Polarization Effect of Antireflection Coating for SOI Material System

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Abstract: ***For Silicon on Insulator (SOI) material system light transmission & polarization effect due to antireflection coating is investigated with the aid of CAD tool Essential Macleod & MATLAB. In case of one layer coating the transmission is 93.0440 % for TM polarized light and 92.6245 % for TE polarized light after layer thickness optimization. Multilayer coating for SOI material system (using different thicknesses and materials) some time gave identical result and some time less than the transmission got for single layer coating. Average transmission of light is increased about 19% due to the use of antireflection coating.***

Keywords: Polarization, *Silicon on Insulator, Transverse Electric, Transverse Magnetic*

1. Introduction

The propagation of electromagnetic waves generated from any light source normally influenced by the layered stack of media. The travelling light waves will be reflected, transmitted, refracted multiple times by interfaces between different media. So, different waves will present to the electromagnetic field in each layer of the stack which results interference phenomena [1], [2]. Some of the light incident on the stack of layers will be transmitted, part of it will be absorbed and part of it will be reflected. Maximum transmission and minimum reflection is desired at many applications. One of these applications is the antireflection (AR) coating, the design and fabrication method is discussed in [3]. One example of this AR coating is the efficient coupling of light from a fiber to waveguide or photonic integrated circuit and its surrounding medium. This AR coating is used in several related applications [4]-[6] Here an antireflection coating is developed so that the transmission of the guided mode of the waveguide structure through the interface between the photonic integrated circuit and its surrounding medium (air) is maximized [7] and to observe the polarization effect of light on antireflection coating. This AR coating is also used in telecommunication application [8].

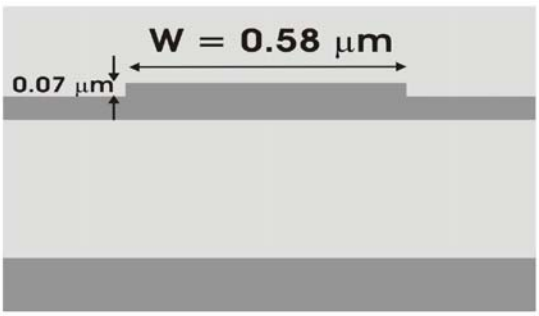

Figure 1. Waveguide facets for SOI material system

At the end facets (input and output side) of a photonic integrated circuit light is coupled respectively from and to an optical fiber. In order to maximize the transmission for horizontal coupling an antireflection coating can be deposited on the facets of the chip. Such an antireflection coating consists of a stack of thin films with accurately chosen thicknesses and refractive indices. For our analysis we will be considering the system as shown in Figure 1.The guided mode of the waveguide shown in Figure 1 is approximated by a Gaussian beam. In Table 1 the properties of this beam are given, σ_x and σ_y are the typical dimensions of the Gaussian function.

In Essential Macleod all layers of a stack are homogeneous. In this case the substrate is the cross section of a waveguide structure, which obviously is not homogeneous. Consequently, we modeled this cross-section by one single number, i.e. the effective index n_{eff} of the guided mode of the waveguide. Here λ_0 is the wavelength.

Table 1: Dimensions of the Gaussian field profile

Material System	λ_0 *[μm]*	σ_x *[μm]*	σ_y *[μm]*	n (n_{eff})
SOI	1.55	0.39	0.46	2.7

2. Design & Simulation of AR Coating

The AR coating is used to maximize the transmission and to analyze the polarization effect of the AR coating, to achieve this a single-layer coating is designed, then it was optimized and finally design of a multi-layer coating with the aid of the CAD tool Essential Macleod was conducted.

We consider the transmission at the interface of the waveguides (**Error! Reference source not found.**). In Essential Macleod we can only calculate the transmission through a stack of homogeneous layers, so we model the cross section of the waveguide structure by one single number, the effective index n_{eff} of the guided mode of the structure.

The CAD software enables us to calculate the transmission of plane waves incident at an arbitrary angle, but the guided modes of the waveguide structures are approximated by Gaussian beams (the properties of which are given in **Error! Reference source not found.**). We can solve this problem by decomposing the Gaussian beam into its plane wave components through spatial Fourier transform, calculating the transmission for each of these components and then using the inverse Fourier transform to obtain the transmitted beam.

