On-Chip Grating Based Multi-wavelength Optical Reflector for Multichannel Optoelectronic devices

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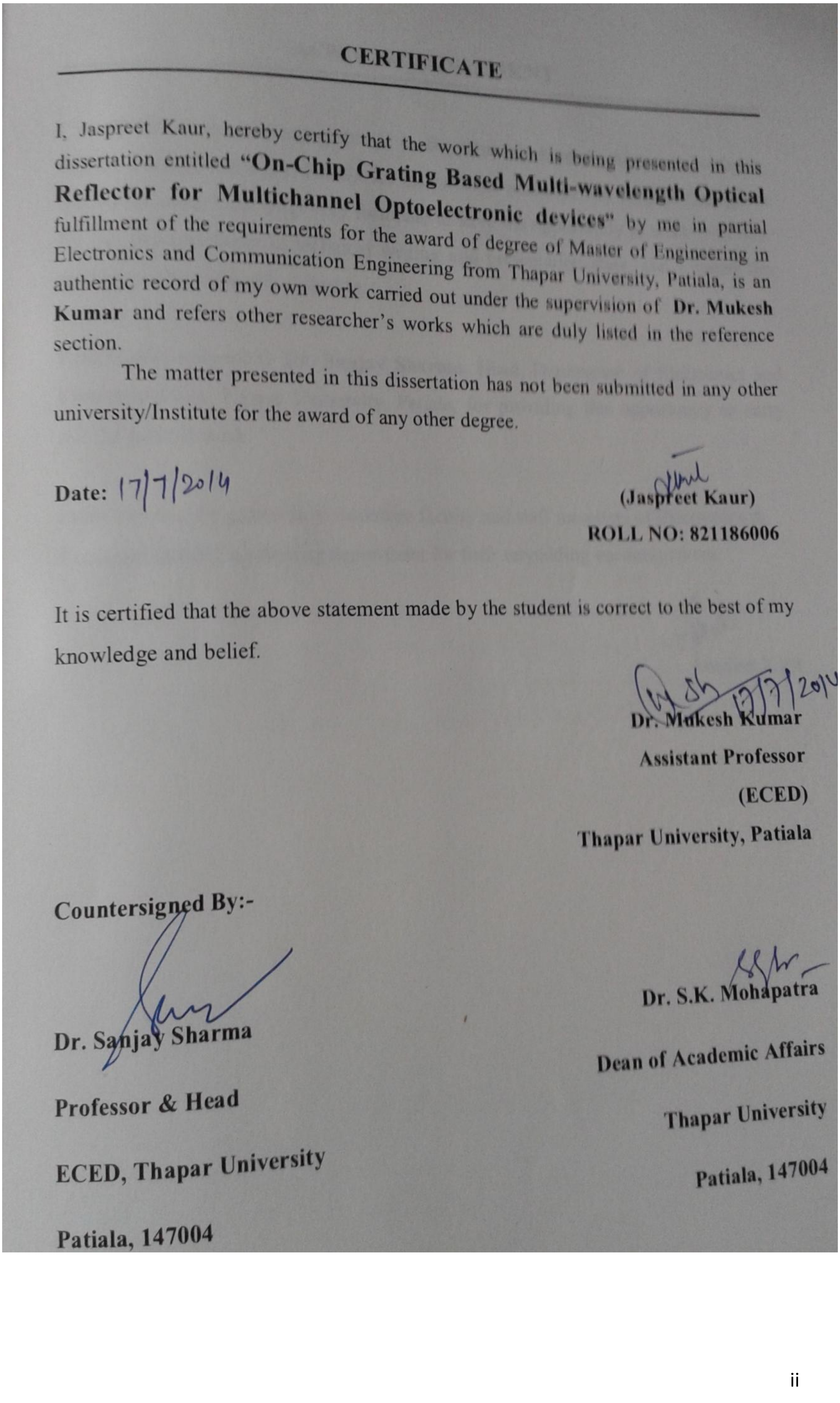

CERTIFICATE

I, Jaspreet Kaur, hereby certify that the work which is being presented in this dissertation entitled **"On-Chip Grating Based Multi-wavelength Optical Reflector for Multichannel Optoelectronic devices"** by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Mukesh Kumar** and refers other researcher's works which are duly listed in the reference section.

The matter presented in this dissertation has not been submitted in any other university/Institute for the award of any other degree.

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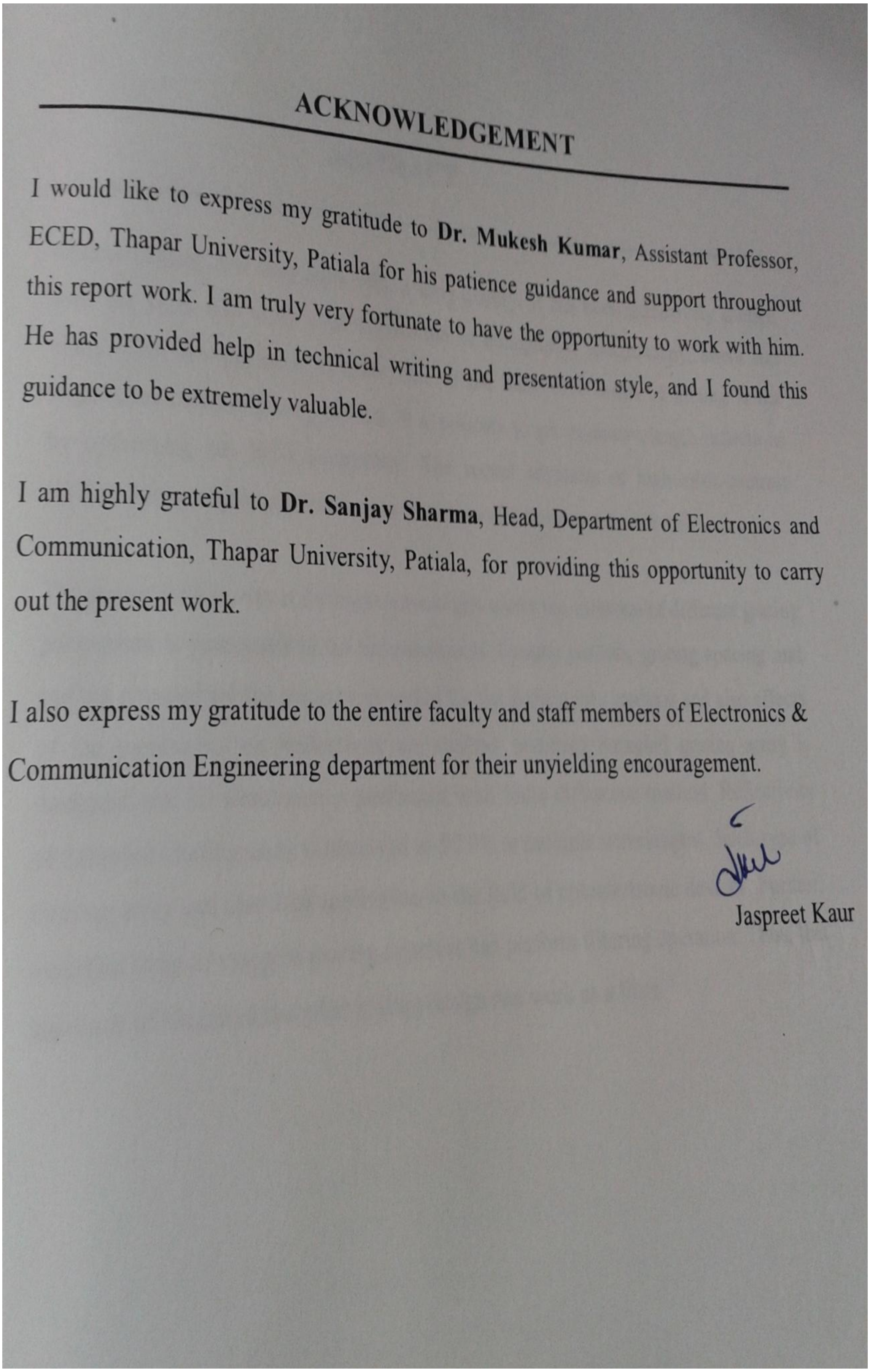

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ABSTRACT

Optical Grating is a long topic with a long history. It has been extensively studied over the years due to its wide application in holography, spectroscopy, lasers and many other optoelectronic devices.One of theinnovative forms of grating is the High-index contrast grating (HCG). It is possible to get multiwavelength reflections by optimizing the HCG parameters. The recent advances of high-index-contrast (HCG) grating and its applications in optoelectronic devices are reviewed.

The power Reflectivity at different wavelength under the variation of different grating parameters is demonstrated on the simulation. Grating periods, grating spacing and grating removal are the parameters varied for the Reflectivity analysis and also effects of the parameters on Reflectivity are studied. Standard Sampled grating array is designed and 2D simulation is performed with finite difference method. Reflectivity of Sampled Grating array is observed as 100% at multiple wavelengths. Such type of Grating array can also find application in the field of optoelectronic devices. Further, modified form of sampled grating structure can perform filtering operation. Thus, this approach of Modified Sampled grating design can work as a filter.

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CHAPTER 1

Introduction to Photonic Crystals

1.1 Motivation

In the lastsome decades, wonderful changes have been brought to our the social order and the life with the newprogression of semiconductor technology. The free market has invested hugeamount of money into high technology companiesthat employ the advances in integrated optical systems. The large resistance and consequently long delay time correlated with the small feature size, and the synchronization problems become increasingly serious concern for electronic devices that emerging due to the transmission of high speed of data [1].

Competition in today's telecommunications market in delivering low cost, highly reliable, and high class telephone, video serviceand internet to the office and home is a driving factor in photonic component and PLCs (planer light wave circuits) development.Thephotonic devices having much higher bandwidththan that can be provide by conventional electronic devices. Theenergy density of electronic devices can be much lesser than the energy density of light. Lasers are the standardcitation. High losses are exhibit by electrons in solids as they arefrequently scattered by phonons and impurities at room temperature.By changing the energy of the electrons, it is not possible to shape coherent electronicdevices due to the far getting effect of scattering which changes de Broglie wavelength. Insituation of photonic devices, the losses of power can be scale down to minimumby proper choices of medium. Whereas, for mostof mediumthe light, loses a small portionof its powerwhile traveling, but the inflexible scattering of light is negligibly small. That is the objective behind the maintenance of the coherence of lightthroughout its propagation. The cohesiveness of light is significant to its role inthe information age.

There are many examples all over history of man manipulating and usingthe observable properties of optics. It is accepted that Euclid, in 300 B.C., knew of the Law of Reflection, and Plato, in 50 A.D, accepted the bending of light in water[2] and By the end of the thirteenth century, Bacan(1215-1294) began inventing lenses for the use of correcting vision [2].

However, in the late 1800's, discoveries in a short periodof time created a huge leap forward in acceptingmade by a few people. Planck, in 1899, published histheory of quantization of light, which directly affected the development of Einstein's photoelectric effect in 1905. At the same time as Lord Rayleigh began studying wavepropagation in a periodic media [3], later succeeding to more straight studies ofa one-dimensional PBG, in which he showed devices that produced such effects [3].Later in 1904, he discovered Rayleigh scattering phenomenon. In1922, the study of Bohr's model of the atom gives the understanding of the nature of photons on the atomic scale. Bloch, in 1928 studied wavepropagation in a 3-D periodic material proving, by adding up Maxwell'sequations and Schrodinger's equations that waves can propagatewithout scatteringin such media[3].In 1979, derived the vector-spherical-wave expansion method, allowing the Calculations of dispersion and transmittance for arrays of dielectric spheres [4]. But,the most directly related advancement was made in 1987, when two independentResearchers, Sajeev John and Eli Yablonovitch, submittedproposals within months of each other on the probability and possibility of PBG's [4].Since then, three-dimensional structures have been predicted [5] and fabricated byJohn and Yablonovitch in 1987.

