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Effect of Silicon Thickness on the Optical Properties Using Slab Waveguide

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Abstract

The optical characteristics of silicon material are studied using a layer slab waveguide. The study examines the TE-mode and its properties as a function of silicon thickness at a constant frequency. In both macroscopic and microscopic opto-mechanical applications, silicon being commonlyemployed as an optical material. Optical waveguides were utilized like components in integrated optical circuits and as the transmission medium in local and long-distance optical communication systems. The purpose of this research is to look into the effect of silicon thickness on the TE-mode and its properties at a constant frequency. The effectiveness of these factors was simulated and studied using the MATLAB software program, which included the number of modes, cut-off frequencies, attenuation wavenumber, propagation wavenumber, and internal reflection angles. The propagation of microwaves, EM waves, and their interaction are discussed in this paper.

On silicon material with a thickness of 1 cm, a frequency of 35 GHz was applied. As a result, the 16 TE-modes are reliant on the structure of silicon and its refractive index value, as well as wave propagation at frequencies over a cut-off frequency; notice that the lowest order mode propagates at any frequency. Internal reflection angles decrease as the thickness of the silicon material rises, and internal reflection at a particular angle is dependent on the polarization of the EM wave. Furthermore, when the number of modes equals zero, the field distribution of the lowest order TE-mode resembles that of a Gaussian beam, but guide light does not propagate in the transverse direction as it does in the axial direction.

Keywords: Slab Waveguide, Number of modes, Cut-off frequency,Attenuation, Microwave propagation.

Introduction

Silicon is broadly utilized in plainly visible and minute opto-mechanical applications as an optical material. Due to the huge retention of interband advances in transmissive optics, the circuitous band hole of generally 1.12 eV limits usage in the noticeable range. Notwithstanding, past about 1200 nm, activity in the close to infrared band gives an adequately low optical assimilation for high-power applications. As a result of the incredible power and solidness of lasers around 1550 nm utilized in fiber-optic correspondence, this frequency is a fantastic competitor for silicon optics. Moreover, silicon's low mechanical misfortune at cryogenic temperatures [1,2] recommends that it very well may be utilized in low-warm commotion tests like gravity wave locators [3,4] or laser recurrence adjustment holes [5.[

A uniform dielectric waveguide is the most major plan in fiber and joined optics. Consequently, the assessment of the secluded characteristics of uniform dielectric waveguides is a focal investigation topic [6,7]. Since such incalculable critical genuine resemblances exist among dielectric and metal waveguides, it has all the earmarks of being that the grounded procedures for analyzing metallic waveguides can be viably and clearly applied to dielectric waveguides [8]. Nevertheless, this is only occasionally the circumstance. It may happen that a strategy that is incredibly powerful for metallic waveguides may become unsuitable, if not inconsequential, for the dielectric accomplices. This is particularly legitimate for coherent procedures. For example, the procedure for parcel of elements applies shockingly well to a rectangular metallic waveguide yet misfires for a rectangular dielectric shaft because of the presence of interfaces between different dielectrics [9].

The optical waveguide was an actual design for directing the electromagnetic waves in the optical range. Anisotropic materials had been taken inconsideration in coordinated optics since there is a significant job in applications, for example, mode converters, modulators, isolators and circulators [10, 11]. A presence of anisotropic dielectrics in activity of gadgets relies upon the properties of electromagnetic waves directed by the construction. The waves show up like trademark arrangement of the limit esteem issue for anisotropic multi-facet chunk waveguide. Then, at that point, the issues of the wave modes in these aides have likewise been explored for a very long time structures as the essential idea for the applications [12, 13].