The transmission through a layer stack is calculated, which is built up of a semi-infinite substrate layer (in this case the waveguide), a number of thin films and another semi-infinite medium (in this case air). The thickness of each layer can be set by a physical thickness and by an optical thickness. The optical thickness is equal to the number of wavelengths the layer contains:

$$Optical\ thickness = \frac{physical\ thickness}{\lambda/n}$$

3. Result & Analysis

3.1 Without AR coating

To have clear understanding first of all the measurement was done without any coating so that we can use it as reference. In this case there is no transmission above critical angle i.e.

$$Critical\ angle = \sin^{-1}\left(\frac{1}{2.7}\right) = 21.74^{o}$$

We also observed 100% transmission at Brewster angle i.e.

$$Brewster\ angle = \tan^{-1}\left(\frac{1}{2.7}\right) = 20.32^{o}$$

For perpendicular incidence (incident angle=0^0) transmission can be calculated [9] as-

$$r = \frac{n_{eff} - 1}{n_{eff} + 1} = 0.46$$

$$T = 1 - R = 1 - r^2 = 79\%$$

The phase is zero everywhere i.e. Phase = 0.
Because there is no coatings, as there is coatings as a result no phase change and no interference.

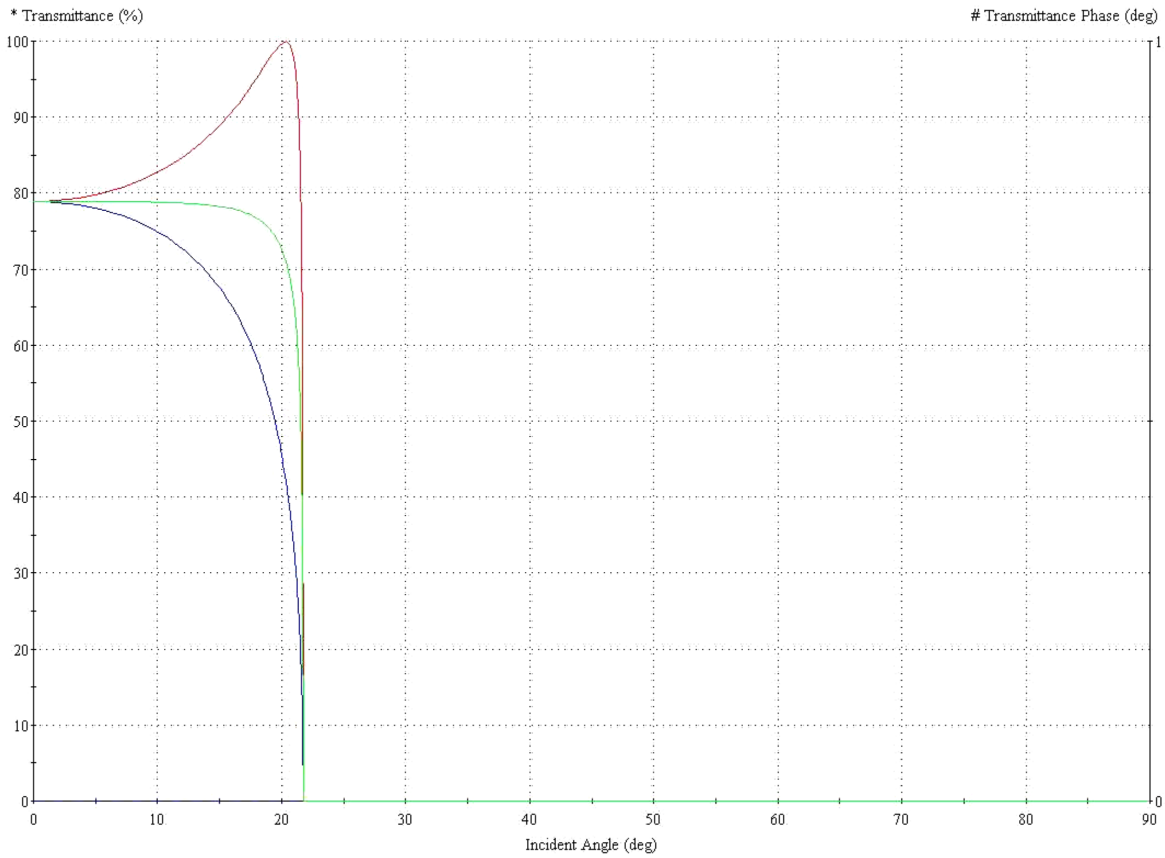

Figure 1: Transmission for all polarizations when there is no coating: magnitude (solid lines) and phase (dashed lines).