And the phenomenon (photonic band gap and photonic crystal) were adopted, and they arecredited with being the fathers of this field.

Encouragement for using optical communication includes:

1. Large information can be carried on a given link, because of wider bandwidth of Optical communication than copper or microwave links.

2. In glass fibers, the attenuation is less than in copper or microwave systems. Rarerrepeaters are required for longer distances.

3. Optical systems are lighter, smaller and giving them an improvement in crowded ducts oraircraft.

4. Optical waveguides are tough to tap or monitor, so data security ishigher.

5. Optical waveguides are immune from electromagnetic interference, inducedcross talk, etc.

6. Finally, and perhaps most important, semiconductor technology has settled a family oflasers, detectors, and other integrated optical devices that are compatible with optical fibers inpower, wavelength, and size.

1.2. Fundamentals of Photonic Crystals

A PhC is a medium whose index value shows a periodical inflection with a lattice constant on the order of the operating wavelength. Inside the larger family of periodic photonicstructures lies in the high contrast of the periodic inflection (generally greater than that 200%); this specific featureis central for the control of the spatial-temporal trajectory of photons and theirperiodic oscillation durationat the scale of their wavelength [6].

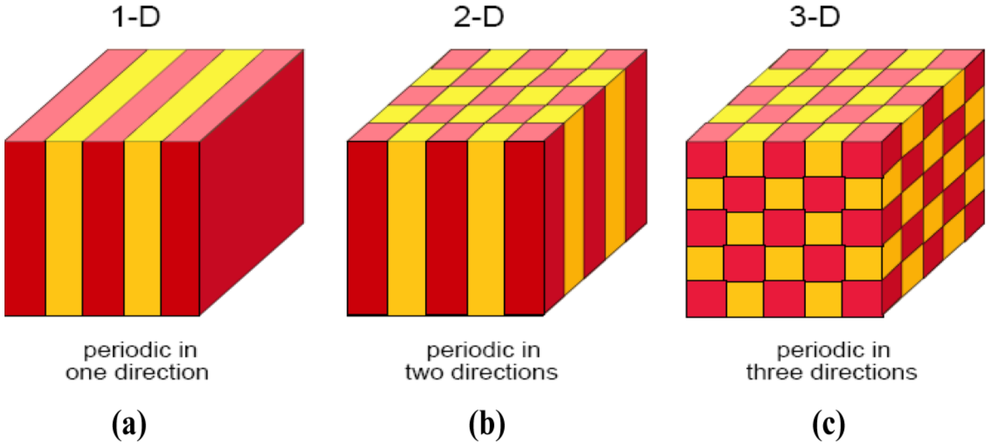

Fig. 1.1: Schematic view of PhC with different dimensions ranging from (a)1D (b)2D (c)3D.[11]

A PhC is a periodic structure of different dielectrics that creates a PBG. Andcrystal-like material that has a periodic arrangement of atoms or molecules [4]. One-dimensional photonic crystals (1DPC) have been around for quite a long time in the very fertile field of thin film optics; however, the periodic structuration has been restricted to only one direction in space, and their ‘lateral’ dimension cannot be made very compact.However, in the optical domain fabrication technology of 3DPC is very difficult. The examples of mass production of such structures can be found in nature, owing to miracles (or to the 500 million years of research) of the natural morphogenesis. In between, 2DPC are far more accessible than 3DPC, since they may be fabricated using planar technological schemes which are familiar to the world of integrated optics and micro-electronics. They provide, in addition, a considerable amount of new degrees of freedom with respect to 1D structure. [6].

The geometric assignment of these periodic arrangements is essential to the design ofPhC’s – photonic because they scatter light, crystals because they are of a periodic Arrangement [7]. Thus, the fundamental principles of a Photonic Band Gap are the similar as that of the energy band gap of a semiconductor and related qualities exist between the two. The energy band gap of a semiconductor restricts the survival of electrons of the energy band gap states to exist in the material. A three-dimensional PhC, with a PBG, has the same characteristics as that of the energy band gap of a semiconductor. PhC's prevent the propagation of certain frequencies (frequencies on the order of the periodic arrangement); thus, if such a frequency is incident upon the PhC, it will be reflected. The full three-dimensional PBG is a PBG in the crystal and restricts the ability of any photon of that wavelength, propagating at any angle, to exist in the material. A one-dimensional or two- dimensional PhC that contains a PBG does not have a complete PBG based on the previous definition; depending on the angle of incidence, a different periodic structure will be realized and there will be a momentum vector in the reciprocal lattice space (Brillouin zone or k-space) in which the frequency can exist within the crystal.Understanding the details of a PBG requires solving Maxwell's equations within a periodic dielectric material. Maxwell's equations govern the propagation of light [4].

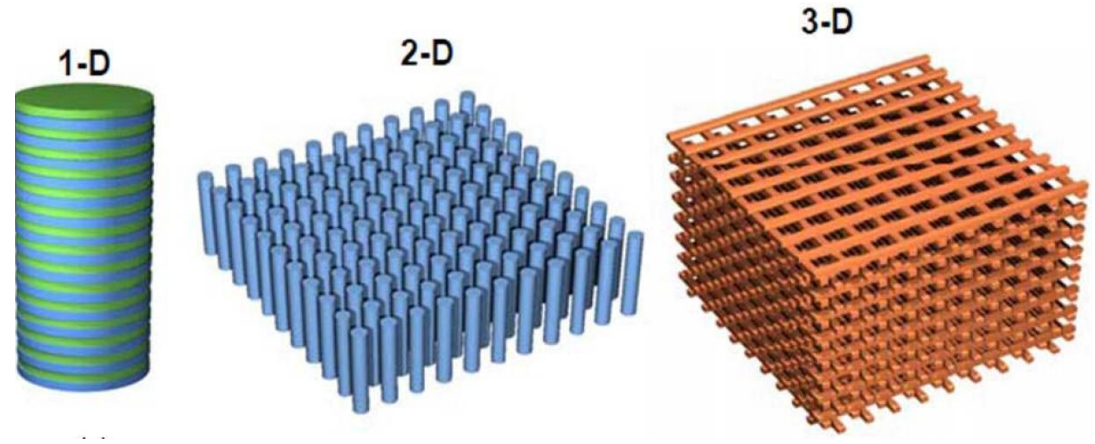

Fig. 1.2: Schematic illustrations of photonic crystals (a) 1D (b) 2D and (c) 3D.[11]

In future, the completeposition of light guiding has been change by the usage of photonic bandgap materials which has potential of doing the same. Inconventionalwaveguides,the light can guided by the total internal reflection which is worked at optical range and occurs at the boundary of the waveguide. Whereas,at microwave range the Operation of waveguide has somewhat different scenario like if the metallic waveguides are used. Thus it shows that there are no constraints on the reflection angle but reflections internally can be restricted when we consider thepropagation of microwave in suchmetallic waveguides.For waveguiding the dielectric waveguidesare theperfect choice becausemetallic waveguides resulting in tremendous lossesat optical frequencies.Withrespectto the surfaces of waveguidethe reflectionsareconfining to small incident angles only.A new “convolution” on light guiding has been placed with the growth of photonic crystals. When the frequency of the light falls in the bandgap of the photonic crystal or photonic bandgap, light does notable to propagate inside the crystal. For any incident angle such lightwill be reflected totallywhenever light is incident onto the surface of thecrystal. Acountless deal of flexibility for lightguiding is provided by it. The guiding of light via a sharpbend is the well suitable example, which gives very large efficiency[9]. Many of the groups conduct the investigational studies and calculate efficiency numerically for several photonic waveguides [8, 10]. Hence, analyticaleducationslaglater.

1.3 Applications of Photonic Crystals

The belief of photonic crystal is actuallyattractive, but quite difficult in implementation point of view. A thumb ruleis that generally the photonic crystallattice constant is a constant distance between centre of two close neighboring air-holes is about one half to one third of the operating wavelength.Even if the operating wavelength is selected at the infrared range, of about 1.55μm, this means a lattice constant of about 0.7 to 1.3μm. And the rest of parameters should also be smaller indimensions inside the cell.

However, for theendless study in the severalareasphotonic crystals have such abilities to become a soliddynamic force.The one of the mostencouragingapplication in photonic crystals is high quality factor Qcavity [1]. Mainly generation of laser desire this type of high$Q$cavity. Essential improvement of spontaneous emissionhappens which is resulting from spatial volumes which are small in size and high Q quality factor. Themajor improvement available is practically$Q$when the smallest volume Ωhave an order of theλ^3.In order to achieve such largest improvement factors, it is essential to fabricate cavities with spatial dimensionswhich areanalogous to the wavelength of light. Though the fabrication of cavities necessitateslithographic techniques but for the realization of such microcavities, single defect photonic crystals are one of themodesttechnique. But the surface disorder will not be able to effect upon the quality of the microcavities, which will surely be existing due to the small feature dimensions. This insensitiveness of surface disorder on the quality of microcavity gives the confidence to fabricate it for practical use.

Another importantapplication of the photonic crystal is the channel drop filters. This is basically an important component of wavelength division multiplexing devices.Because of the outstandingadvancement of Internet, the abilities of telecommunication channelspresently in use are readily being reached to its limits.Theuncertainadvancement may leadthese new fibers to go extinctwithin two or three years.The wavelength division multiplexing scheme acquire more attractivenessfor multiplication of the communication capacity of presently installed fibers in order to improve the handling of the presentlyinstalled optical fibers. For information to be transmitted completely, oneway is to simply break, and then convert it into some codes, placed those codes into optical channels of different wavelength and then conversion of information take place. However, this wavelength says1.55 μm ofinfrared range lying in the attenuation windows ofthe fibers. To limit crosstalk and interference between dissimilar channels it needsmaintaininga minimum separation between channels, for these reason available wavelengthsis closelylimited. With wavelength division multiplexing technologythe bandwidth of every separate channel mustnot be less than 0.5 nmand the distance among two channels is about1.6 nm. In order to attainthese compelling requirements, the practical experiments are face by optical device designing.

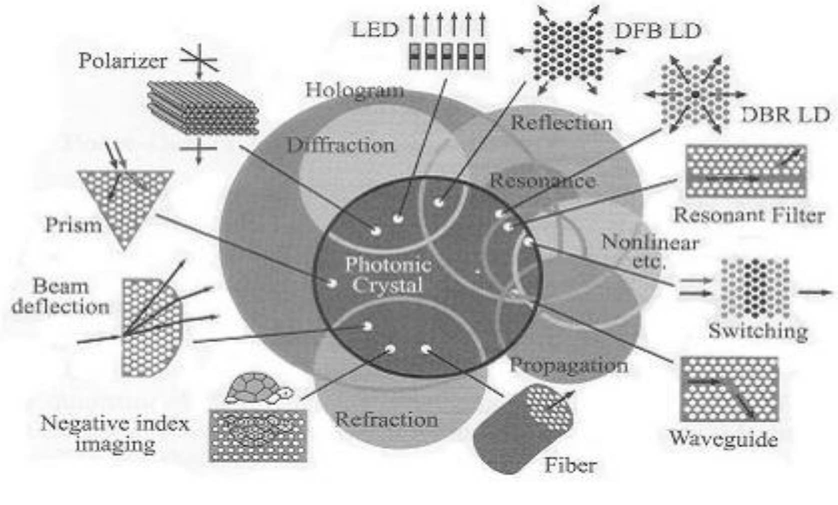

Fig. 1.3: Applications of Photonic Crystals[11].

The applications of PC utilize the phenomenon of PBG that opens the new road to design optical components in micrometer (μm) range. Waveguides that confine light via PBG's are a new progress. Generally, the waveguide is projected to transportation of waves of a particular frequency from one place to another place through a curved path. Using this waveguide various optical components are stated in the literature such as power splitter/power divider [12] which divides the power in an input waveguide equally between output waveguides, Y splitter [13], and directional couplers [14] and so on.

