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Enhancing SiN Thermo-Optic Effect

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Abstract:
In this paper, we improve the TOE (Thermo-optic Efficiency) of SiN using SiOC as upper clad layer to simulate the waveguide and analyzed the refractive index by using MEEP/Beam-prop software for superior experimental results. In order to create photonic integrated circuits, a number of material platforms have been researched. (PICs). The semiconductors (Si, InP, GaAS) are not fulfil the complete requirement of photonics. So, we use dielectrics SiON, SiO_2, SiN, and SiOC at 1550 nm become well-established platforms lowest losses possible, they suffer from relatively lower coefficient of themo-optic, about 10^{-5} / C. Silicon Nitride (SiN) has low TOC 2×10^{-5} / K and the recently silicon oxycarbide (SiOC) has been shown to highest TOC among the dielectrics 4×10^{-4} / K.

Introduction:

In the 1980s the photonic IC technology appeared is a logical development of Silicon Photonics. As a result of integration, efficient photonic circuits may now process and transmit light in a manner similar to that of electronic integrated circuits. As Integrated Photonics is a developing filed of optical communication in which devices and waveguides are manufactured as an integrated structure on the surface level. The semiconductors Silicon (Si), Indium Phosphide (InP), Gallium arsenide (GaAS) and dielectrics (SiO_2, SiON, SiN) have been used in integrated photonics. Dielectric platforms at the standard telecom wavelength of 1550 nm have become well-established and exhibit low losses. In optical materials, semiconductors such as Silicon (Si) is mostly used in detectors, Indium Phosphide (InP) is used in lasers. Dielectrics platforms are well known for passive technologies like waveguides and devices. The optical characteristics of silicon oxycarbide fill were determined using spectroscopic ellipsometery in the near infrared spectrum on the order of 102.10^2 · The refractive index can be theoretically tuned from 1.45 to 2 due to the greater losses in silicon nitride compounds, whereas SIOC has various applications including Li-ion batteries [10], photoluminescence [11], [12], electro-luminescence [17] and others [18]. The change has been found in the SIOC from ~1.45 to ~3.0. [1]. The other optical properties of interest include refractive index [16], absorption coefficient and thermo-optic coefficient [14],

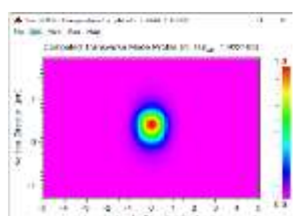
	Dielectric platforms	Refractive Indices	Losses [dB/cm]	Thermo-optic Coefficient
Dielectrics	Silica	1.45	0.1	0.9×10^{-5} /°C
	Silicon Nitride	1.99	0.1	2.5×10^{-5} /°C
Semiconductor	Silicon	3.44	4-8	1.8×10^{-4} /°C

[15] as compared to other materials such as silicon nitride and silica [19]. As shown in the table, the dielectric platforms suffer from a

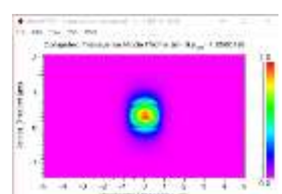
relatively lower coefficient of thermo-optic, that is around 10^{-5} /^{o} C. The refractive index of a material, denoted by n, specifies how rapidly light will flow through it. The thermo-optic effect is the thermal modulation of a material's refractive index by means of changing temperature, and it has the formula n=c/v, where c denotes the speed of light in a vacuum and v denotes the phase velocity of light. It is very popular because of many materials like fabrication ease and design simplicity [13]. This phenomenon has been employed in optoelectronics and sensor technologies to create a wide range of devices, including switches, tunable lasers, and fiber optic sensors. Silicon Nitride is well established platform with appealing characteristics such as moderate refractive index, lower losses and CMOS compatibility [7]. However it exhibits lower thermo-optic coefficient (TOC), on the order of 10^{-5}/ ˚C that is too low to enable efficient reconfigurable photonic devices and systems. Improve SIN's thermo-optic performance using silicon oxycarbide (SIOC). Silicon Nitride (SiN) enables the applications of biophotonics, optical signal processing, and sensing from visible to near mid-infrared wavelengths due to the broadband nature of the material [2] [24]. There are various material systems Doped glass, III-V semiconductors, polymers, silicon all are active in us today and have their own advantages. Silicon Oxycarbide (SiOC) has shown promising properties such as tunable refractive index, low losses, and higher thermo-optic coefficient of about 2.5×10^{-4} /^{o}C. The TOC of SiOC is 10 times larger than SiN. Through optical waveguides the PIC light is directed and processed [3], [4]. The optical properties, structural and morphological of SiOC thin film deposited by RF-magnetron sputtering, showing low stress, low level of impurities and achieved refractive index ranging from less than that of silica (about 1.40) to 3.0 (silicon carbide) [5]. In Silicon photonics one of the widely used reconfiguration techniques are the integration of metallic microheaters through thermal reconfiguration [6]. Where as integrated microwave photonics is a technology of combining radio frequency (RF) with equal levels of flexibility functions as compare to electronic counterparts [8]. Silicon oxycarbide (SiOC) has high theoretical capacity and good structural stability [9].