TM: red, TE: blue, Mean: green

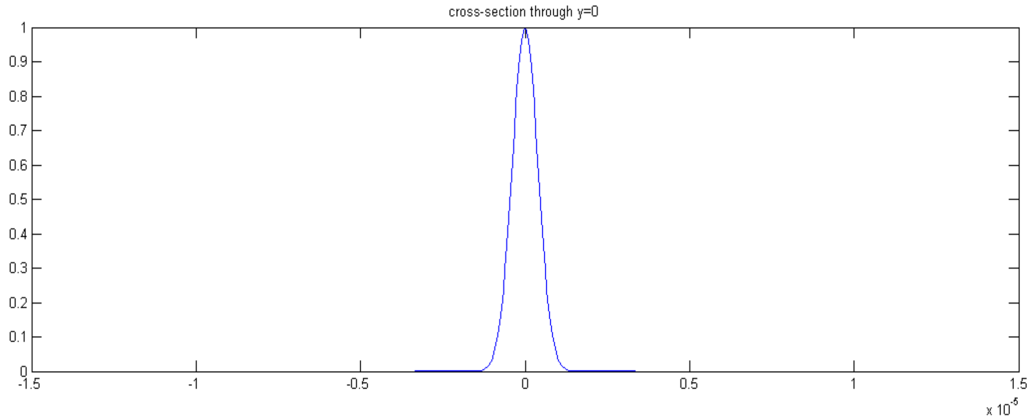

Figure 2: Input field amplitude

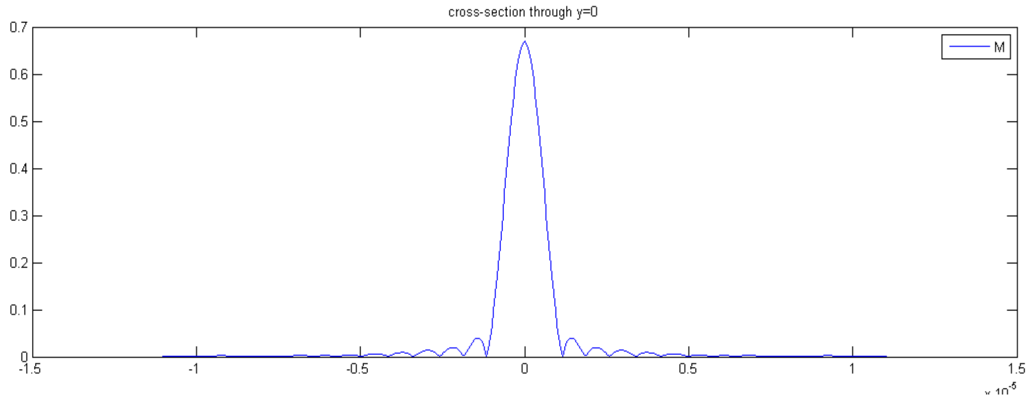

Figure 3: Output field amplitude (mean)

From the Figure 2 it is clear that Transverse-Electric (TE) polarized light transmission is slightly lower than the Transverse-Magnetic (TM) polarized light because of the Brewster angle but both polarizations (TE & TM) have similar amplitude profile. As there is no coating it is desired that there will be no interference at the output. The output should be as input (Figure 3). But it is clear from the Figure 4 that there are interferences at the output. These interference fringes around the edges of the Gaussian beam because the beam width is small compared to the wavelength, which causes diffraction. Global transmission is calculated using the Table 1 parameters and MATLAB simulator. Thus we got global transmission as-

TM Polarized Light = 79.6163%
TE Polarized Light = 67.3830%
Mean = 73.4983%

As expected, the global value is slightly lower than the value for perpendicular incidence because the Gaussian beam also has plane wave components with a more oblique incidence, for which the transmittance is lower (Figure 2).