Now days it is require havingultra-narrow pass band width,low insertion losses and flat-top transfer function for high-pitchededges. It was first suggested by Fan *et. al.* [15]thatthe bandgap in photonic materialdeliver a recentresolution to wavelength division multiplexing filters. A resonator is used which deliver side coupling between the two waveguides. Micro cavitiesthat constructed by introducingflaws inside the photonic crystalswhichformresonator system. When any signal having pre-defined frequency join up with the resonatorsystem is entirely transferred from one waveguide to theanother waveguide the optimized channel get attain bykeeping rest of other signalsunaltered.

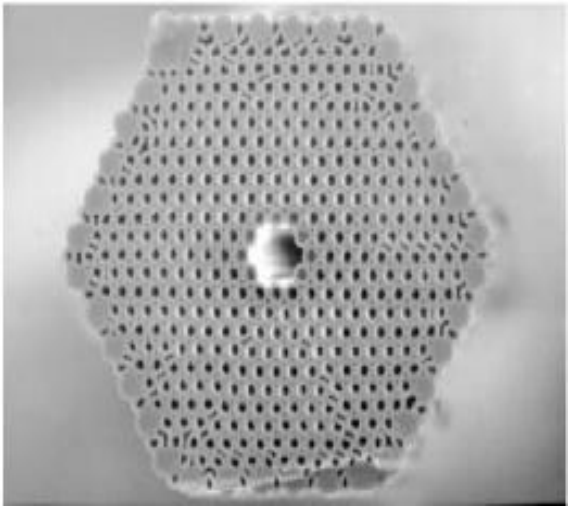

Figure 1.4: Schematic view ofphotonic crystal fiber [16].

For both old-style and experienced research the high dimensional photonic crystals are always of great interestand the two dimensional ones are being generally have commercial applications. Photonic crystal fiber and waveguides are the most common commercially available products that involve two dimensional periodic photonic crystals both are using a micro-scale arrangement to confine light with totally different characteristics compared to conventional optical fiber and waveguides.Photonic crystals are always attraction for manipulation and regulating the flow of electromagnetic wavesamong all optical materials.

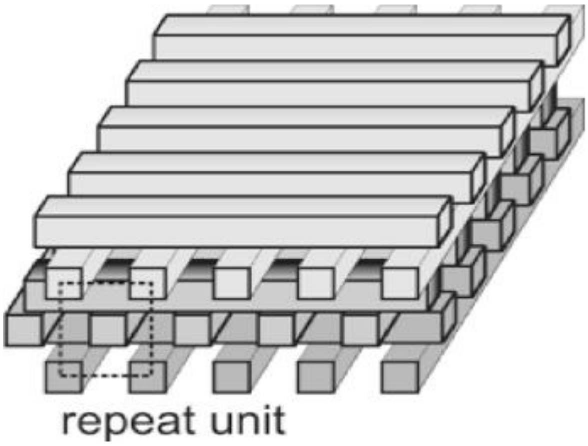

Figure 1.5: A woodpile structure in three dimensional photonic crystals [17].

The three-dimensional photonic crystals are still problematic to implement and away from the business point of view, but stillsuggestsignificant features like optical nonlinearity which is required for the operation of optical transistors and used now days in optical computers.

Marvelous applications of photonic crystal will originate out as the study of photonic crystal progress. In this information age the range of application of photonic crystal is only imperfectby the acuteness of human minds.

1.4Introduction to High-Index Contrast Grating

Ahigh contrast grating is a single layer near-wavelengthgratingphysical structure where the grating substantial has a large contrast in index of refraction with its surroundings. The term near-wavelength refers to the grating period, which has a value between one optical wavelength in the grating material and that in its surrounding material.

The high contrast gratings have many separate attributes that are not found in conventional gratings. These features include broadband ultra-high reflectivity, broadband ultra-high transmission, and very high quality factorresonance, for optical beam surface-normal or in oblique incidence to the grating surface. The high reflectivity grating can be ultrathin, only <0.15 optical wavelength. The reflection and transmission phase of the optical beam through the high contrast grating can be planned to cover a full 2π range while continuing a high reflection or transmission coefficient [55].Subwavelegnth gratings are also of interest for a wide range of integrated optoelectronic device applications, including lasers, filters, splitters, couplers, etc., because the elimination of non-zero diffraction orders increases coupling efficiency. subwavelength dielectric gratings with a high contrast of refractive indices have been demonstrated, referred to as high contrast gratings (HCGs), having reflectivity higher than 99%.

In 2008, a single layer of high contrast grating was demonstrated as a high quality factor cavity. In 2009, hollow-core waveguides using high contrast grating were proposed,followed by experimentally demonstration in 2012. This experiment is the first demonstration to show a high contrast grating reflecting optical beam propagating in the direction parallel to the gratings, which is a major distinction from photonic crystalor distributed Bragg reflector.

1.5 Purpose and Outline of Work

The purpose of our research is to design and analyzeSampled Grating based photonic crystal waveguide on air wafer.Main focus of the work will be on Silicon Gratingbased photonic crystal waveguide.In this dissertation, Sampled Grating based photonic crystal waveguide is proposed based on one dimensional photonic crystals. The simulation is done using finite difference time domain method.This dissertation present a fully two dimensional finite difference time domain simulation model to estimate high Reflectance and characteristics for both the TE like polarization and TM like polarization in photonic crystal slab waveguides.

Chapter 2 provides an introduction to Optical Grating based photonic crystal waveguide including their types, Reflectivity from Grating and area of Application.

Chapter 3 discussed about the research work done in the Grating based photonic crystal waveguide.

Chapter4 discussed the design and simulation of Sampled Grating based photoniccrystal waveguide structure.

CHAPTER 2

Fundamentals &Applications of High-Index Contrast Grating

Optical grating is a research area with a extensive history. It has been broadly studied over the years due to its extensive applications in holography, spectroscopy, lasers, and many other optoelectronic devices. In this Chapter,study of periodic structures, as well as of wave propagation in periodic medium andoverview of wave guiding theory is given and the waveguide structures that are going to be used in this work are presented.

2.1 Introduction of Bragg Gratings

Bragg grating plays an important role in the many applications. In order to interpret the optical behavior of these structures particular knowledge of the underlying principle is required. The majority of Bragg grating produced nowadays is based on optical fiber and often referred to as fiber Bragg gratings (FBG) [52].

In the simplest configuration, a Bragg grating is an optical wavelength filter shaped by periodic modulations of the effective index of a waveguide. This modulation is most commonly attained by variation of refractive index or the physical dimensions of the waveguide core. With the change of refractive index, reflections of propagating wave occur. The repeated modulation of refractive index results in multiple reflections of the forward travelling light. The period of index modulation relative to the wavelength of light defines the relative phase of all the reflected light. At a particular wavelength, known as Bragg wavelength, all reflected signals are in phase and add constructively and a back reflected signal centered about the Bragg wavelength is observed.

More complex configurations than that described above can be fabricated. The period and amplitude of index modulation can be controlled along the length of the grating to shape the wavelength response. Additionally, grating planes can be tilted so that they are not perpendicular to the path of propagation, resulting in light coupled into waveguide cladding.

The following discussion is restricted to uniform Bragg gratings, where the planes are perpendicular to the path of wave propagation in the waveguide. Using the principles of energy and momentum conservation the center wavelength reflected by uniform grating can be determined. For energy to be conserved there is no change in frequency as a result of reflections at grating planes. For conservation of momentum the sum of incident wave vector k_i and the grating wave vector K must equal to the wave vector of reflected wave k_r.

$$k_i + \mathrm{K} = k_r \tag{2.2}$$

When the Bragg condition is satisfied, $k_r = -k_i$ and so equation 2.2 can be rewritten as:

$$\frac{2\pi}{\lambda} n_{eff} + \frac{2\pi}{\Lambda} = -\frac{2\pi}{\lambda} n_{eff} \tag{2.3}$$

Which in turn simplify the equation relating the Bragg Wavelength, effective index, grating period.

$$\lambda_B = 2n_{eff}\Lambda \tag{2.4}$$

Where, λ_B is the Bragg wavelength, Λ is the grating period and n_{eff} is the effective waveguide index.

This simple relation does not give any information about the strength of reflections. A common mean of predicting this information is the use of coupled mode theory, which is found to allow modeling of uniform and highly structured grating [51, 52].

2.2Types of Bragg grating Structures

2.2.1 UniformBragg grating Structure

Uniform fiber Bragg grating structureis a device that periodically modifies the phaseor the intensity of a wave reflected on, or transmittedthrough, it. The propagating wave is reflected, if its wavelength equals Bragg resonance wavelengthλ_{Bragg}, in theother case is transmitted. The uniformmeans that the grating period,Λ, and the refractive index change, δn, are constant over whole length of the grating[27]. The equationrelatingthegrating spatial periodicity and the Bragg resonance wavelength is give above in equation (2.4).

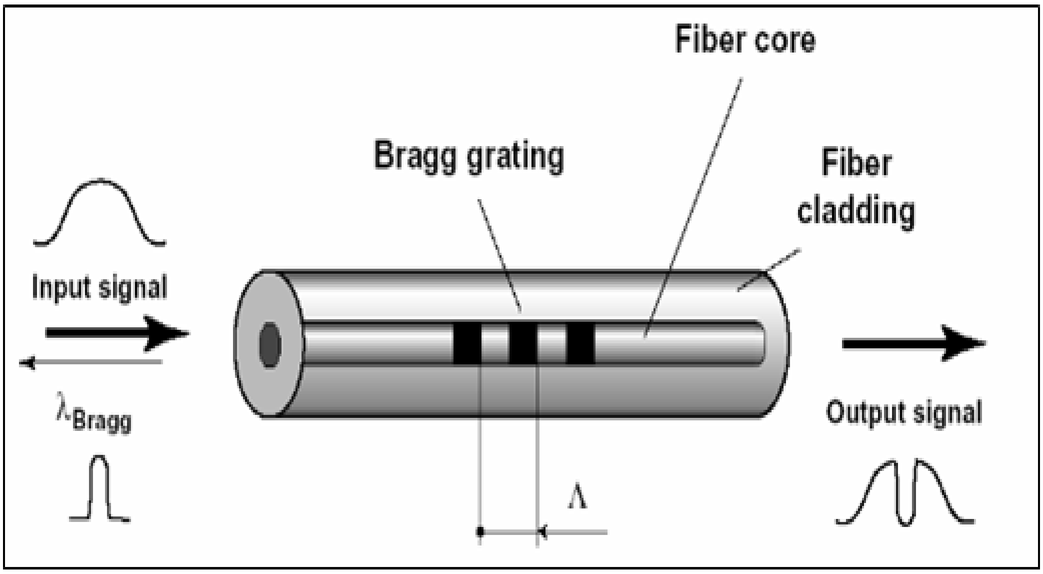

Figure 2.1: Schematic of Uniform Bragg grating structure [52].

As Earlier said, Bragg resonance wavelength depends on grating period, Λ,and effective mode index,n_{eff}. The fiber effective mode index depends on the propagation constant, β, and on the vacuum wave number, k; k =2π/λ, where λis wavelength:

$$n_{eff}=\frac{\beta}{k} \tag{2.5}$$

In the mostcases, uniform grating can berepresented as a sinusoidal modulation ofrefractive index, n(z), through the fiber core given by:

$$R(L,\lambda) =\frac{\Omega^2 sinh^2(sL)}{\Delta k^2 sinh^2(sL)+ s^2\, cosh^2(sL)} \tag{2.6}$$

Where R(L, λ)is reflectivity as function of grating length, L, and wavelength, λ, Ωis coupling coefficient,Δk = β– π/Λis detuning wave vector, β is propagation constant. The coupling coefficient, Ω, for the sinusoidal refractive index modulation is given by:

$$\boldsymbol{\Omega} =\frac{\Omega\delta n\eta(V)}{\lambda} \tag{2.7}$$

Where η(V)is function of fiber V parameter and is, approximately, η(V)= $1 - 1/V^2$.

