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Design and Computation of Ring Resonator using FDTD Modeling

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Abstract:
In this paper, Ring resonator with Nano-photonic Crystal is designed and computational study is made for different structures. The main work is to remove holes of the rectangular lattice and hexagonal lattice from a three-dimensional (3-D) silicon slab. Each crystal in the silicon slab are of nanometer size. The various parameters like material and refractive indices are deployed for these crystal structures. Parameters like Ring radius and the Coupling Distance is varied and the performance of the nano-ring resonator using FDTD modeling tool is investigated.

Index Terms: **FDTD, photonic crystal (3D), ring resonator.**

I. INTRODUCTION

Nanophotonics describes the study of the behavior of light at sub-wavelength scales. It encompasses a wide range of materials and technologies which have applications in a number of sectors. For example, plasmonics is a promising technology which may be used to enable the interconnection of optical and electronic components. However, it also has applications in fields like photovoltaic's and sensing[1].

Waveguides are typically structures in which a material with a high index of refraction is surrounded by a low index cladding material. The structure is therefore able to guide photons along its length. it has not been possible to create a three dimensional photonic crystal that reflects visible light. Michael Bartl at the University of Utah has attempted to solve this by analyzing the structure of the scales of a Brazilian beetle, which exhibits these desired optical properties. A number of groups (e.g. Technical University of Denmark, IMEC) are using electron beam lithography and deep UV lithography and to fabricate nanophotonics structures from silicon. Nanoimprint lithography has also demonstrated some utility in this area [2].

Optical ring resonators consist of a waveguide in a closed loop coupled to one or more input/output (or bus) waveguides. When light of the appropriate wavelength is coupled to the loop by the input waveguide, it builds up in intensity over multiple round-trips due to constructive interference. It can then be picked up by a detector waveguide. Since only some wavelengths resonate within the loop, it functions as a filter.

Photonic crystals (PCs) [3], as we call them now, are periodic dielectric, or metallic structures, which possess a variety of band dispersions, and band gaps, where the propagation is prohibited for certain ranges of wavelengths. Using different materials (i.e., different dielectric constants) and by adjusting geometrical parameters, the propagation of light can be modified virtually in any way in a controllable manner.

The FDTD algorithm is useful for design and investigation in a wide variety of applications involving the propagation of electromagnetic radiation through complicated media. It is especially useful for describing radiation incident upon or propagating through structures with strong scattering or diffractive properties. The Finite Difference Time Domain (FDTD) method has become the state-of-the-art method for solving Maxwell's equations in complex geometries.

FDTD Solutions can solve the two and three dimensional Maxwell's equations in dispersive media and some simple non-linear media, where the user can specify arbitrary geometric structures and various input excitation sources. The two dimensional FDTD simulator solves the TE and/or TM Maxwell equations.

The Ring resonator is designed using a hexagonal and rectangular lattices structures where each crystal is of nano meter scale. The working of this crystal structures are investigated for different ring radius of the crystal and different coupling distance between the ring structure and the waveguide.

II. RELATED WORK

De Vos *et al.* have reported detection of protein concentration down to 10 ng/ml based on a micro-ring resonator of 10nm size, while the concept of packaging this micro-ring resonator inside a micro fluidic channel has been revealed as well [4]. The circular resonant mode of ring wave-guide is excited by incoming light from bus waveguide, and the light of resonant wavelength will be coupled into drop wave-guide eventually. Thus, output spectrum of drop port reveals a resonant peak. The refractive index change of ambient fluidics or biomolecules bound on the surface of ring waveguide leads to the variation of resonant condition hence it shifts the resonant wavelength. In order to enlarge the free space range and enhance the quality factor of micro-ring resonator, the reduction of ring radius is required. However, it results in obvious increment of bending loss of conventional dielectric micro-ring waveguide.

