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Optimization of Reluctance and Diffraction Efficiency of SOI Grating Structure for Planar Light Wave Circuits

G Palai

Gandhi Institute for Technological Advancement, Bhubaneswar, Odisha, India.

INFO

E-mail Id:
gpalai28@gmail.com

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ABSTRACT

Now days the top layer silicon is made inform of grating structure for the sake of Planner light wave circuits. The grating structure is consists of alternate layers of two materials, for an example alternate layers of silicon carbide and silicon monoxide. When light incidents on SOI waveguide light propagates through the grating. The efficiency of SOI waveguide depends on the grating structure, which is placed on the top of the insulator. In this research, we discusses about silicon grating SOI Structure. Mathematical analysis is described and simulation results with discussions are made for Si-SiC SOI grating structure.

Keywords: SOI, Si-SiC, CMOS

Introduction

Silicon on Insulator (SOI) is a layered of silicon insulator silicon substrate instead of conventional silicon substrate in semiconductor technology. Basically SOI belongs to microelectronics category.[1] To improve its performance, one has to reduce the parasitic capacitance.[2] SOI based devices differ from conventional silicon substrate in that the silicon junction is above an electrical insulator, typically silicon dioxide or sapphire.[3,4] The insulation part in SOI plays vital role for the sake of applications, for an example silicon dioxide is used for Planer light wave circuits.[5] Apart from the insulation layer, the top most, silicon layer plays major role for SOI applications. The first industrial applications of SOI were announced by IBM in the year 1998.[6] The reason for the implementation of SOI technology is to continue the miniaturation of microelectronic devices colloquially referred to as extending Moor's law.[7] It is also seen that SOI technology has two key benefits over ordinary silicon substrate (bulk CMOS) such as lower parasitic capacitance and resistance to latch. Beside these, it is also observed that SOI substrates are more compatible with most conventional fabrication process.

SOI wafers are widely used in silicon photonics.[8] The crystalline silicon layer on insulation can be used as optical waveguide. This enables the propagation of electromagnetic waves in the waveguide on the basis of total internal reflection. Basically, SOI is a heart of silicon photonics. The concept of light confinement in SOI waveguide near infrared is given by Richard Soref in the year 1986.[9] Using the concept of Richard Soref, after few years silicon waveguide started being design. In this case the silicon is usually patterned with sub-micrometer precision, into microphotonic components.[10] These operate in the infrared, most commonly at the 1.55 micrometer wavelength used by most fiber optic telecommunication systems. The silicon typically lies on top of a layer of silica in what (by analogy with a similar construction in microelectronics) is known as silicon on insulator. The propagation of light through silicon devices is governed by a range of nonlinear optical phenomena including the Kerr effect[11], the Raman effect[12], two photon absorption and interactions between photons [13] and free charge carriers.[14]