3.2 One layer AR coating

Theoretical values for single layer coating can be calculated as [10]-

$$n_{AR} = \sqrt{2.7} = 1.64$$

$$physical\ thickness = \frac{1}{4} \cdot \frac{\lambda}{n_{AR}}$$

So, Layer thickness is 236.25 nm.
According to the Snell's law-

$$n_{SOI} \cdot \sin(\theta_{SOI}) = n_{AR} \cdot \sin(\theta_{AR}) = n_{air} \cdot \sin(\theta_{air})$$

Critical angle when θ_{air} = 90° or θ_{AR} = 90° is-

$$\theta_{SOI,crit} = \min\left\{\sin^{-1}\left(\frac{n_{air}}{n_{SOI}}\right), \sin^{-1}\left(\frac{n_{AR}}{n_{SOI}}\right)\right\}$$

$$= \sin^{-1}\left(\frac{n_{air}}{n_{SOI}}\right) = 21.74°$$

In this case the phase change will be different for TE & TM polarization.
Due to the fact that there is a phase change, the different plane wave components of the Gaussian beam will interfere between each other. This will cause a lower transmission than we see in Figure 6.

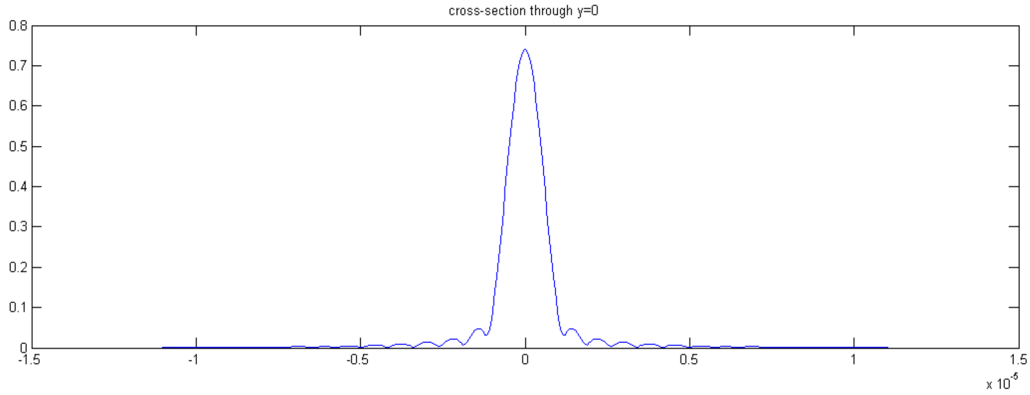

Figure 5: Output field amplitude (Mean)