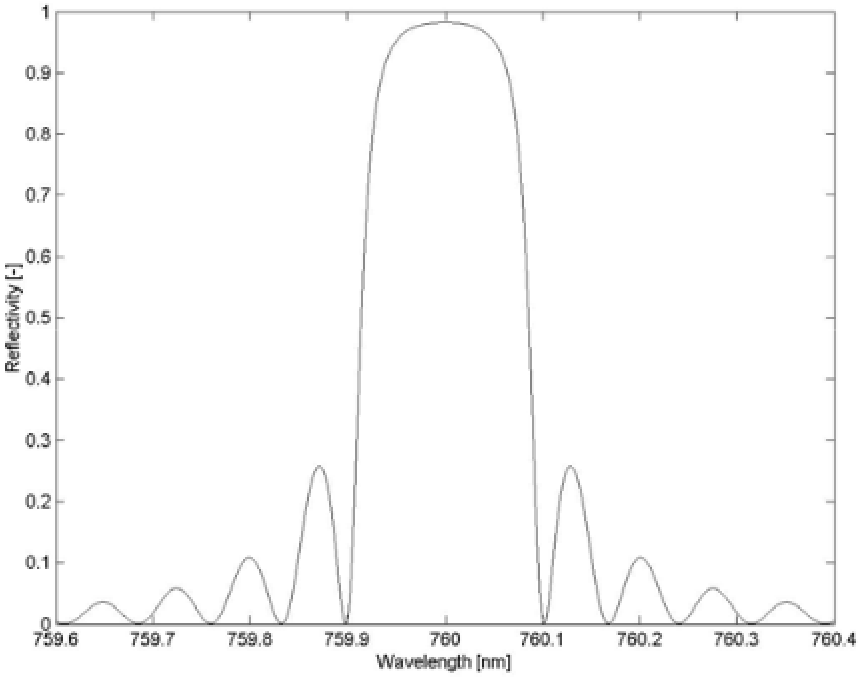

Figure 2.2: Schematic of Reflectivity against Wavelength for Uniform Bragg grating structure [53].

It is clear, that the spectral properties of the uniformgrating are similar to sinc function. The bandwidth ofthe gratingis considered betweenthe zeroes ofthe main peak. The bandwidthand the peak reflectivity are dependent on the grating length and the refractive index changes [53].

2.2.2Chirped Bragg grating Structure

One of the most interesting Bragg grating structures with immediate applicationsin telecommunications is the chirped Bragg grating. This grating has a monotonically varying period. There are certain characteristic properties offered by monotonically varying the period of gratings that are considered advantages for specific applications in telecommunication and sensor technology, such as dispersion compensation and the stable synthesis of multiple-wavelength sources. These types of gratings can be realized by axially varying either the period of the grating **Λ** or the index of refraction of the core, or both.

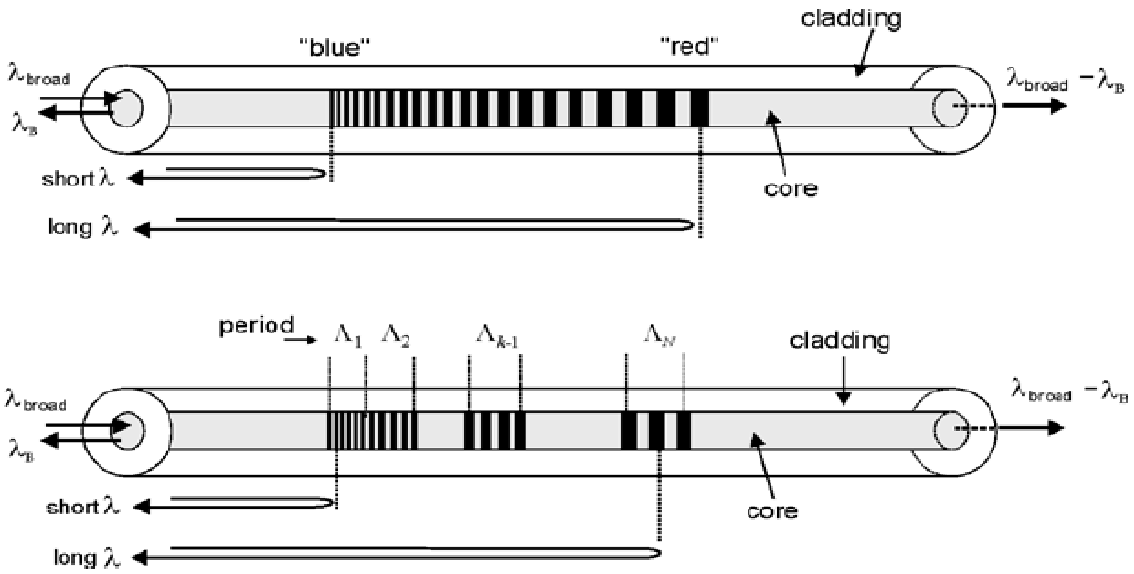

Figure 2.3: Schematic diagram of a chirped grating with an aperiodic pitch. For forward-propagating light as shown, long wavelengths travel further into the grating than shorter wavelengths before being reflected. And Schematic diagram of a cascade of several gratings with increasing period that are used to simulate long, chirped gratings.

The simplest type of chirped grating structure is one with a linear variationof the grating period

$$\Lambda(Z) = \Lambda_0 + \Lambda_1 z \tag{2.8}$$

Where $\Lambda_0$is the starting period and $\Lambda_1$is the linear change (slope) along thelength of the grating. One may consider such a grating structure made upof a series of smaller length uniform Bragg gratings increasing in period. If such a structure is designed properly one may realize a broadband reflector. Typically the linear chirped grating has associated with it a chirp value/unit lengthand the starting period [52, 53].

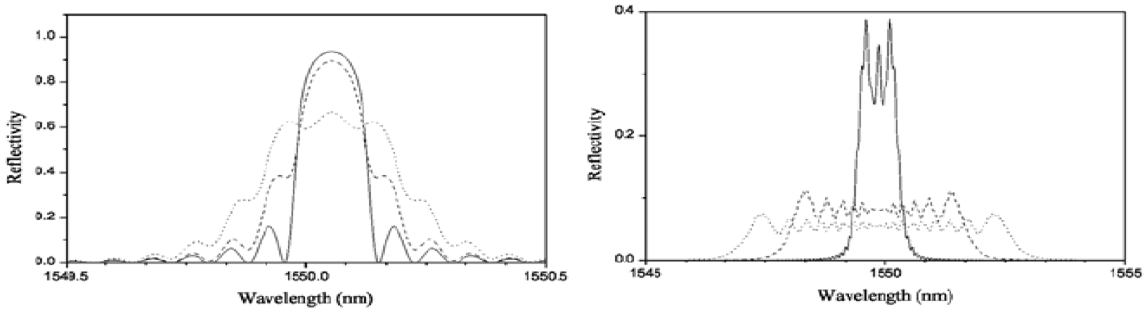

Figure 2.4: Schematic of Spectral reflectivity response from different Bragg gratings showing theeffect of chirping.

2.2.3TiltedBragg grating Structure

Fiber optic gratings are developing fast in recent yearsas a novel passive fiber optic device charactering small volume, high sensitivity and easy to wavelength division multiplexing. It is widely used in fiber optic sensors and fiber optic communications. Titled fiber Bragg gratings are also called slanted gratings or blazed gratings which is a special kind of short-term fiber optic gratings. Like normal fiber Bragg gratings, titled fiber Bragg gratings have periodical index variation in axial direction. The boundary surface of the varied index is not vertical with respect to the fiber axis but has a certain angle, which gives titled fiber Bragg gratings some particular characteristics other than normal fiber Bragg gratings. One feature of tilted fiber Bragg gratings is that they can couple guided-modes with co-propagating modes or counter-propagating modes in specific wavelengths. Because of this characteristic, tilted fiber Bragg gratings can be used as gain flattened erbium fiber amplifiers [54], optical spectrum analyzers, modal power distribution measurers, add-drop filtersand etc. Another feature of tilted fiber Bragg gratings is that they are sensitive to the surrounding refractive index outside the gratings, due to which they can be functioned as refractometersand concentration meters[52]. Tiltedfiber Bragg gratings which have large tilt angles are alsoshow good sensitivity to the polarization state of the incident light.

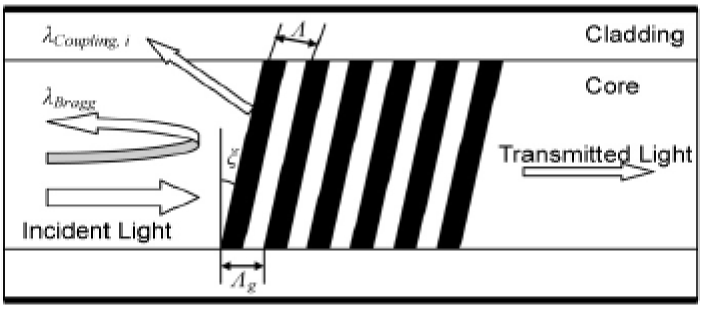

Figure 2.5: Schematic of Tilted fiber Bragg grating structure**.**

2.2.4SuperstructureBragg grating Structure

Superstructure fiber Bragg gratings (FBGs) have been widely analyzed with Fourier theory and experimentally demonstrated. By using Fourier transforms, it has been proven that the traditional uniform FBG produces only a single response in the spectrum, multiple phase-sampled gratings can be regarded as independent interleaved FBGs with different phases, and the multiple phase sampling technique has the capacity to density the spectral channels. Based on Fourier theory, a kind of superstructure FBGs with multiple ultra-narrow transmission windows, obtained by introducing a π phase shift into the center of grating and along the whole length in different cases.

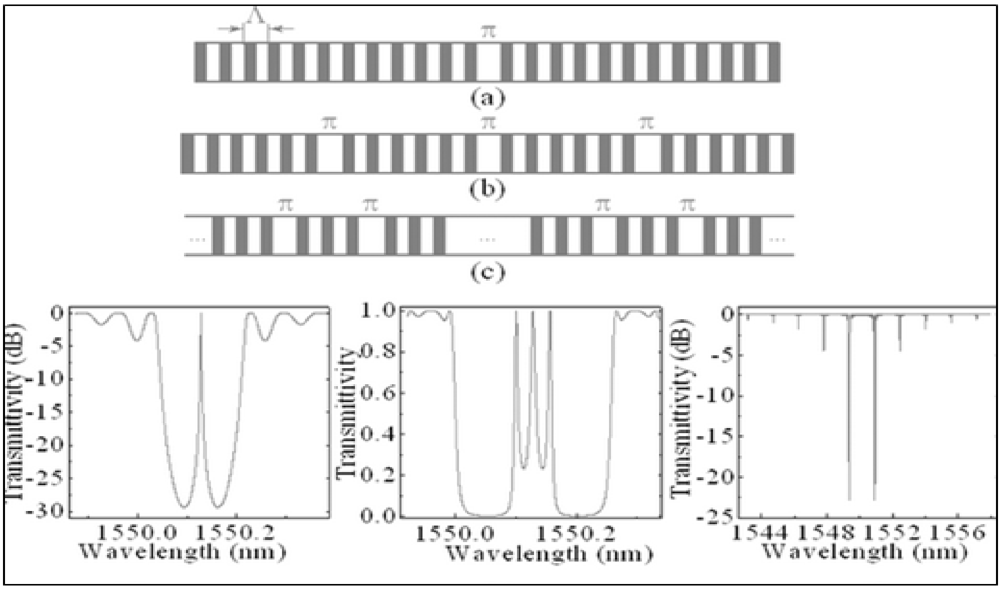

Figure 2.6: Schematic of Superstructures fiber Bragg grating structure. (a)π phase shift into thecenter of grating (b) π phase shifts having equal distance along the length (c)π phase shift periodically along the length.

