for *H* polarization. 4(c) The refractive index of the tuned medium is 3.9 for GaAs. Which has few resonant mode but the highest one at 101 nm for *H* polarization. But the resonant amplitude is fair enough. 4(d) The refractive index of the tuned medium is 4 for Germanium. Which has few resonant mode at 101 nm for *H* polarization. But the resonant amplitude is slightly low.

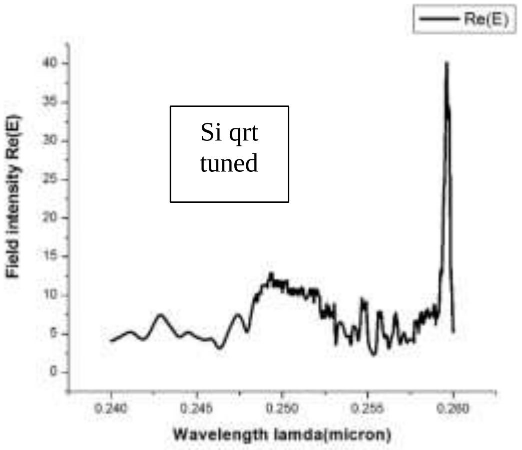

Figure 4(b)

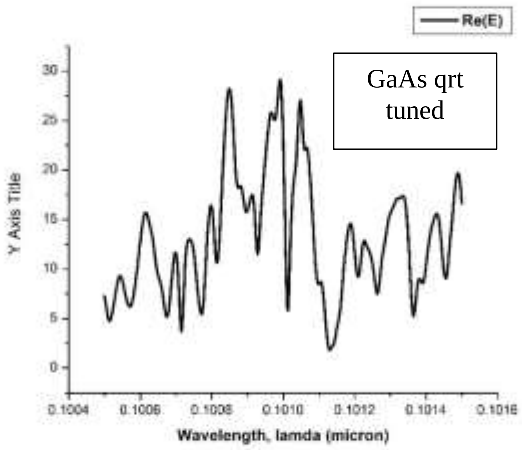

Figure 4(c)

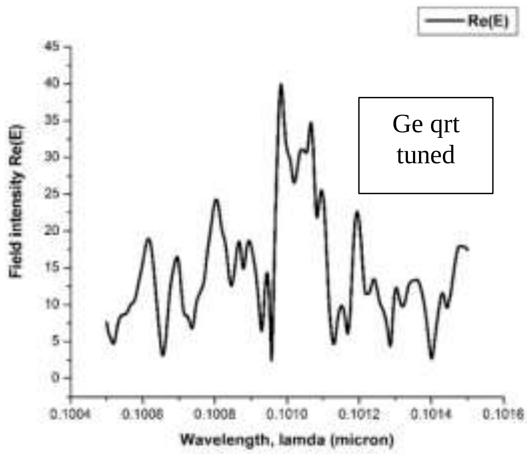

Figure 4(d)

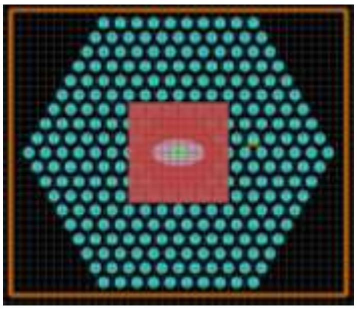

Figure 5(a)

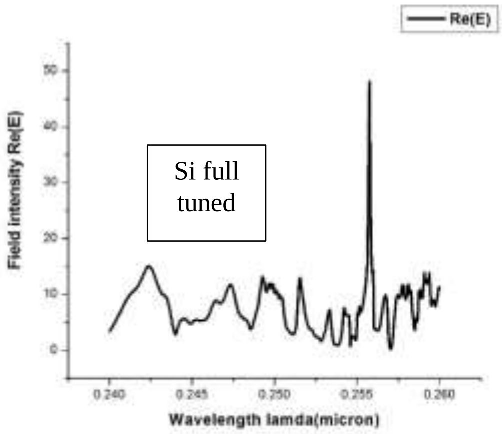

Figure 5(b)

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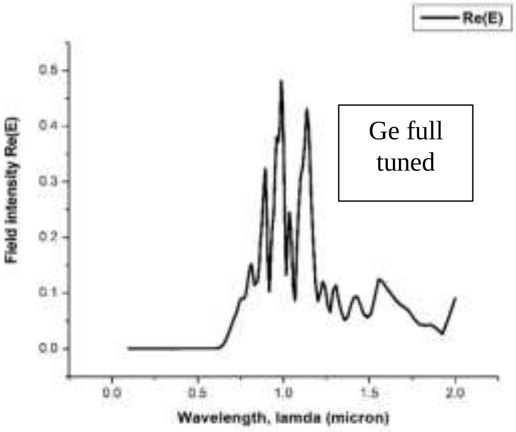

Figure 5(c)

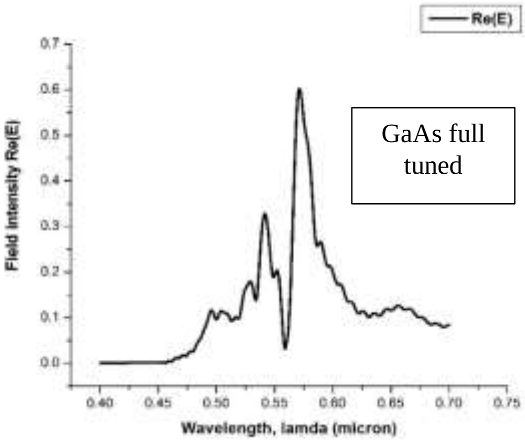

Figure 5(d)

Figure 5: 5(a)Wavelength conversion in a fully tuned (red area) hexagonal PC cavity. The lattice constant and radius are same. Schematic of the cavity in a 2D hexagonal air hole PC slab. Wavelength spectra with the index tuning are show in graph. 5(b) The refractive index of the center red region is 3.4 for silicon. Which has a resonant mode at 256 nm for *H* polarization. 5(c) The refractive index of the tuned medium is 3.9 for GaAs. Which has few resonant mode but the highest one at 557 nm for *H* polarization. But the resonant amplitude is so low. 5(d) The refractive index of the tuned medium is 4 for Germanium. Which has few resonant mode at 1000 nm for *H* polarization. But the resonant amplitude is very low.

Note that there is no noticeable peak at the original wavelength in Figure 2(b), after the tuning all the field intensity peak are changed, which means that 100% wavelength conversion occurs in this process. We have used three different types of tuning of the cavity and applied three different material (Si, GaAs, and Ge) to find out which one shows the more better result. In our investigation among these tuning, wavelength of silicon shows more suitable result. So, in this perspective, for these materials half tuning has shown better performance than the fully or quarterly tuning.

IV. Conclusion

The results agreed well with calculation, indicating that these results may further stimulate the development of light sources with short wavelengths as well as the conversion of light or wavelength for information processing and communication. No one has expressively discussed the use of this tuning of wavelength or light with the hexagonal PC cavity for wavelength conversion as far as our knowledge. We believe that the wavelength conversion investigated here will be a significant role optical process phenomena. This wavelength conversion process can be noticed in clear eye. The significance of this research project is that it shows us a path to choose dielectric medium and also to choose which ways of tuning should be taken care of for the future work.

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