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MODAL FIELD CONFINEMENT IN SUBWAVELENGTH WAVEGUIDING STRUCTURE MODELED BY USING SCHRODINGER WAVE EQUATION

SHILPA KULKARNI[1*] AND SUJATA PATRIKAR[2]

[1]Department Applied Physics, Ramdeobaba college of Engineering and Management, Nagpur-13, MS, India.
[2]Department of Applied Physics, Visvesvaraya National Institute of Technology, Nagpur -10, MS, India.
*Corresponding Author: Email- shilpaku@rediffmail.com

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Abstract- Equivalence between Maxwell's equations and Schrodinger wave equation is already established which works for weak guidance condition**.** Modal distribution in waveguiding structures can be obtained by using Maxwell's equations. Silicon-on Insulator waveguides have now a day gained much attention in view of building integrated optical devices. Waveguides with high refractive index contrast between core and cladding enable tight light confinement. However, in nanoscale dimension waveguides, the confinement factor reduces. In this paper, a novel method has been used to model field confinement in nanoscale waveguiding structure using Schrodinger wave equation. In this work, light confined in the nanoscale waveguide is treated as photon trapped in a potential well and an equation based on Schrödinger wave equation is obtained for modeling the loss. Field confinement obtained by using this equation show trends similar to those obtained by conventional theory and the experimental results.
Keywords- Field confinement, Schrödinger wave equation, nanoscale silicon waveguide, trapped photon

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Introduction

Photonics promises an increase in computing speed and efficiency for microprocessors by reducing the response time of global interconnects and thus reducing delays.[1] It is now a days desired that networking devices should be all-optical devices, which could be directly connected to the computers. Existing optical devices are made from III-V based compounds such as Indium phosphide (InP), gallium arsenide (GaAs) or the electro-optic crystal lithium niobate ($LiNbO_3$) and are very expensive. Also, they are large, bulky, and mostly assembled from discrete components [2]. For futuristic application of optical devices for networking, they should be suitable to get integrated with existing electronic devices. Existing optical devices are not suitable for integration**.**

In light of this, Silicon (Si) could be a potential candidate for building optical devices. Silicon has various useful characteristics and distinct capabilities to build optical functionalities in it. Band gap of silicon (≈ 1.1 eV) makes it transparent to the wavelengths commonly used for optical communication (1.3-1.6 μm). Standard lithography techniques meant for electronic device processing can also be used to fabricate optical devices on silicon. Because of favorable electronic, optical and physical properties of silicon and established CMOS fabrication processing technology, large scale integration of functional optical devices on silicon has become possible; including its integration with relatively complex electronic components.

The need to integrate optical devices with existing nanoscale electronic devices demands that the optical devices should be of nanoscale dimension.

In nanoscale optical devices, because of reduced dimensions, Total Internal Reflection (TIR) should be maintained at smaller angles. This is facilitated by a high refractive index of silicon, and it is key property to build optical components on it. Now, high refractive index contrast between core and cladding leads to good field confinement. For this reason, the single crystal silicon waveguide with refractive index 3.5 with a thin amorphous layer of

silicon dioxide (SiO2) with refractive index of 1.5 as cladding are widely used. These waveguides are preferred since index difference of the two materials is ≈2. This allows small angles for TIR and tight bends in waveguides.[3] Because of this, silicon waveguided devices can be scaled down to ultra small cross sections, < 0.1 μm2. [4]. The SiO_2 layer below optically isolates the waveguide from underlying bulk silicon wafer. This waveguide is commonly called as Silicon-on-Insulator (SOI) waveguide. The planar SOI waveguide has SiO_2 as the substrate and air as upper clad.
Most optical devices need single mode operation and this can be achieved by selecting suitable refractive index contrast between core and cladding. So, this becomes a critical parameter that decides the maximum thickness for which slab waveguide will be single mode. For Si-SiO2 waveguide, with their refractive indices, silicon layer must be kept to a thickness of less than about 250nm. [5]

What is Done so Far
In the reported theoretical work, for analyzing optical waveguides, researchers have used standard analytical cosine function in waveguide region and exponentially decaying function in cladding region.[6] In nanoscale dimension waveguides, field confinement reduces. For weak guidance condition, equivalence between Maxwell's equations and Schrodinger wave equation is established.
Hence, in this work, a novel method is used to model the field confinement in nanoscale waveguiding structure using Schrodinger wave equation.