2.3Sampled Bragg grating

A sampled grating consists of a right grating at a wavelength probably defined, multiplied by a sampling function. It is possible to model the reflectivity complex of sampled grating using the theory of coupled mode and the theory of transfer matrices, but it must first define the key parameters which modify its properties in phase and amplitude.A sampled grating is a conventional grating from which we remove portions periodically. In other words, there is an alternation between sections with gratin and sections without a grating as described in Fig (2.8).A Bragg grating wavelength λ_{Bragg} (defined by the step Λ and the effective indexn_{eff}) and located on a distance $z_1$with a coupling coefficient the grating is then repeated m times (number of sampling periods) with a period z_0. The total length of sampled grating is L_{Tot}= mz_0. The spectral response of this grating is the Fourier transform of the profile index. The result is a comb Bragg reflectors, regularly spaced with the sampling frequency ISL_{SBG}most often expressed in GHz [39].

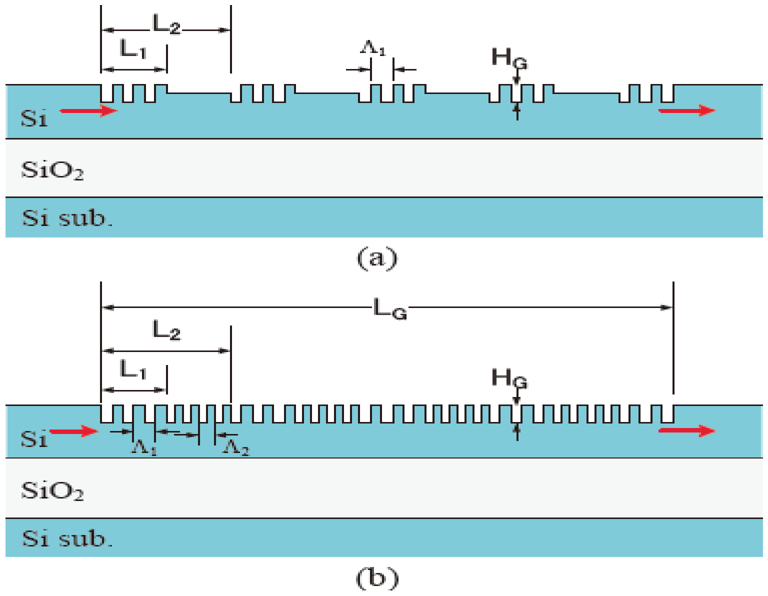

Figure 2.7: (a) Schematic of Sampled bragg grating (b) Sampled bragg grating having different grating period in continuous manner[44].

The relative grating phases of each sampled gratingwere synchronized by precisely controlling the length and the effective refractive index of the space region. For the space region of the sampled grating, a grating with another pitch is formed to adjust the effective refractive index of the region as shown in Fig.2.8 (b). As the Bragg wavelength of this region is far from the signal wavelength, this region acted as the space region [44].

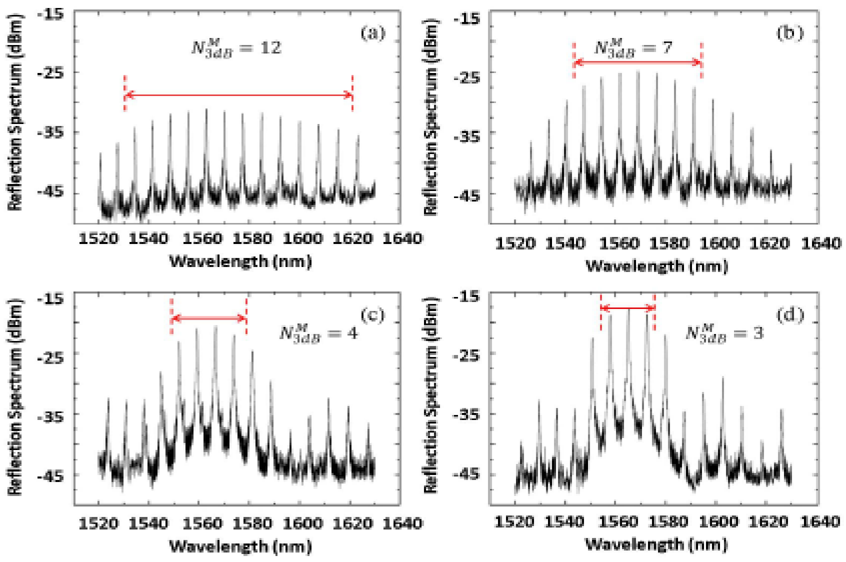

Figure 2.9: (a) Schematic of Reflection spectra of four different sampled gratings. The number of Corrugations in one sampling periods are 5, 8, 15, and 20 in (a), (b), (c), and (d), respectively [43].

From the design parameters, they have the same grating period and sampling period, but the number of grating corrugations (NCs) within each sampling period was set to be 5, 8, 15, and 20, respectively. The reflection spectra of the four sampled gratings are shown in Fig. (2.9).

2.4 Applications of Bragg gratingin Optical Communication

2.6.1 Optical Interconnects

As the complexity and speed of integrated circuits and computer systems increase, there is atrade-off between the length of a wire signal path and the bandwidth supported by thosepaths. Optical interconnects do not exhibit this trade off and in the future will likely replace metal wiring for long interconnects. Researchers have also shown that optical interconnects provide advantages over electrical interconnects in terms of fan-out, energy conversion, latency, and electromagnetic interference immunity. Several researchers have implemented diffractive grating couplers as the coupling element for optical interconnect systems.Gratings are desirable because they are more compact than other coupling schemes.

2.6.2Integrated Optical Devices

Gratings also find an application in integrated optical devices. Integrated optical devices attempt to accomplish the same task as bulk optics, but on a compact and integrated scale. Some examples of diffractive integrated optical devices are beam expanders, polarization dependent devices, and holographic filters for beam intensity profile reshaping. Other integrated optical devices with applications to computer systems are optical read/write heads, grating coupled surface emitting lasers, optical sensors, and printer heads.

2.6.3 Fiber Optical Communications

Another area in which gratings have found application is in fiber optical communications. Optical communications over fiber optic links have potentially large bandwidths and experience low loss for long distances. One advance in the bandwidth of optical communications is wavelength division multiplexing. Wavelength division multiplexing and dense wavelength division multiplexing require devices that are highly sensitive to wavelength for interacting with narrow wavelength communication channels. Gratings have the potential to play an important role in this arena. Some grating devices that have been demonstrated by researchers are Bragg gratings for wavelength division multiplexing and optical filters.A reflectoris the structure formed from multiple layers of alternating materials with varying refractive index, or by periodic variation of some characteristic (such as height) of a dielectric waveguide, resulting in periodic variation in the effective refractive index in the guide. For waves whose wavelength is close to four times the optical thicknessof the layers, the many reflections combine with constructive interference, and the layers act as a high-quality reflector. The range of wavelengths that are reflected is called the photonic stop band.

CHAPTER 3

Literature Survey

The modest possible photonic crystal consists of alternating layers of material with different dielectric constants. This arrangement is not a new idea. Lord Rayleigh (1887) published one of the first investigates of the optical properties of multilayer films. As we will see, this type of photonic crystal can act as a mirror (a Bragg mirror) for light with a frequency within a specified range.These concepts are commonly used in dielectric mirrors and optical filters (as in, e.g., Hecht and Zajac, 1997). The traditional way to analyze this system, pioneered by Lord Rayleigh (1917), is to imagine that a plane wave propagates through the material and to consider the sum of the multiple reflections and refractions that occur at each interface. Research methodologies established within the last decade in the field of photonic crystal waveguides are presented below:

Magné, Julien, *et al.* in 2005 [51] presented a new class of all-fiber frequency comb filter that exhibits unprecedented capabilities for tuning the comb's free spectral range (FSR). The filter exploits a spectral Talbot-like effect in a sampled chirped fiber Bragg grating. The FSR is tailored by application of a linear strain gradient to modify the relative phase between the samples. The FSR can be tuned in discrete steps that correspond to the nominal value of the FSR of the sampled unchirped grating divided by integer factors. In this demonstration the FSR is varied from 51 to 3.9 GHz.

Hartl, I., *et al*. in 2005 [47] presented an optically integrated self-referenced frequency comb laser is demonstrated. The system consists of a passively-modelocked Er-fiber laser, a butt-coupled periodically poled lithium niobate (PPLN) waveguide phase-sensor and an electronic feedback loop for carrier-envelope-offset (CEO) phase stabilization. The f_{ceo}-beat-signal has a linewidth of 62 kHz and is detected with a S/N-ratio of 40 dB, with greatly reduced pulse energy requirements compared to bulk crystal phase-sensors.

To our knowledge this is the first self-referenced frequency-comb system entirely based on guided-wave technology.

Kim, K., *et al.* in 2006 [29] proposed significant improvement (+24 dB) of the optical beat note between a 657 nm cw laser and the second-harmonic generation of the tailored continuum at 1314 nm generated with a femtosecond Cr:forsterite laser and a nonlinear fiber Bragg grating. The same continuum is used to alleviate the carrier-envelope offset frequency of the Cr:forsterite femtosecond laser and permits better optical stabilization of the frequency comb from 1.0 to $2.2\,\mu$m . Using a common optical reference at 657 nm, a relative fractional frequency instability of 2.0×10^{-15} is achieved between the repetition rates of Cr:forsterite and Ti:sapphire laser systems in 10 s averaging time. The fractional frequency offset between the optically stabilized frequency combs of the Cr:forsterite and Ti:sapphire lasers is $\pm(0.024 \pm 6.1) \times 10^{-17}$.

Kanamori, Yoshiaki, Masaya Shimono, and Kazuhiro Hane.,in2006 [28] present theoretically and experimentally transmission color filters using silicon subwavelength gratings on quartz substrates. Every grating area is 120 mum-square, which is appropriate pixel size for shows and multichannel detectors. In the fabrication, electron beam lithography and fast atom beam etching are used. The grating periods are 400, 350, and 440 nm for the red, green, and blue filters, respectively. The transmission spectrum obtained from a coupling between an incident light and the submicrometer periodic grating matches with human color perception. The transmittances of 71.1%, 58.1%, and 59.3% are obtained for the red, green, and blue filters, respectively.

Cheben, Pavel,*et al.* in 2006 [30]proposed a new diffractive scheme for light coupling between a planar optical waveguide and free space is proposed. The device utilizes a second-order waveguide grating to diffract the fundamental waveguide mode into two free propagating beams and a subwavelength grating (SWG) mirror to chain the two free propagating beams into a single beam. The finite-difference time-domain (FDTD) simulations show that the SWG mirror improves the coupling efficiency of the waveguide fundamental mode into the single out-coupled beam from about 30% to 92%. A high efficiency (>90%) is predicted for a broad wavelength range of 1520-1580nm. The proposed device is compact (~80 μm in length) and it eliminates the need for blazing the waveguide grating.

Zou, Xi-Hua, *et al.* in 2006 [50] presented periodically chirped sampled fiber Bragg gratings (PC-SFBGs) are proposed as multichannel comb filters. A PC-SFBG consists of many chirp periods corresponding to the periodic chirp effect. With the same chirp coefficient released for a linearly chirped SFBG (LC-SFBG), the spectral self-imaging phenomenon is also observed in the PC-SFBG. Compared with a uniform SFBG, the PC-SFBG exhibits a narrower channel spacing and a similar group-delay characteristic in the reflection bands. Meanwhile, the PC-SFBG ensures a more accurate phase-shift condition (or a better tolerance on the chirp coefficient) and higher peak reflectivities than the LC-SFBG.

Hu, Juan Juan, *et al.*in 2007 [25] present the universal finite-difference time-domain full-vectorial method by reformulating the time-dependent Maxwell's curl equations with electric flux density and magnetic field intensity, with auxiliary differential equations using complex-conjugate pole-residue pairs. The model is general and robust to give general frequency-dependent material and nonlinear material. The Sellmeier equation is implicitly incorporated as a different case of the general formulation to account for material dispersion of fused silica. The results are in good contract with the results from the multipole method. Kerr nonlinearity is also incorporated in the model and demonstrated. Nonlinear solutions for a one ring photonic crystal fiberare provided which taken as an example.