Results and Simulation Details:

For the purpose of simulating and calculating the effective refractive index (neff) values of the modes propagating in the middle part of a directional coupler, RSoft's beam propagation method software, known as BeamPROP, was utilised. Here, we achieved the best values for a single mode operation by adjusting the waveguides' width and height because multiple modes add a lot of complexity. For this investigation, it was necessary to determine the waveguides' width, height, core and cladding refractive indices, index difference, projected model dimensions, and many other variables. where the core material's width and height were chosen to be 1 and 0.3 microns, respectively, using the refractive index of core n_{core} = 1.99 (SiN) and cladding n_{clad} = 1.45 (Silica) and performed the Electromagnetic simulations TE and TM fundamental mode to understand the single mode operation of SiN waveguide. The
Neff (TE) = 1.922463 and Neff (TM) =1.856018.

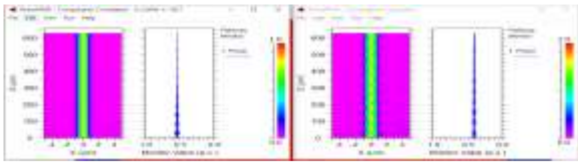


Computed TE
fundamental mode

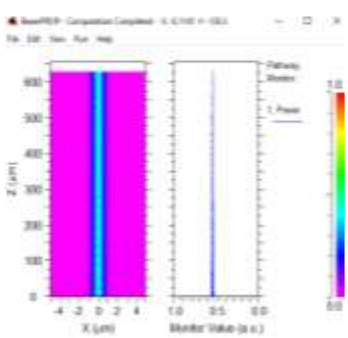


Computed TM
fundamental mode

In addition to perform coupling efficiency and mode confinement factor of SiN channel waveguide at different width and height. Coupling efficiency is the power transfer between two optical components. It is typically expressed as the ratio converted to percent of the input power, i.e., the available power from one component to the power transmitted to the other component.TE__H=0.3, W=1.2, neff= 1.89081 TM__H=0.3, W=1.2, neff= 1.81681



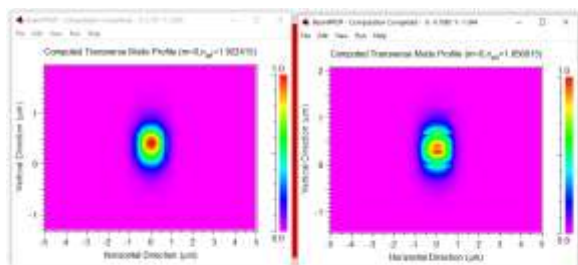
For confinement factor that electromagnetic field is confined to the core at the both Fiber mode of W=1.2 , H=0.3, and WG power of W=1.2 , H=1.3 that When the core thickness is greater than the electromagnetic signal's wavelength, wave propagation is restricted to the core. There will be a low optical waveguide confinement factor as the core thickness lowers because the electromagnetic field will radiate out from the core. Hence at the Width = 1μm Height = 0.3 μm the 96% waveguide confined.



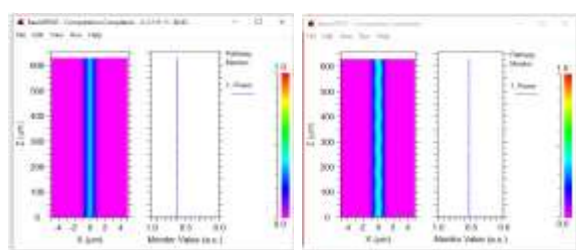
SiN/SiOC Waveguide:

As Silicon Oxycarbide (SiOC) has promising properties like tunable refractive index, low losses, and a higher thermo-optic coefficient of about 2.510-4 / C and 10 times larger TOC than other dielectrics, this ME thesis is to addressed the thermo-optic efficiency of SiN waveguides and devices that has been improved by using a SiOC layer for the application of reconfigurable photonic systems [25]. SiOC is a good example of a platform that is effective for both large-scale integration and photonic applications.We report on SiOC channel waveguides with silica buried in them, where it is found a record TOC that was even greater than that of silicon waveguides and around 30 times larger than that of waveguides made of silica [22] [23]. SiN/SiOC waveguide simulations performed at width w=1 microns and height H=0.35

microns to analyzed the coupling efficiency and confinement factor too with net effect at TE and TM mode.