Present Work
Concept of trapped photon
Similar to quantum confinement of electron in nanoscale dimension structures; when dimensions of optical waveguide become comparable to subwavelength size, photon can be regarded as trapped in a potential well, with a finite probability of existence outside the well. Thus, light has a nonzero field in cladding region. Hence, penetration of field is found in cladding region [6], which is commonly known as evanescent field. As per our understanding of trapped photon, core region with high refractive index contrast is a region of photon confinement and barrier tunneling occurs in cladding region. The potential barrier condition has been established at core and cladding interface on both sides of the waveguide, in terms of ratio of their refractive indices. The entire profile is generated by using solution of Schrödinger wave equation, in a single shot. Similar to the way in which tunneling probability of electron in a potential well depends upon height of potential barrier, here, percentage penetration in cladding depends upon refractive index contrast between core and cladding.

Schrödinger wave equation
In our analysis, following Schrödinger wave equations for core and cladding regions respectively have been used.

$$\frac{\partial^2\phi}{\partial x^2}+\frac{8\pi^2(\mu^2)_{clad}}{\lambda hc}\left(\frac{hc}{\lambda}-\frac{\mu_{core}}{\mu_{clad}}\right)\phi=0$$

$$\frac{\partial^2\phi}{\partial x^2}+\frac{8\pi^2(\mu^2)_{core}}{\lambda hc}\left(\frac{hc}{\lambda}-1\right)\phi=0$$

These equations have been written for a slab waveguide with variation in refractive index along x-direction and structure is uniform along y-direction. Here, f represents electric field in y-direction, l being incident wavelength and μ is the refractive index. Other symbols carry usual meaning.
These differential equations are discretised using method of finite differences and solved rigorously to calculate electric field in core and cladding region. The boundary conditions used are: both f and their spatial derivatives are continuous at core and cladding boundary and f is zero at large distance from the interface.
The discretised equations for core and cladding regions respectively are:

$$\frac{\phi[x+d]-2\phi[x]+\phi[x-d]}{d^2}+\frac{8\pi^2(\mu^2)_{clad}}{\lambda hc}\left(\frac{hc}{\lambda}-\frac{\mu_{core}}{\mu_{clad}}\right)\phi[x]=0$$

$$\frac{\phi[x+d]-2\phi[x]+\phi[x-d]}{d^2}+\frac{8\pi^2(\mu^2)_{core}}{\lambda hc}\left(\frac{hc}{\lambda}-1\right)\phi[x]=0$$

Here, 'd' is the discretisation parameter. In the calculations, incident wavelength is in micrometer range. Intensity of electric field is calculated at about 200 points and plotted graphically. The field profile so obtained is as expected, with maximum confinement in core and exponentially decreasing in the cladding region.

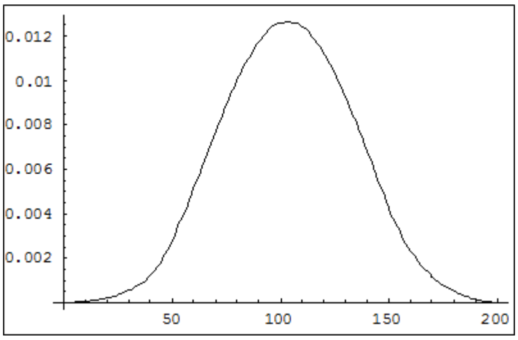

Fig.1- Percentage field in air and in SiO_2 for a wavelength of 1.3 μm, and waveguide height 233nm.

Validity of the concept
For testing the validity of this concept, a nanometer dimension Silicon-on-Insulator waveguide with SiO_2 as the substrate and air as upper clad is used. Calculations are done for various waveguide heights and various wavelengths. It is observed that results of our calculations show trends similar to the experimental data given in available literature. All the calculations are done using software package 'Mathematica'.
Following are some cases of our study:

Field confinement in nanometer dimension Air-Si-SiO_2 Waveguide and its Variation with Waveguide Height
This calculation is done for Silicon-on-Insulator waveguide with air as the other cladding, considering smooth waveguide. Field confinement is calculated for various waveguide heights. It has been observed that field confinement decreases with decrease in waveguide dimension, as shown in Fig (2). It is also found that field in SiO_2 is more than that in air, as expected. This result supports the fact that high refractive index contrast is required for better field confinement.