Chen, Chao, *et al.* in 2007 [27] present Photonic crystal waveguide sampled gratings (PCWSG) are proposed to realize multi-channel optical filter in a photonic crystal (PC) waveguide. The reflection features of the filter are examined by using the coupled-mode theory (CMT) together with transfer-matrix method (TMM). It is shown that the reflection spectrum of the filter exhibits a group of reflection peaks, which are distributed with equal frequency spacing within the photonic crystal bandgap (PBG). The theoretically designed effects are numerically confirmed by using two-dimensional (2D) finite-difference time-domain (FDTD) method.

Viktorovitch, Pierre, *et al.* in 2007 [6] designed The art of micro photonics consists in confining photons, in more than one directions, in structures having dimensions about the wavelength, and doing this for the longest possible period. The objective is then to associate these microstructures in order to carry out a photonic integration allowing data processing in very squeezed systems and using low optical powers. Photonic crystals have largely showed these last years their capacity to achieve these goals.

Zou, Xi-Hua, *et al.* in 2007 [32] introduced For one-dimensional (1-D) photonic crystals, the amplitude reversal in refractive index profile is defined as an equivalent π phase shift. With these defined π phase shifts, the binary phase-only sampling approach can be implemented to design 1-D photonic crystal-based multichannel filters. Such filters exhibit high-count channels and excellent channel uniformity, which is identical with the phenomena obtained in sampled fiber Bragg gratings (SFBGs). Simulations of a nine-channel filter are set out and the distribution of reflection peaks is consistent with that of SFBGs. Then, the impact of structural parameters on filtering characteristics (especially the peak-trough contrast ratio) is discussed, such as optical length of unit cell, optical thickness ratio of alternative dielectric layers, and apodization technique.

Schmid, Jens H., *et al.* in 2007 [35] present experimentally and by simulations the use of subwavelength grating patterns on the facets of planar waveguides as a means of modifying facet reflectivity over a wide range of values, from antireflective to highly reflective. An antireflective structure can be obtained from a gradient index effect with triangular gratings. Square gratings can be used to obtain either antireflective or highly reflective facets by an interference effect. Finite difference time domain simulations and calculations based on effective medium theory show that reflectivities well below 1% can be achieved with triangular gratings. Experimentally, facet reflectivities as low as 2.0% and 2.4% for the fundamental TE and TM waveguide modes, respectively, are demonstrated for light of 1.55 μm wavelength in silicon-on-insulator ridge waveguides. The experimental results are in good agreement with both effective medium theory and finite difference time domain simulations. The polarization dependence of the effects is also discussed in detail.

He, Xiaoying, *et al.* in 2008 [38] present an analytical method is proposed for calculating reflection-spectrum envelopes (RSEs) of various multipeak gratings. Consequently, impacts of parameters on the envelope of the sampled grating are analyzed in detail both with and without refractive index variation. Accuracy of those proposed methods has been verified by the good agreement with the simulated reflectivity spectrum of the transfer matrix method. A technology of multiple reflection spectrum envelopes concatenation (MRSEC) is proposed to design multipeak gratings with broad flat-top spectrum envelopes: one is the digital concatenated grating; the other is the consecutive interleaved sampled grating. The proposed technology can densify spectral channels of sampled gratings with fixed reflectivity peak space, as well as spatially physical corrugation of structure.

Tu, Xing-hua, *et al.* in 2008 [39] presents which is Based on a sampled fiber Bragg grating, a novel approach to obtain high channel-count comb filters is proposed for wavelength-division-multiplexing (WDM) system in this letter. There is a non-continuous linear chirped structure like a ladder in grating period. And refractive index modulation amplitude with Hamming spatial profile is used within the samples. The 26-channel comb filter with channel spacing of 50 GHz is then fabricated, it features in multiple equalized pass bands with flat-top steep-edge and high transmittance which will benefit as multi-channel optical add/drop filters in WDM system.

He, Xiaoying, *et al.* in 2008 [41] present an analytical method is proposed for calculating reflection-spectrum envelopes (RSEs) of various multipeak gratings. Consequently, impacts of parameters on the envelope of the sampled grating are analyzed in detail both with and without refractive index variation. Accuracy of those proposed methods has been verified by the good agreement with the simulated reflectivity spectrum of the transfer matrix method. A technology of multiple reflection spectrum envelopes concatenation (MRSEC) is proposed to design multipeak gratings with broad flat-top spectrum envelopes: one is the digital concatenated grating; the other is the consecutive interleaved sampled grating. The proposed technology can densify spectral channels of sampled gratings with fixed reflectivity peak space, as well as spatially physical corrugation of structure.

Damljanović, V., *et al.* in 2010 [40] designed and demonstrated method of calculation of the reflectivity of one dimensional photonic crystal described in but with significantly higher resolution and applied for the case of volume Bragg gratings which are made in our laboratory using dichromated pullulan. We show that calculated reflectivity as a function of incident wavelength contains rapidly oscillating part, which is not observable if the resolution of calculation is low. We show good agreement between results of the model and measured reflectivity of the 1D photonic crystal fabricated in dichromated pullulan.

Wu, H. *et al.* in 2010 [37] introduced and analyzeda broadband reflector exhibiting a flattened band stop spectral response is proposed by using a multilayered grating structure possessing multi-subpart profile. It is shown that with the properly configured profile and a strongly modulated grating layer, in transverse electric (TE) polarized wave the presented reflector experimentally demonstrated a 240 nm-wide reflection spectrum from 1.56 to 1.8 μm, very high reflectivity (>97%), and a low sensitivity to incident angle at the range of $-13.8° < \theta < +14°$. Effects of deviation from the design parameters on the performance of the reflector are also illustrated, and a reasonably good tolerance of fabrication error is exhibited in the proposed device.

Das, Narottam, *et al.* in 2011 [34] present the light absorption enhancement factor dependence on the design of nanogratings inscribed into metal-semiconductor-metal photo detector (MSM-PD) structures. These devices are optimized geometrically, leading to light absorption improvement through plasmon-assisted effects. Finite-difference time-domain (FDTD) simulation results show ~50 times light absorption enhancement for 850 nm light due to improved optical signal propagation through the nanogratings. Also, we show that the light absorption enhancement is strongly dependent on the nanograting shapes in MSM-PDs.

Giuntoni, Ivano, *et al.* in 2011 [42] analyzed the design and fabrication of sampled gratings on silicon-on-insulator rib waveguides is presented. A multiple reflection up to 20 channels with a spacing of 0.78 nm is demonstrated, with potential filtering applications in WDM networks.

Sirbu, Lilian, *et al.* in 2012 [26]present a theoretical model for propagation of EM wave. in various kinds of structures such as arrays of monolayer cylinders, multilayer cylinders, non-metallized and metallized pores. An investigative method was developed for the deduction of dispersion law in a multilayer nanocilinder array system. The proposed structure can be used to focus the EM wave. The simulation was performed by using FDTD model (OptiFDTD software) for conical InP pores organized by electrochemical technique. The results of this work demonstrate the existence of ultra short modes at low frequencies in porous systems.

Banerji, Sourangsu. in 2013[33] discussed the forward and backward propagating modes in an optical waveguide structure namely the fiber Bragg filter also considered as a one dimensional photonic crystal, are analytically calculated as a function of grating length for coupled optical modes. AlxGa1-xN/GaN material composition is considered as a unit block of the periodic organization, and refractive index of AlxGa1-xN/GaN is taken to be dependent on material composition, bandgap and operating wavelength following Adachi's model. Expressions of propagating wave are derived expending coupled mode theory. Simulated results help us to study the propagation of forward and backward wave propagating modes inside fiber and waveguide devices.

Liu, Dongliang, et al. in 2013 [43] analyzed Sampled gratings based on low-loss buried silicon nitride waveguides in polymer have been fabricated and investigated. Low-temperature plasma enhanced chemical vapor deposition and standard photolithography are used to form the silicon nitride core layer directly on polymer. These gratings show a common peak interval of 7.3 nm but varying 3-dB mode numbers according to the design. Since the optical mode expands largely into the cladding, the thermo-optic effect of the polymer material dominates. With buried heating electrodes, wavelength tuning of 8.1 nm has been achieved at ~ 100 mW of electrical heating power.

Kato, A., K. Nakatsuhara, and T. Nakagami. in 2013 [44] presented a sampled grating in a silicon-on-insulator waveguide having ferro-electric liquid crystal cladding for tunable transmission filters. Bistable tuning operation of narrow-stop-band, which was due to the sampled grating, was obtained.

Zhuo, Ning, *et al.* in 2013 [46] presented a novel complex-coupled distributed feedback quantum cascade laser emitting around $\lambda \sim 4.7$ μm is demonstrated by a sampled Bragg grating (SBG). The key superiorities are to utilize the +1st-order (positive first order) transmission of the SBG for laser single-mode operation, and use conventional holographic exposure combined with the optical photolithography technology to fabricate the sampled grating, which lead to improved flexibility, repeatability, and cost-effectiveness. Selective single-mode lasing with a mean side mode suppression ratio above 20 dB and wavelength coverage range of 87 nm is achieved by changing the sampling period.

Ghoumid, Kamal, et al. in 2013 [48] presented a double filtering function has been obtained by realization of a double Bragg gratings (BGs) structure based on titanium-diffused optical waveguides in lithium niobate Ti:LiNbO3 has been reported. Focused Ion Beam (FIB) technique is being used in order to obtain homogeneous periodic microstructures. This double structure (D.S.) is characterized by wavelengths reflected around the bands 1203nm and 1527nmwith a coefficient of about 96% and Full widths at half maximums are in the vicinity of 50 and 56nm. Experimental results agree well with the results of the simulations. As a perspective, an improvement in the bandwidth of this structure is considered so that it can find its application in coding/decoding optical CDMA is discussed.

CHAPTER 4

Design and Simulation of Sampled Grating based1D PhC

4.1 Structure of ConventionalGrating Based 1DPhotonic Crystal

The Conventional subwavelength metal grating structure, namely, wire grids equally distributed on the transparent substrate. The mechanism of the unique polarization characteristic is that TE polarized light could stimulate current formed by the nanowires electronics, which allowed the light along this direction reflected back. However, for TM polarized light, for the existence of the air gap between the nanowires, it can just be transmitted. Here,w_s is the groove depth, k is the grating period, and w_d is the width of Glass Substrate. Owing to different metal materials with different Reflectivity, thus choosing the right metal is the primary problem. Combining with micro processing capacity at present and the characteristic curves of aluminum, silver, gold, and chromium, the basic parameters of the proposed grating period(k) = 0.5µm, the material Silicon and the refraction index of substrate is 3.48 and 1.6. Substrate is the type of Glass, which is called as Flint Glass. Where,w_s= 0.1µm, w_d= 2.5µm and the incident wavelength is 1.55µm.

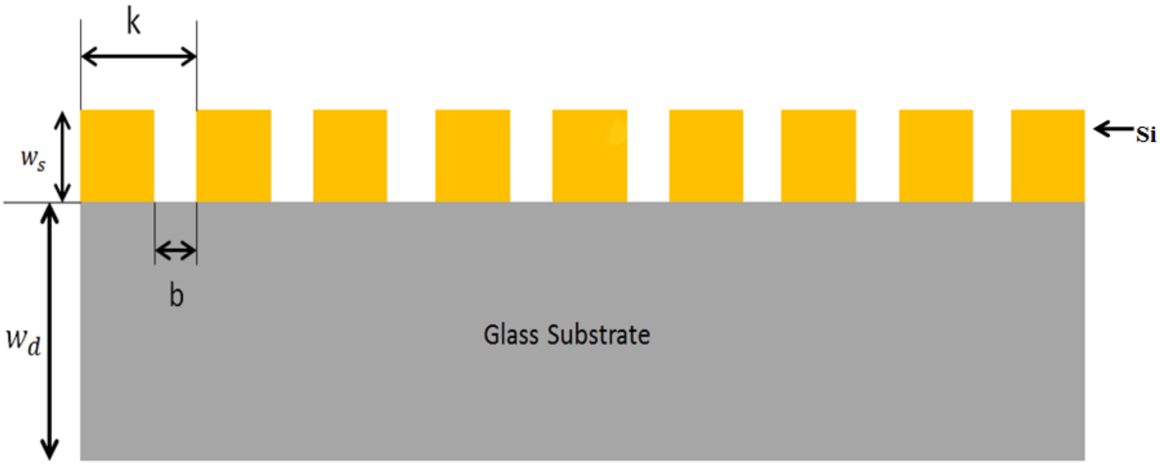

Figure.4.1: Schematic of ConventionalGrating Based 1D photonic crystal, where Grating period (k) =0.5µm and Grating Spacing (b)=0.25µm.