This work, layer slab waveguide is utilized for concentrating on optical properties of the silicon material. Research the impact of silicon thickness with steady recurrence on the TE-mode and its boundaries. The boundaries are the quantity of modes, remove frequencies, weakening wavenumber, engendering wavenumber and interior reflection points. In this exploration, the made optical carriers with high data rate can convey truly pleasant sources in media transmission frameworks, for example, 4G LTE and 5G Massive MIMO [14]. Furthermore, it can correspondingly help to control the highlights and boundaries influencing most kinds of microwave spread execution and Slab Waveguide [15,16,17.[

This paper is coordinated as follows. Area 2 momentarily depicts silicon material that design and its properties, additionally application. The approval procedure clarifies how mathematical technique is utilized for help and how the boundaries are changed over to the hypothetical examination is uncovered in area 3. The got reproduction results are introduced in area 4 and afterward completely talked about in same segment. At last, segment 5 contains the ends summing up the result of the current work.

Silicon

The silicon semiconductors are strong translucent substances that will generally have more prominent electrical conductivity than protectors, yet not exactly great channels. Silicon takes shape in a monster covalent design at standard conditions, explicitly in a precious stone cubic grid. It subsequently has a high softening mark of 1414 °C, as a ton of energy is needed to break the solid covalent bonds and dissolve the strong. Silicon solidifies in a similar example as jewel, in a design which Ashcroft and Mermin call "two interpenetrating face focused cubic" crude grids. The lines between silicon molecules in the cross section delineation demonstrate closest neighbor securities. The block side for silicon is 0.543 nm Silicon's electrical conductivity increments with higher temperatures. Unadulterated silicon has too low a conductivity (i.e., too high a resistivity) to be utilized as a circuit component in gadgets. By and by, unadulterated silicon is doped with little centralizations of specific different components, which significantly increment its conductivity and change its electrical reaction by controlling the number and charge (positive or negative) of actuated transporters [18]. Recoil silicon is a functioning up-and-comer in the sustainable power region because of its possible applications in sunlight based cells. It is additionally utilized as material for picture sensors, bio-sensors miniature electro mechanical designs (MEMS), light-emanating gadgets and antibacterial covering [19, 20, 21]. Silicon Nano gems implanted in a SiO2 network are widely considered as the give the likelihood to applications in Si-based optoelectronic gadgets with the benefit of being viable with standard free metal-oxide-semiconductor (CMOS) process [22,23,24]. At long last, in material science utilization of material with great optical properties have low ingestion misfortune is major.

Thermotical Analysis

Here, the theoreticalanalysis of TE modes beingexaminedforobtaining the impacts of expanding silicon thickness on optical properties and their boundaries utilizing chunk waveguide. As a rule, EM fields spread inside and outside chunk waveguide. The media was something similar in the left and right of the section [25]. Electrical fields summed up in two structures that are add and even TE-modes as displayed in (1) and (2), respectively.

$$E_y(x) = \begin{cases} E_1 \sin k_c x\, for \quad -a \leq x \leq a \\ E_1 \sin k_c a\, e^{-\alpha_c (x-a)} for x \geq a \\ -E_1 \sin k_c a\, e^{\alpha_c (x+a)} for x \leq -a \end{cases} \qquad (1)$$

$$E_y(x) = \begin{cases} E_1 \cos k_c x \, for \quad -a \le x \le a \\ E_1 \cos k_c a \, e^{-\alpha_c (x-a)} forx \ge a \\ E_1 \cos k_c a \, e^{\alpha_c (x+a)} forx \le -a \end{cases} (2)$$

Where E_1 is a constant value based on the tangential elements of the magnetic and electric scopes, $k_C$denotes the cut-off wavenumber in (3) for each angle of incidenceθ, α_c,was the EM scope attenuation in (4) for each angle of incidence θ, and a indicates the thickness of silicon material which is a constant value $a = 1$ cm in the present research. $1/\alpha_c$ is also the skin depth distance that was occupied by EM fields [25].

$$k_c = -\frac{\alpha_c}{\cot kc\, a} (3)$$

$$\alpha_c = k_c \tan k_c \,\mathrm{a} (4)$$

Given the operating frequency w Equations (3) and (4) provide three unknownsk_c, α_c, β.

$$\alpha_c{}^2 + k_c{}^2 = k_0{}^2 (n_1{}^2 - n_2{}^2) = \frac{\mathrm{w}^2}{c_0{}^2} (n_1{}^2 - n_2{}^2) \qquad (5)$$

Where $k_0 = w/c_0$is the free space wave numbers, $\epsilon_1 and n_1, n_2$denotes the inside and outside refractive indices as refractive index depends on the semiconductor material.