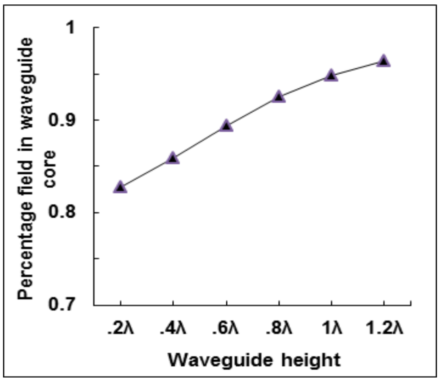

Fig. 2- Field confinement inwaveguide core of SOI waveguide, for various waveguide heights of nanometer dimension. (l=1.3mm).

Field confinement in nanometer dimension Air-Si-SiO2 Waveguide and Variation with Wavelength

In this case, field confinement is studied for various wavelengths. Fig. 3 shows that percentage field confinement is higher at a wavelength of 1.3 μm and lower for 1.5 μm. The theoretical result so obtained shows a trend similar to the experimental data given in [7]. It is also observed that evanescent field in air is low as compared to that in SiO_2.

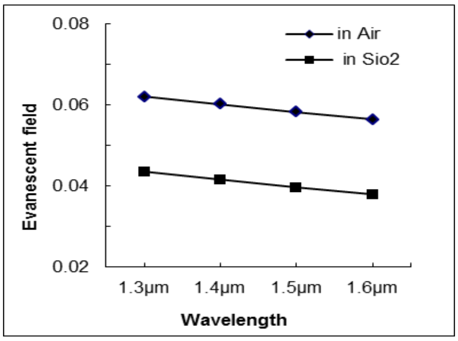

Fig. 3- Field in air and in SiO_2 for various wavelengths.

Field confinement in Silica fiber

Field confinement in silica fiber, dipped in alcohol media, has been calculated for various fiber diameters of micrometer dimension. Fig. 4 shows that percentage field confinement increases with fiber diameter. Our theoretical result shows a trend similar to the experimental data given in published literature in [8]

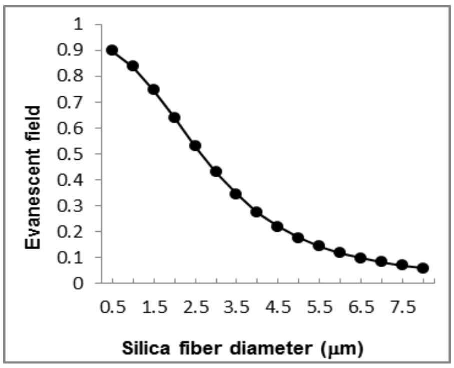

Fig. 4- Evanescent field in silica fiber dipped in alcohol for various waveguide heights of micrometer dimension

The model of Schrödinger wave equation given in this paper supports some more experimental results; which include field confinement in micrometer dimension SiO_2-Si-SiO_2 waveguide for various waveguide heights and for waveguides with cladding of various refractive indices and for various core diameters.

Conclusion

Field confinement in nanoscale dimension waveguide is modeled by using a novel concept of trapped photon. The model is based on Schrödinger wave equation and is useful to obtain field distribution in the nanoscale waveguide. The field confinement and its variation with respect to various parameters such as waveguide height, refractive index contrast and wavelength, is found to be in good agreement with conventional theory and available the experimental results, for nanoscale dimension SOI waveguide and micrometer dimension silica fiber.

References

[1] Knights A.P. and Jessop P.E. (2007) *Optical waveguides: from theory to applied technologies*.

[2] Reed G.T. and Knights A.P. (2004) *Silicon Photonics*, *John Wiley & Sons, Ltd*.

[3] Bynum M.R. (2006) *Silicon Photonics, Physics* 464 *Applied Optics, winter*.

[4] Osgood R.M. (2009) *Advances in Optics and Photonics* 1, 162 –235.

[5] Suhara T., Haruna M. (1989) *Optical Integrated Circuits*, *McGraw-Hill Professional*.

[6] Nelson T., Arif R., Jin Z. (2006) *Materials and Nanoscience*, *Sensors, nanoscience, biomedical engineering, and instruments*, 5.

[7] Vlasov Y.A., McNab S.J. (2004) *Optics Express*, 1622, 12(8).

[8] Chenghua S., biqing Y, Zheming Z. (2006) *IEEE conference on optics and optoelectronic*.