Photonic crystals (PCs) is an even more attractive sensing platform, because two-dimensional (2-D) silicon based Photonic Crystal(PCs) comprise a group of holes in a silicon slab to form a periodic dielectric structure which is compliant with photonic band gap (PBG). The propagation of light within PBG frequency range is forbidden in PCs structure [5], [6]. The light within the PBG frequency range is enabled to be guided or localized by introducing certain defects in the PCs structure. Therefore the local electromagnetic field is modified by surface state of holes, e.g., the various concentration of solution on top of PCs sensors. S. C. Buswell *et al.* demonstrated specific detection of proteins by sensing the cut-off wavelength of waveguide transmission mode based on 2-D PCs waveguides. Using immobilized biotin as probe, 2.5-nm-thick streptavidin film captured by biotin on the whole PC waveguide surface results in a 0.86 nm cutoff red-shift [7]. In contrast to the cutoff wavelength detection, measurement of resonant wavelength shift is a preferred sensing approach because the resonant peak of high quality factor enables high detection resolution.

With the aid of defects, micro cavity or nanocavity based PCs resonators are demonstrated as PC sensors of high sensitivity in terms of resonant wavelength detection. First of all, PC resonator sensors are integrated in micro beams and micro can-tilevers for force and mechanical strain detection [8]–[10].

III. RESONATOR CONFIGURATION AND OPTIMIZATION

In the proposed resonator configuration, the high index crystals are 45nm wide with a Refractive index of 1.4. The ring has an outer radius of 2300nm and is roughly with 200nm waveguide. FDTD Solutions contains a mode source with an integrated mode solver. When light of appropriate frequency 193.1 THz is coupled into the loop by the input waveguide, it builds up its intensity over multiple round-trips due to constructive interference. The dielectric for the crystal used is Germanium(Ge) initially and different dielectrics can also be used for fabrication. Height of the crystal is 100nm and the lattice constant between the crystal structure is 130nm.

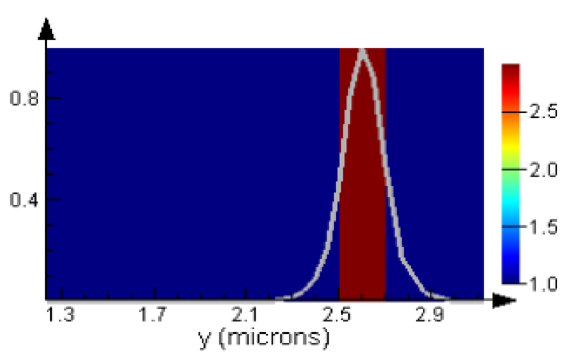

Fig.1.Mode source for ring resonator

The number of modes are selected 8, the polarization is in Transverse Magnetic(TM) and the material of index 2.9 this would take approximately simulation time of,

t = d / (c/n) = 199µm / (3e8/2.9) m/s = 1920fs.

The crystals located at the coupling points can also made out of other dielectric materials in order to bring maximum coupling, which is under investigation. A temporal light pulse is launched into the bus waveguide. t the drop port or output port. The output spectrum is obtained by applying the Fast-Fourier Transform (FFT) to the temporal signal recorded by the time monitor.

In our design, the FDTD based nano-ring resonator is formed by integrating terminal waveguides and a hexagonal ring waveguide, i.e., a hexagon trace of ring resonator design, as shown in Fig.2.

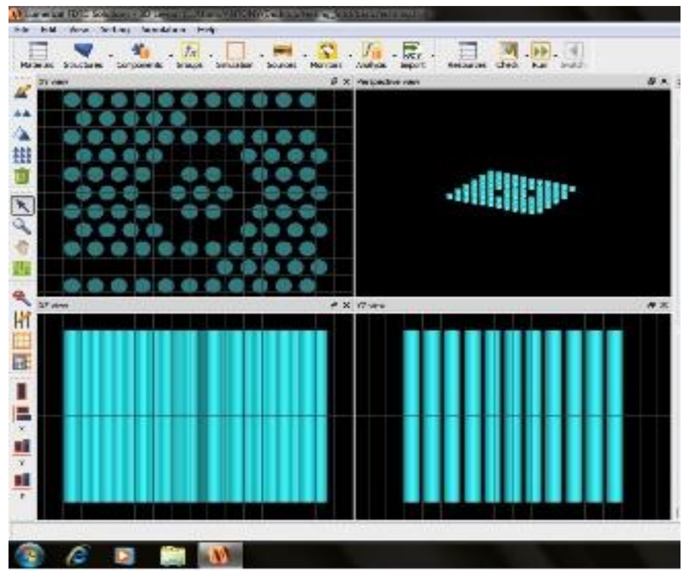

Fig.2.Resonator Design in FDTD.