A monochromatic plane wave is incident from the air with an incident angle θ=0˚. The simulation is performed with finite difference time-domain (FDTD) method.

4.2 Proposed Design of SampledGrating Based 1D PhC

A sampled grating consists of a right grating at a wavelength probably defined, multiplied by a sampling function. It is possible to model the reflectivity complex of sampled grating using the theory of coupled mode and the theory of transfer matrices, but it must first define the key parameters which modify its properties in phase and amplitude. A sampled grating is a conventional grating from which we remove portions periodically. In other words, there is an alternation between sections with grating and sections without a grating.

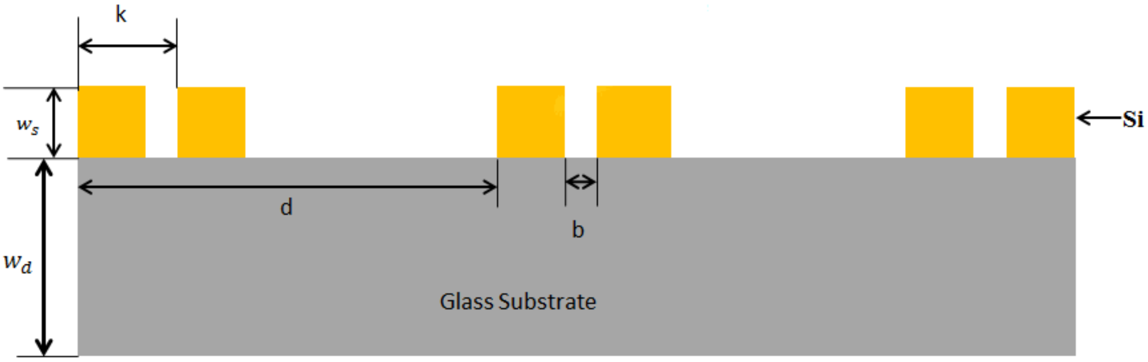

Figure.4.2: Schematic of ProposedSampled Grating Based 1D photonic crystal, whereGrating period (k) =0.5µm and Grating Spacing(b)=0.25µm. and Sampling period (d)=3.5µm.

Thesubwavelength proposed Si sampled grating structure, where samples of Si repeats periodically.Here,w_s is the groove depth, k is the grating period, and w_d is the width of Glass Substrate. Here we are taking four samples and then equal area, which is withoutgrating. Here,k = 0.5µm, the material Silicon and the refraction index of substrate is 3.48 and 1.6. Substrate is Flint Glass type. Where,w_s= 0.1µm,w_d= 2.5µm, d=3.5µmand the incident wavelength is 1.55µm.Thus, a monochromatic plane wave is incident from the air with an incident angle θ=0˚. The simulation is performed with finite difference time-domain (FDTD) method.

4.3 Effects of different parameters onGrating Based 1D Photonic Crystal

4.3.1 Variation of Reflectivity versus Wavelength at different input Wavelength:

Fig.4.3 shows the Reflectivity versus wavelength of Conventional Grating based waveguide structure of 1D PhC at various values of incident wavelength on taking waveguide parameters, grating period(k) = 0.5µm, grating Spacing=0.25µm at different input wavelengths of 1.15µm,1.25µm,1.35µm,1.55µm.

It is noticed that on giving different incident values of wavelength in Conventional Grating Structure, high reflectivity is found almost at single wavelength.For Optical Source IW=1.15µm, observation 99.9% reflectivity near 900nm-1000nm.

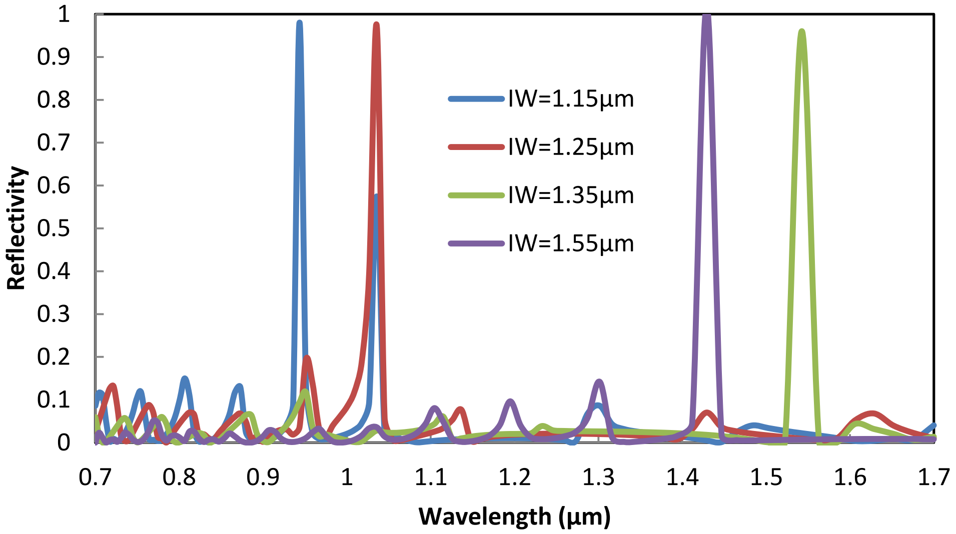

Figure.4.3: Reflectivity vs. wavelength for conventional Grating Based Structureat different input values of wavelength.Waveguide parameter, Grating Period of Si is 0.5µm, w_s= 0.1µm,w_d= 2.5µmat different input wavelength.

As input Source IW=1.25µm, Reflectivity is maximum near 980nm-1050nm. Similarly, for IW=1.35µm, Reflectivity is 90% near 1550nm-1600nm. As IW=1.55µm, Reflectivity is 99.9% near 1400nm-1450nm.

Fig.4.4 shows the Reflectivity versus wavelength of Proposed Sampled Grating based waveguide structure of 1D PhC at various values of input wavelength on taking waveguide parameters, grating period(k) = 0.5µm, grating Spacing=0.25µm, w_s = 0.1µm, w_d = 2.5µm, d=3.5µm at different input wavelengths of 1.15µm,1.25µm,1.35µm,1.55µm.

It is observed that for different wavelength values of incident wave in Grating structure where we are using sampled grooves, multichannel wavelength high reflectivity is observed at different wavelength ranges.For Optical Source IW=1.15µm, observation is near about99.9% reflectivity near 1000-1050nm.As input Source IW=1.25µm, Reflectivity is 99.9% near 1050nm-1150nm. Similarly, forIW=1.35µm, Reflectivity is

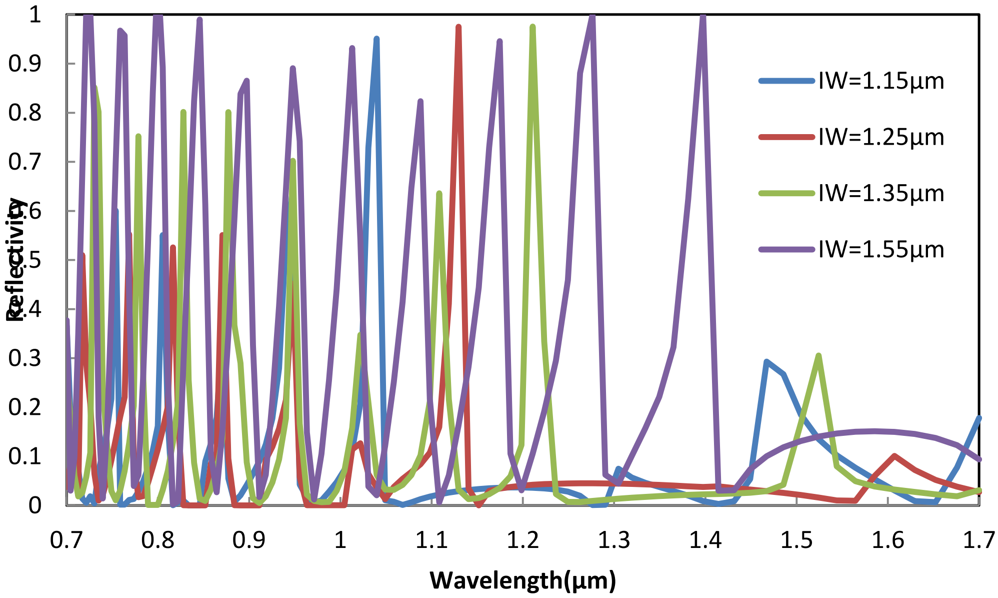

Figure.4.4: Reflectivity vs. wavelength for Sampled Grating Based Structureat different input values of wavelength. Photonic waveguide parameter, Grating Period of Si is 0.5µm,Grating Spacing(b)=0.25µm, Sampling period(d)=3.5µm,w_s= 0.1µm,w_d= 2.5µmat different input wavelength.

Near about 99.9% between1200nm-1250nm. As IW=1.55µm, Reflectivity is near about99.9% at various wavelength regions.

From Fig.4.3 and Fig.4.4, it is observed that in Traditional Grating Structure, high reflectivity is found almost at single wavelength for IW=1.55µm. For Sampled Grating based waveguide structure, maximum reflectivity is found at multichannel for IW=1.55µm. The observation from this case having the best results for Optoelectronic devices, which is named as Grating based Multiwavelength Optical Reflector.

4.3.2 Variation of Reflectivity versus Wavelength with Grating Period (k):

Fig.4.5 shows the Reflectivity versus wavelength of Proposed Sampled Grating based waveguide structure, on taking waveguide parameters, grating period(k) = 0.4µm, w_s= 0.1µm,w_d= 2.5µm, d=3.5µm at input wavelengths of 1.55µm. Here we are varying the values of Grating Spacing b. AsGrating Spacing(b)=0.24µm, multiwavelength reflectivity can be found. Reflections are found to be 70% for highest peak and 50% for other peaks at different wavelengths.

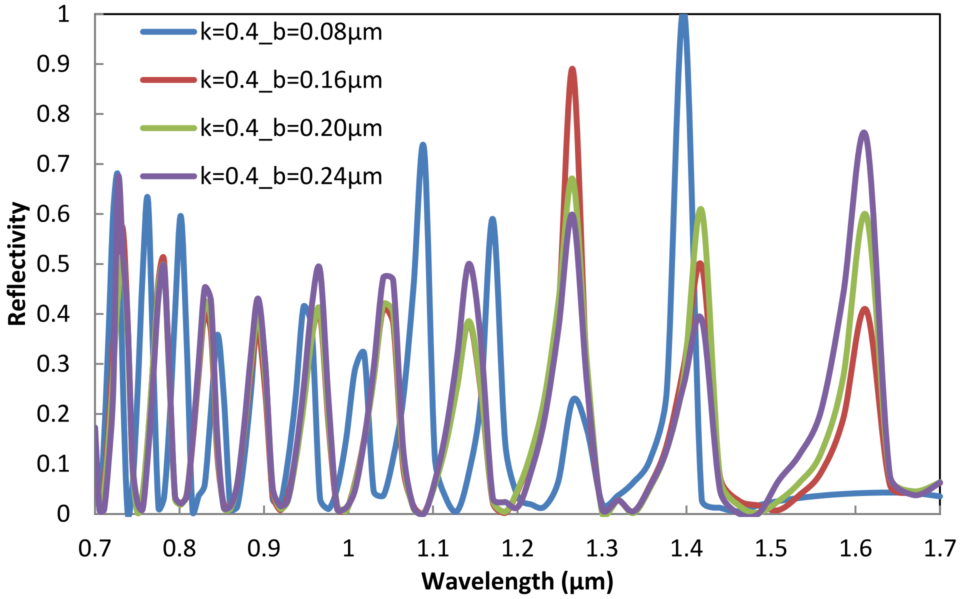

Figure.4.5: Reflectivity vs. wavelength for Sampled Grating Based Structure withGrating Period of Si is 0.4µm for different Grating Spacing, Sampling period(d)=3.5µm,w_s= 0.1µm,w_d= 2.5µmat 1.55µm input wavelength.