Where β denotes the propagation wavenumber in (6) for each angle of incidencesθ.

$$\beta = k_1 \sin\theta = k_0 n_1 \sin\theta (6)$$

On the other hand; $(M + 1)$ modes take place between odd and even, if the normalized frequency variable R in (7) in the interval (8).

$$R = k_0 a N_A = \frac{\mathrm{wa}}{c_0} N_A = \frac{2\pi a}{\lambda} N_A \qquad (7)$$

$$\frac{M\pi}{2} \le R < \frac{(M+1)\pi}{2} \qquad (8)$$

Where N_A indicates the numerical aperture of the slab in (9).

$$N_A = \sqrt{n_1{}^2 - n_2{}^2} \qquad (9)$$

Thus; the maximum mode (M) number can be calculated by (10).

$$M = floor\left(\frac{2R}{\pi}\right) \ (10)$$

So, the cut-off frequency of each mode can be calculated in (11).

$$f_{c_m} = \frac{mc_0}{4\, aN_A} form = 0, 1, 2, \dots, M \qquad (11)$$

Simulation Result

Here, the simulation results are clarified and talked about by MATLAB code. Silicon materials were carried out in piece waveguide to concentrate on execution and optical properties. Silicon material has own properties and diverse worth of waveguide boundary which are number of mode, remove recurrence, constriction wave number, spread wave number, interior reflection points skin profundity, that prompts exploit the silicon material in different applications like current combination optics, controlled rectifier and quantum figuring. In microwave spreads, EM wave with recurrence 35 GHz was applied on silicon material with worth of thickness which is a = 1 cm.

Figure (1) presents that the field dispersion of the most reduced request TE-mode when number of modes equivalent zero is comparable in shape to that of the Gaussian bar, however guide light doesn't spread the cross over way as it proliferates the pivotal way. The least mode has a most extreme force at the middle and moves a long thickness of silicon with higher spread wave number. It is striking for silicon material that the EM waves could sinusoidal conveyed inside material, and dramatically disseminated outside it. Besides, every one of these electric field designs have normal arrangement. In each example, the electric field wavers inside material and transitory encompassing it with various spread example for every TE-mode.

The consequence of figure (2) displays that the sixteen quantities of TE-modes rely upon the construction of silicon material and its refractive record esteem. High refractive file can accomplish with our material. Which can finish up from figure (2) that the silicon material center should associate with 1 cm thick for the material to be higher request modes in the symmetric case. Besides, the quantity of modes thickness in a specific recurrence.