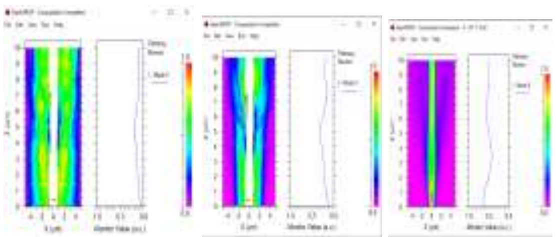


Height and width of waveguide	**Neff of TE & TM fundamental mode**
Width = 1 μm Height = 0.35 μm	TE=1.922415 TM=1.856015



TE mode TM mode

SiN/SiOC Waveguide Confinement Factor:



Standard fiber Small Core Fiber Tapped Fiber mode

The TOC of SiOC was determined by measuring the optical transmission of the produced waveguides at various temperatures [20] [21]. The waveguide's actual thermo-optic coefficient, abbreviated Keff, is given by the expression $n_g d\lambda$

$$Ke = \lambda dT \quad (1)$$

$$dn/dT = \sum Ki\gamma i \quad (2)$$

and results to be $K_{eff} = 2.5 \times 10^{-4}\ °C^{-1}$, with respect of SiO_2. The thermo-optic coefficient of the SiOC material can be evaluated by considering the overlap of the optical mode with all the materials the waveguide:

Ɣ= Confinment Factor

$$\Delta\lambda = \frac{dn/dT \times \lambda \times \Delta T}{Ng}$$

$$\Delta\lambda = 2.5\times10^{-5} \times 1.55\times10^{-6} \times 1 / 1.95$$

$\Delta\lambda = 1.92\times10^{-11}$ m or $\Delta\lambda = 19.2$ pm

The findings show that integrated systems can be reconfigured to be more energy-efficient. photonics with a wavelength of 1550 nm by effectively utilising the high TOC of SiOC.

$$dn/dT = dn/dT_{SiO2} \times \gamma_{SiO2} + dn/dT \times \gamma_{SiOC} + dn/dT_{SiN} \times \gamma_{SiN}$$

$$dn/dT = 0.9\times10^{-5} \times 0.475 + 2.5\times10^{-4} \times 0.2625 + 2.5\times10^{-5} \times 0.2625$$

$$dn/dT = 0.4275 \times10^{-5} + 0.6562\times10^{-5} + 0.65625 \times10^{-4}$$

$$SiOC/SiN = 7.6425\times10^{-5}\ °C^{-1}$$

The SiOC layer's measured refractive index is roughly 2.2.

$$\Delta\lambda = dn/dT \times \lambda \times \Delta T / ng = 7.6425\times10^{-5} \times 1.55\times10^{-6} \times 1 / 1.95$$

$\Delta\lambda = 6\times10^{-11}$m or 60pm

SiOC's high TOC suggests that it might be used as a component in high-integration-scale and low-control-power integrated optics, in addition to its transparency at telecommunication wavelengths and high refractive index. Here, we recommend and demonstrate the use of SiOC to build incredibly powerful thermo-optic phase shifters in well-established and conventional photonic technologies, such as Ge-doped SiO2 and SiON waveguides.

Different from previous work:

As 20 years before Photonics was a new filed but today systems are evolved. Previously, dielectric materials were typically used as a single platform for fabricating the waveguide and have used thermal tuners for reconfigurable systems but in this research have used core as a SiN and SiOC as upper layer research to observe that light has been confined 50% in the core and 50% in SiOC upper clad layer and it has more tunable effect than other dielectric materials. As SiN is good dielectric platform and have many useful properties, lower losses and moderate refractive index that is used by different foundries across the world for realization of integrated photonic circuits for different applications, In addition, medium to high contrast refractive index which is good for achieving large scale integration.

Conclusion:

This paper expected to address the thermo-optic efficiency of Silicon Nitride (SiN) waveguides and devices that would be improved by using a SiOC layer for the application of reconfigurable photonic systems as Silicon oxycarbide (SiOC) has a promising properties such as such as tunable refractive index, low losses, and higher TOC of about 2.5×10^{-4} /°C and 10 times larger TOC than other dielectrics. Hence, SiOC demonstrating an efficient platform for large scale integration and for photonic applications.

Future work:

A unique material with a high TOC dependency termed SiOC is used in this research to thermally tune photonic waveguides and other passive devices, providing a futuristic viewpoint on integrated photonics and results suggests that it is possible to perform an energy-efficient reconfiguration of integrated photonic circuits based on traditional technologies like Ge:SiO2, SiON, SiN, and others by effectively utilizing the high TOC of SiOC.

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