As Grating Spacing(b)=0.20µm, reflectivity at different wavelengths are less as compared to previous case. For Grating Spacing(b)=0.16µm, reflectivity is 90% near 1200nm-1300nm. The Multichannel reflectivity is observed for Grating Spacing(b)=0.08µm. This case having the best results for Multichannel reflectivity.

Fig.4.6 shows the Reflectivity versus wavelength of Sampled Grating based waveguide structure, on taking waveguide parameters, grating period(k) = 0.5µm, w_s= 0.1µm,w_d= 2.5µm, d=3.5µm at input wavelengths of 1.55µm. Similarly, from the previous case variation of the values of Grating Spacing(b) is performed.

It is noticed that, as Grating Spacing (b)=0.30µm, multiwavelength reflectivity can be found. Reflections are found near to be 100% for single highest peak and very less for other peaks at different wavelengths. For Grating Spacing(b)=0.25µm,99.9% reflectivity at different wavelengths areobserved. For Grating Spacing(b)=0.20µm and 0.10µm, reflectivity is less as compared to previous value of Grating Spacing.

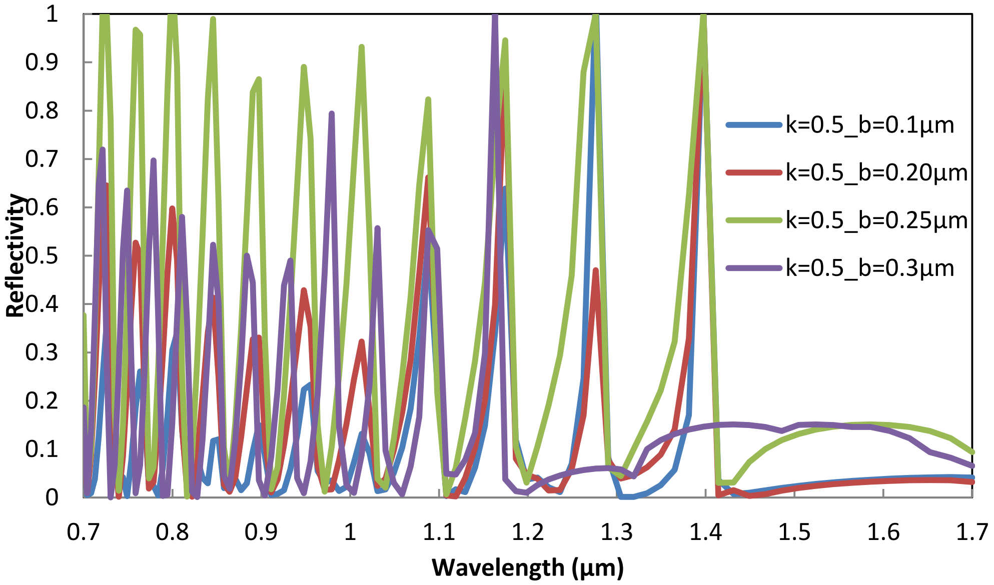

Figure.4.6: Reflectivity vs. wavelength for Sampled Grating Based Structure withGrating Period of Si is 0.5µm for different Grating Spacing, Sampling period(d)=3.5µm, $w_s =$ 0.1µm, $w_d =$ 2.5µmat input wavelength 1.55µm.

From Fig.4.5 and Fig.4.6,when spacing (b) is 0.08µm for period (K) as 0.4µm i.e. spacing is 20% of the period, then very high Reflectivity is found, compared with those cases having slightly large spacing size. Lowest Reflectivity is seen for largespacing (0.24µm) i.e. spacing is 80% of the grating period.

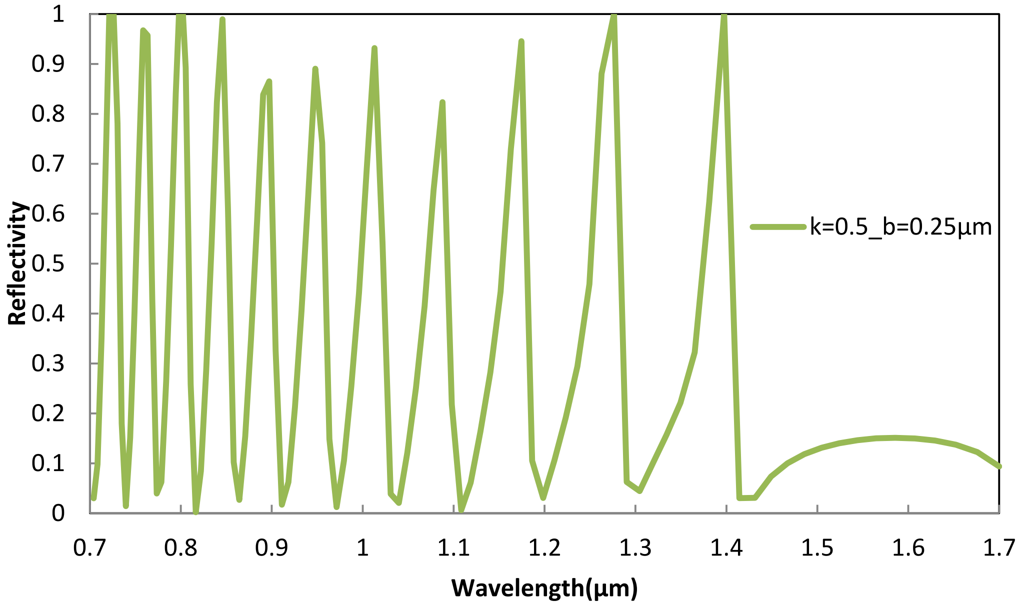

Figure.4.7: Reflectivity vs. wavelength for Grating Spacing is 50% of Grating Period, which is 0.5μmSampling period(d)=3.5μm,w_s= 0.1μm,w_d= 2.5μmat input wavelength 1.55μm.

The better result is seen in the case for K = 0.5μm. Both cases showed some exciting results, (a) maximum Reflectivity is found at when grating is 80% of the grating period and (b) for 50% spacing Reflectivity is observed much better results if we compare both. Fig.4.8 showing the Case(b) i.e. Best Result for Multiwavelength Reflectivity.

4.4 Modified Structure of Sampled Grating used for Filtering

The Modified subwavelength Si Sampled grating structure, where first and fourth sample of Si are removed. Here, w_s is the groove depth, k is the grating period, and w_d is the width of Glass Substrate. Here we are taking two samples only. Here,k = 0.5μm,w_s= 0.1μm,w_d= 2.5μm, d=3.5μm and the incident wavelength is 1.55μm.

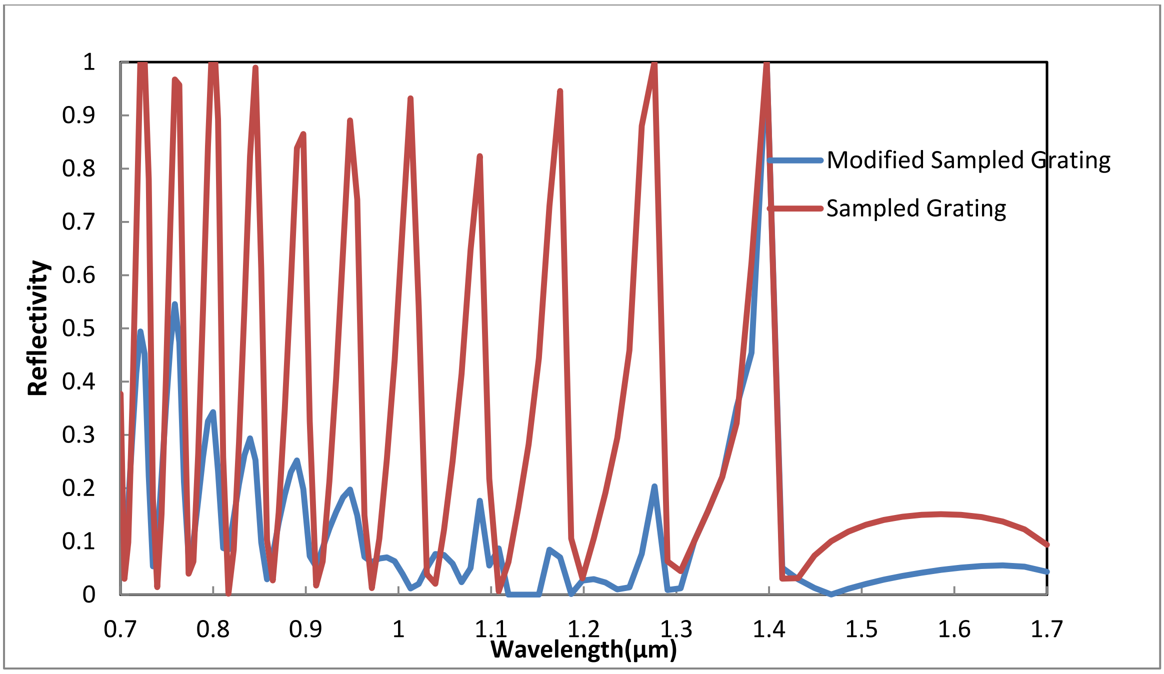

Figure.4.8: Reflectivity vs. wavelength for Modified Structure of Sampled Grating, where Spacing is 50% of Grating Period i.e. is 0.5µm for two samples only. Sampling period (d)=3.5µm,$w_s =$ 0.1µm,$w_d =$ 2.5µmat input wavelength 1.55µm and Sampled grating structure.

From Fig.4.8, it is noticed that with Proposed Sampled grating structure, multiwavelength reflectivity can be near about 100% at various wavelength areas. On taking waveguide parameters, grating period(k) = 0.5µm, $w_s =$ 0.1µm, $w_d =$ 2.5µm, d=3.5µm at input wavelengths of 1.55µm for grating spacing (b) =0.25µm. and with Modified Sampled grating structure,multiwavelength reflectivity can be found 99.9% at single wavelength area. The lower reflectivity can be found at other wavelength areas. And some area is totally suppressed. This suppression of some area can be utilized for filtering operation.

CHAPTER 5

CONCLUSION

This dissertationtargets at the design, simulation and analysis of sampled grating waveguide based 1D Photonic Crystal. Sampled grating of Si, which is having higher refractive index (3.54) than the substrate (1.6). A detailed study on reflection spectrum at different wavelength, for different parameters like grating period, grating spacing has been investigated. Modified Sampled Structure also gives exciting results which we used for filtering operation from Multichannel wavelength Reflections.

The subwavelength Si Sampled grating waveguide structureis proposed with a simplified waveguide-design on substrate and samples of Si repeats periodically. Reflectivity at Multichannel wavelength has been investigated. k = 0.5µm, Where, w_s = 0.1µm, w_d = 2.5µm, d=3.5µm and the incident wavelength is 1.55µm.The Sampled grating structure gives more exciting results than Traditional grating structures and with the value of k = 0.5µm at 1.55µm having the more exciting results, The reflectivity from some wavelengths are suppressed out. And this suppression of peaks from some area can be used for filtering operation. Thus, we can use it as a filter.

The Multiwavelength reflections, which are one of the most important features in Sampled Grating waveguides, will bring up new prospects for functional waveguide devices based on photonic crystals. The proposed work suggests by changing Grating period and sampled space, it can be used for more applications in the optical field.

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