Silicon Grating SOI Structure

Silicon-on-Insulator (SOI) is emerging as the platform for large scale integration of optical functions.[15,16] Moreover, standard modern technology can be used to fabricate photonic integrated circuits, increasing the reproducibility and yield and lowering cost of fabrication.[17] SOI plays vital role in the recent explosion of one and two dimensional photonic crystal structures.[18] However silicons large refractive index also poses a number of challenges such as the ability to realize narrow spectral width Bragg's grating of interest for WDM filters as well as for nonlinear pulse propagation.[19] A promising approach is the use of 1D grating SOI structure to obtain its maximum efficiency. Recently it is shown that high efficiency grating can be obtained by optimizing grating design.[20] Basically an ordinary waveguide suffers to use in SOI due to different reasons, for example loss due to reflection at interface. This loss cannot be ignored, particularly in optoelectronic devices.[21] Recently a grating structure is proposed to overcome this problem.[22] The proposed structure is embedded in the SOI waveguide. The merit of using such structure is the for a particular wavelength the reflectance is zero, thereby the reflection loss for said structure is eliminated but another problem which arises in such structure is due to diffraction. We proposed a novel type of grating, where its efficiency can suitably be optimized. Above all, if the absorption in the waveguide can be decreased then the efficiency of overall transmission in the SOI will increase. To realize such grating structure we choose silicon-silicon carbide (Si-SiC) and silicon- silicon monoxide (Si-SiO) materials. The reason for opting such materials is that their absorption coefficient is zero.[23] Taking Si-SiC and Si-SiO material, a grating structure is proposed and then simulation is done for reflectance with respect to wavelength of light. This simulation is done by using Plane Wave Expansion (PWE) method to find a certain wavelength at which reflectance becomes zero. Apart from this, simulation is also made to optimize the diffraction efficiency of the grating structure corresponding to wavelength at which reflectance is zero. To sum up we have optimized the grating structure with respect to reflection loss, absorption loss and diffraction loss to yield maximum overall transmitted efficiency. The structure, we propose to allow high efficiency 1D grating is schematically depicted in Figure 1. In Figure 1, a silicon epitaxial grating layer is grown on oxide layer, which is placed on silicon substrate. In this chapter we propose two different grating structures such as Si-SiC and Si-SiO. The thickness of Si is 1 mm and thickness of SiC is 3 mm. The reason for choosing such thickness and refractive indices is that reflectance is found zero at wavelength 1 for Si-Sic and 1.25 for Si-SiO grating structure. Though a number of papers have appeared in literature relating to absorption loss in SOI waveguides[24-26], but to best of our knowledge a very few papers deal with reflection loss.[27] Moreover for the first time, we have considered the diffraction loss in addition to reflection and absorption loss.

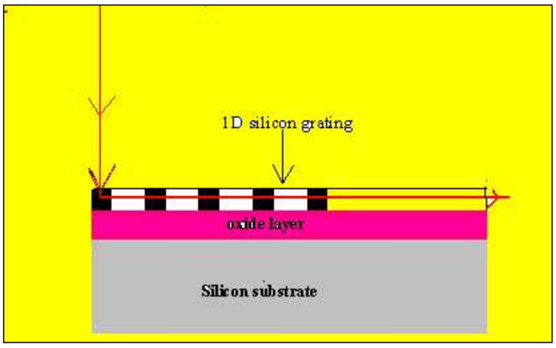

Figure 1.1D Grating SOI Structure

Mathematical Analysis

One can compute the reflectance of 1D grating structure by using wave equation from the system of Maxwell's eqautions which is represented by Helmholtz equation[28]. The Helmholtz equation for 1D grating structure is represented in the following form:

$$\frac{\partial^2 E_z(x)}{\partial x^2} + \varepsilon_r(x).\frac{\omega^2}{c^2}E_z(x) = 0$$

Where Ez(x) is electric field along z direction, which is a function of direction of propgation (x) is the relative permittivity of a grating layer along x-axis is the radiation angular frequency and c is the velocity of light in vacuum. Here we have co-ordinate derivative along on dimension only because the variation of permittivity takes place along this direction only. By using equation (3.1), it is possible to find out the field distribution and reflectance of 1D grating structure. To solve equation (3.1) for finding reflectance, one has to choose correctly the structure parameters such as refractive indices and thickness of layers of 1D grating structure. The said 1D grating structure is shown in Figure 2.

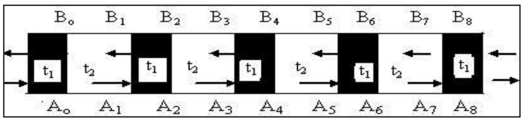

Figure 2.1D Grating Structure Showing Forward and Backward Amplitudes

Where, A0, A1, A2, A3, A4, A5, A6, A7 and A8 are backward waves corresponding each layer. B0, B1, B2, B3, B4, B5, B6, B7 and B8 are forward waves corresponding each layer.