Scripting is used to remove the crystals at specific points, and also to create crystals at some other points. FDTD based scripting language was used for the removal and creation of crystals, were the parameters mainly used are the lattice constant between the crystals, Each crystal radius, Height of the crystal and the dielectric material.

When the mode source is applied in one end of the Hexagonal lattice photonic crystal array. The modes generated from the mode source traverse through the waveguide, then passes through the coupling crystals Coupling distance is an important factor which act as a bridge between waveguide and the ring. After interference of the signal again the signal traverse through the upper coupling crystals, and again along the upper waveguide. The movement of the signal when the ring radius is kept high and the coupling distance is doubled is shown in Fig.3.

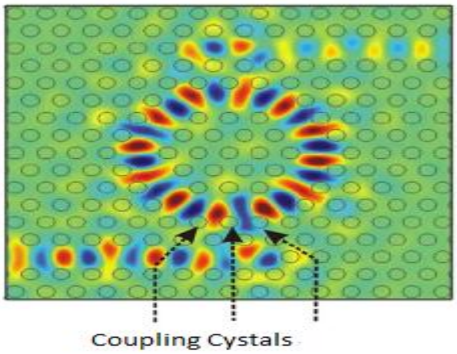

Fig.3. Signal Transmission.

A series of simulations are performed to determine by how much the inner radius of the ring would have to be tuned to result in radiation at 193.1 THz (the center of the telecommunications c-band) to be dropped, rather than transmitted. The coupling distance is kept as small as possible in order to match the waveguide and the inner ring.

IV. RESULTS AND DISCUSSION

The plot for Frequency vs x-transmission is shown in Fig.4, which shows the power transmission the through channel. Notice that the loop is tuned to have high transmission into the through channel at 193.1 THz. Small ripples appears at the maximum transmission values. These ripples would disappear if the simulation time is increased.

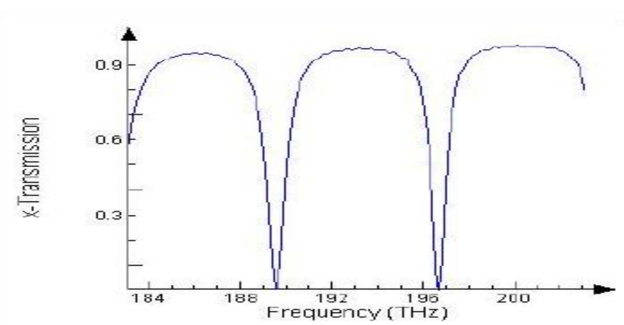

Fig.4.

The plot for Time vs Electric Field is shown in Fig.5, where there are 13 distinct peaks. As the time increases the field Ez size gets reduced.

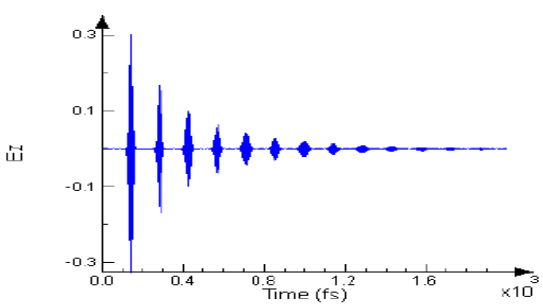

Fig.5.

V. CONCLUSION

In summary, we demonstrated the feasibility of a FDTD-based nano-ring resonator for data transmission. The nano-photonic crystal based ring resonator comprises of hexagonal waveguide also with two terminal waveguides in a 3-D silicon substrate of lattice. The proposed nano-ring resonator combines advantages of ring resonator and 3-D photonic crystal such that it reveals high quality factor, small footprint and very high sensitivity. The geometric configuration of nano-ring resonator was optimized. The results show that the higher coupling distance enhances the quality factor and drop efficiency. We also investigated the sensitivity for the nano-ring resonators for Different coupling distances and inner ring radius. 3D simulations requires much more CPU-time and memory intensive than 2D simulations.

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