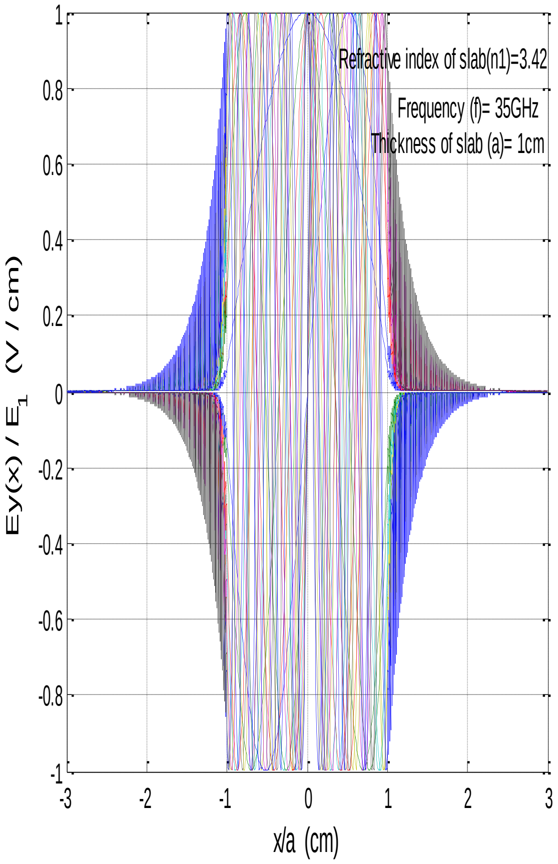

Figure (1) Electric field patterns as a function of (x/a) cm

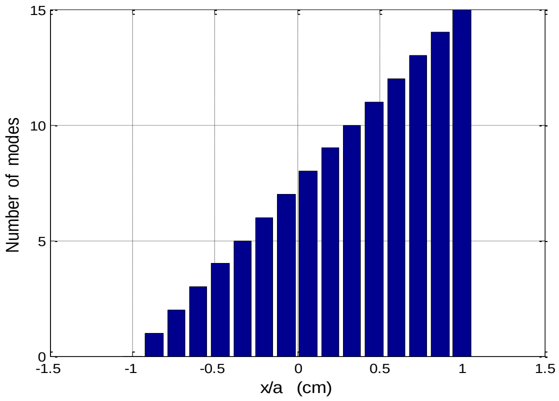

Figure (2) the number of modes versus the thickness of the silicon material for refractive index = 3.42

Figure (3) show that the cut-off frequencies of the TE-modes as a function of (x/a) cm. where fc=w/2π is called the cut-off frequency usually a different value for each mode. Wave propagation for frequencies above a cut-off frequency; note that cut-off frequency, so the lowest order mode propagates at any frequency. In general, increasing the thickness of the silicon material increases the cut-off frequencies. The cut-off wavenumber inside slab increases with increasing the thickness of the material as shown in figure (4) for specific applied frequency.

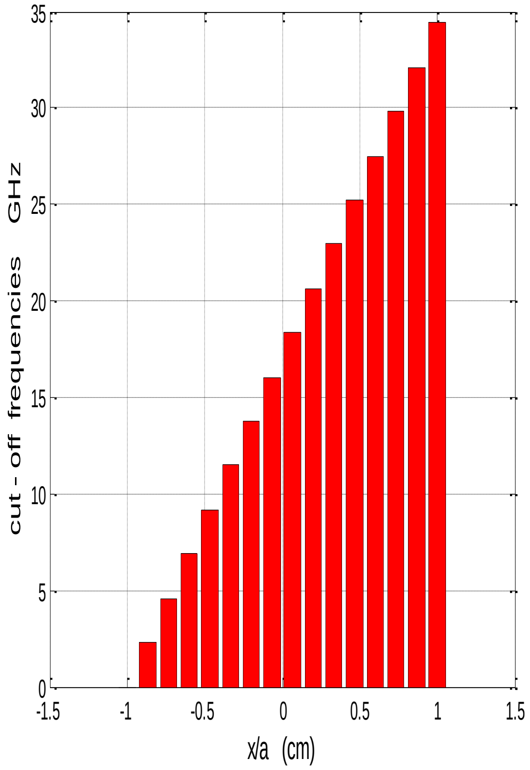

Figure (3) cut-off frequencies versus the thickness of silicon material.

In general, EM waves propagation through a material becomes attenuated in the direction of propagation. As the frequency get large attenuation wavenumber outside slab go to infinite which means that the electric field decays very rapidly outside the slab waveguide. The result of figure (5) shows the attenuation wavenumber decreases with increasing the thickness of the silicon material. The highest propagation wavenumbers exhibit less quantity of thickness. This implies that the quantity of propagation wavenumber parameter reduce with higher thickness in the silicon material as shown in figure (6). The propagation wavenumber depends on the material properties and specific applied frequency. Silicon is confined to the core layer with the highest index of refraction.