t1 and t2 are thickness of grating layers. Where A and B are amplitudes of forward and backward waves correspondingly. The superposition of forward and backward waves give field distribution. To find out value of A and B, we have considered suitable initial and boundary conditions. In this case initial conditions are those on which determine the radiation source. Since the radiation incidents the grating structure from free space, the initial conditions are defined at the boarder of the considered computation regions. As far as boundary conditions are concerned, we have considered the reflectance corresponding last interface is zero (the backward wave amplitudes correspondingly last interface is zero). In case of 1D grating structure, the tangential component of electric field is considered, so boundary conditions are formulated as the equality of the wave functions and their derivatives at the interfaces. Writing down such an equation system for each structure interfaces, i.e.

$$E_j(x) = E_{j+1}(x)$$

$$\frac{\partial E_j(x)}{\partial x} = \frac{\partial E_{j+1}(x)}{\partial x}$$

Where xj is the coordinate of jth interface.

Using equation (3.2), (3.3)and (3.4), the resulting equations are expressed in the following form:

$$A_j e^{i.n_j k.x_j} + B_j e^{-i.n_j k.x_j} = A_{j+1} e^{i.n_{j-1} k.x_j} + B_{j+1} e^{-i.n_{j-1} k.x_j}$$

Writing down such an equation system for each structure interfaces, we obtain the system of linear equations containing 2N+2 equations for the structure having N layers. The system contains 2N+4 unknowns. The system of linear equations can be.

Result and Discussion

For making simulation for Si-SiC grating structure, we have used different input parameters of said grating structure, which is shown in Table 1.

Table 1.Different Input Parameters of Si-Sic Grating Structure

Name of the grating structure	Refractive indices		Thickness in mm	
	Si (n1)	SiC (n2)	Si (t1)	SiC (t2)
Silicon-silicon carbide (Si-SiC)	3.449	2.61	1	3

Using data from Table 1, we have done simulation for Si-SiC grating structure to find out the reflectance with respect to wavelength. The simulation result for Si-SiC is shown in Figure 3.

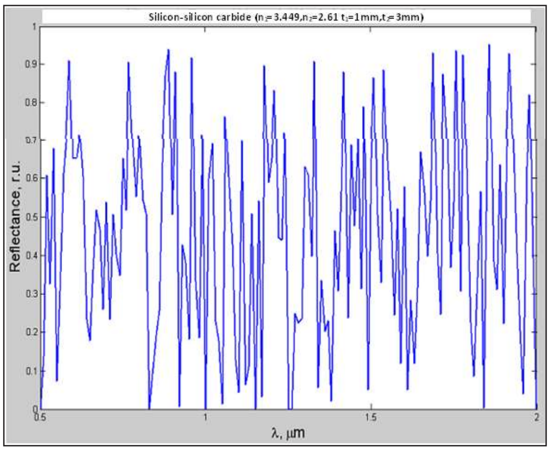

Figure 3.Simulation Graph Reflectance with Respect to Wavelength of 1D Si-SiC Grating Structure

In Figure 3, the top of graph shows the input parameters such n1 (refractive index of silicon) is 3.449, n2 (refractive index of silicon carbide) is 2.61, t1 (thickness of silicon) is 1 mm and t2 (thickness of silicon carbide) is 3 mm. In this graph, the wavelength taken along horizontal axis where as reflectance, r.u.(reflectance unit) is taken along vertical axis. It is seen from above Figure 3, that, there are different wavelengths for which the reflectance becomes zero but out of which we picked up 1 wavelength due to two reasons: firstly, this wavelength is within optical communication window and secondly, the diffraction loss is minimum at this wavelength. It is found that the reflectance is zero corresponding this wavelength, which shown in Figure 4. The top of the graphs shows the input parameters of 1D silicon-silicon carbide grating structure such as refractive index and thickness i.e. n1 (refractive index of silicon) is 3.449, n2 (refractive index of silicon carbide) is 2.61, t1 (thickness of silicon) is 1 mm and t2 (thickness of silicon carbide) is 3 mm and 1. In this Figure, the denuting from Bragg's angle of incidence in radian is taken along x-axis and diffraction efficiency in % is taken along y axis.