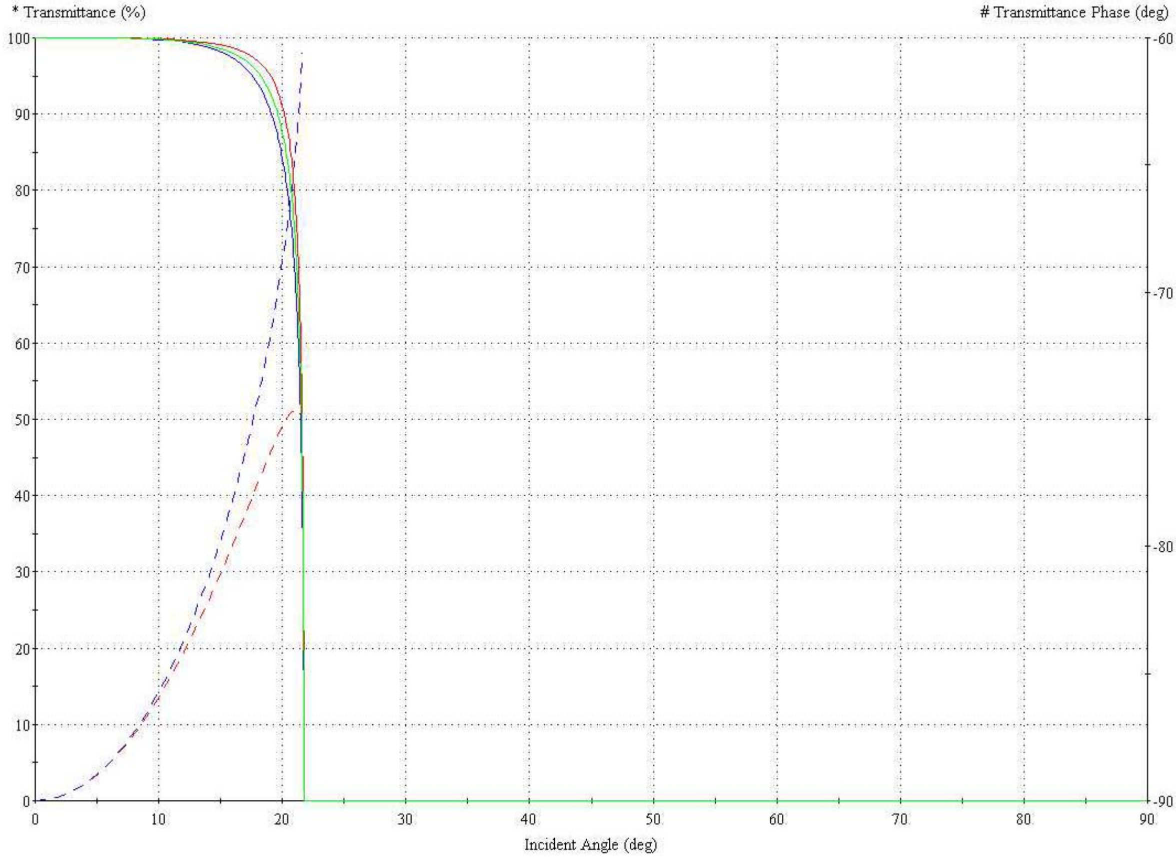

Figure 6: Transmission for all polarisations for a single layer coating: magnitude (solid lines) and phase (dashed lines). TM: red, TE: blue, Mean: green

Mean transmission shows stronger interference fringes, TM also slightly stronger interference than TE.

TM-transmission slightly higher than TE-transmission: smaller phase shift for TM than for TE (Figure 6) results less interference of the plane waves.

Global transmission is-

TM Polarized Light = 93.0245 %
TE Polarized Light = 92.2584%
Mean = 92.6414%

The transmission is much lower than expected, because of (both) interference effects.

3.3 Optimized one layer AR coating

Optimization of the coating was done by changing the thickness of the layer to increase the transmission. We set the targets to a wavelength of 1550 nm, and 100% transmission between 0° and different angles. We obtained the best results for an angle range of 0°-15°. The optimized physical thickness is 246.97 nm.
Global transmission is-

TM Polarized Light = 93.0440 %
TE Polarized Light = 92.6245%
Mean = 92.8342%

The transmission is slightly higher than before the optimization.

3.4 Multi layer AR coating

Optimization for higher transmission with multiple layers was conducted. Used layers were maximum 5 or less, this will limit calculation time and is also more realistic: adding more layers will complicate fabrication.

When we use the same targets as we did and a maximum of 5 layers, the program generates a one-layer coating identical to the one we used in the previous section. Using different targets did not help us find a better solution, on the contrary: some of the multi-layer coatings we created gave a lower transmission than the one layer coating.

4. Conclusion

It is clear from the above analysis that if we use the antireflection coating to maximize the transmission then we get on an average 19% more transmission than if we use no antireflection coating. The main thing to consider is the polarization, when there is no AR coating the difference between TM polarized light transmission (79.6163%) and the TE polarized light transmission (67.3830%) is high. But when we use AR coating the light transmission difference between the TM (93.0245 %) & TE (92.2584%) polarized light become smaller. So by using AR coating we can reduce the polarization effect of lights. Though AR coating reduces the polarization effect but TM polarized light transmission is always higher than the TE polarized light. This type of investigation can also be conducted for Silica on Silicon (SOS) and other material system to find out the optimized way to use AR coatings regarding polarization and maximum transmission of light.

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Author Profile

Imran Khan received his B. Sc. Engineering degree in Electronics and Communication Engineering from Khulna University of Engineering & Technology, Bangladesh in 2008. He completed photonics postgraduate course works from Ghent University (Belgium) and University of Ottawa (Canada) in 2010 & 2011 respectively. He worked as a research assistant in photonics research lab, University of Ottawa, Canada. In 2012 he joined as a faculty member in Jessore Science & Technology University (JSTU), Bangladesh in the Department of Electrical and Electronic Engineering (EEE). His areas of research are photonics, SPR sensors & optoelectronics.