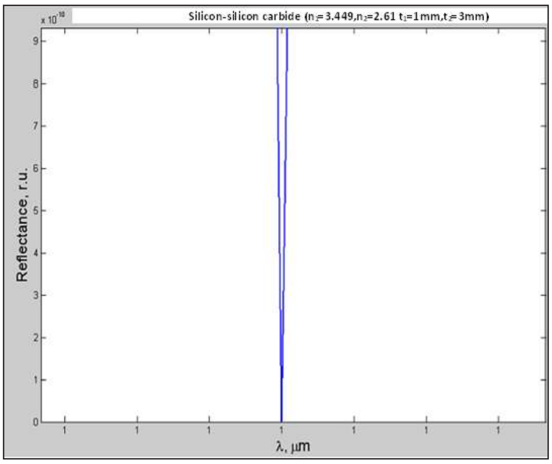

Figure 4.Magnified Diagram for Reflectance with Respect to Wavelength 1 of 1D Si-Sic Grating

Figure 4, depicts the magnified portion of reflectance, r.u., which is zero corresponding to wavelength of 1. As both absorption coefficent and reflectance (R) is zero, the transmitted efficiency (T) is determined by using equation (5.9), which will be 1.

Table 2.Different Input Parameters of Si-Sic Grating

Name of the grating structure	Refractive indices	Thickness in mm		
Silicon-silicon carbide (Si-SiC)	Si (n1)	SiC (n2)	Si (t1)	SiC (t2)
	3.449	1.84	1	3

Again using data from Table 2, we have done simulation by using equation (3.8) for reflectance of Si-SiO grating structure with respect to wavelength. The simulation result for reflectance of Si-SiO grating structure is shown in Figure 5.

Again to determine the diffraction efficiency of Si-SiO grating structure, we have Figure 5 Simulation graph for diffraction efficiency of 1D Si-SiO grating structure we have considerd the wavelength at which reflectance is zero in addition to previous input parameters such as refractive indices and thickness of silicon and silicon monoxide. Besides this, we have taken Bragg's angle of incidence is $90^{0.}$

Taking above parameters (n1, n2, t1, t2 m) and using the above equations, we have carried out for simultion for diffraction efficiency with respect to detuning from Bragg's angle of incidence and its corresponding simulation result shown in Figure 5.

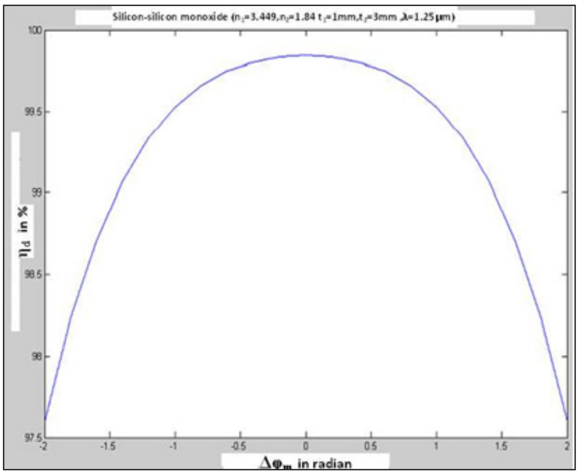

Figure 5.Simulation Graph for Diffraction Efficiency of 1D Si-Sio Grating Structure

In Figure 5, the top of the graph shows the input parameters of 1D silicon-silicon monoxide grating structure such as refractive index and thickness i.e. n1 (refractive index of silicon) is 3.449, n2 (refractive index of silicon monoxide) is 1.84, t1 (thickness of silicon) is 1 mm and t2 (thickness of silicon monoxide) is 3 mm and is 1.25.

Conclusion

From the above, the detunning Bragg's angle of incidence in radian is taken along x-axis and diffraction efficiency)in % is taken along y axis. It is seen that diffraction efficiency decreases very slowly with respect to detuning from Bragg's angle of incidence. Also found that the d is more than 99.5 % within this range (-1 radian to +1). Since is 1, by using eqaution, the overall transmitted efficiency is same with the diffraction efficiency d). So, we obtained that the overall transmitted efficiency of 1D Si-SiO grating structure is more than 99.5%.

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