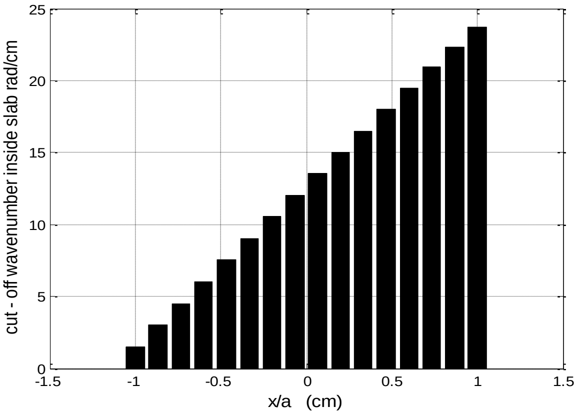

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Figure (4) cut-off wavenumber inside slab versus the thickness of silicon material.

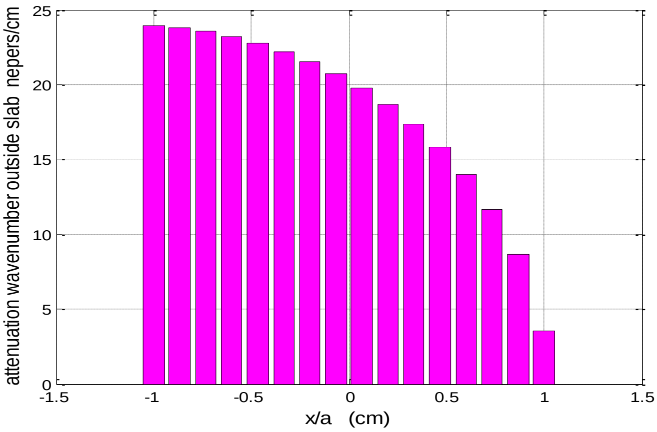

Figure (5) attenuation wavenumber outside slab versusthe thickness of silicon material

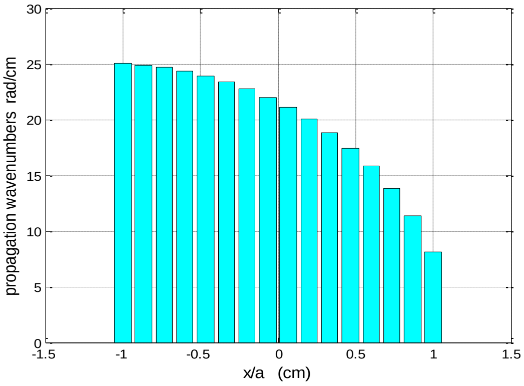

Figure (6) propagation wavenumbers versus the thickness of silicon material

A dielectric slab waveguide uses the concept of total internal reflection to reflect EM wave. The main cause of lossless in dielectric slab waveguides are scattering due to impurities and absorption. Smaller value of internal reflection angle corresponding smaller value of propagation wave number for large value of number of modes. Figure (7) show that the thickness of the silicon material increases leads to the internal reflection angles decreases, and internal reflection at a given angle depend on the polarization of EM wave.

Skin depth denotes the penetration depth is one term that describes the decay of electromagnetic waves inside of material. The EM field with a skin depth distance which is indicated by inverse attenuation wavenumber. Due to increasing the thickness of material, the number of modes increases and skin depth increases, also note that higher modes travel longer distance in the silicon material than do lower order modes as shown in figure (8). Silicon-on-insulator waveguide designs for simultaneously a achieving both low-loss optical confinement and electrical contacts. Optical waveguide are used as component in integrated optical circuits or as the transmission medium in local and long haul optical communication systems.

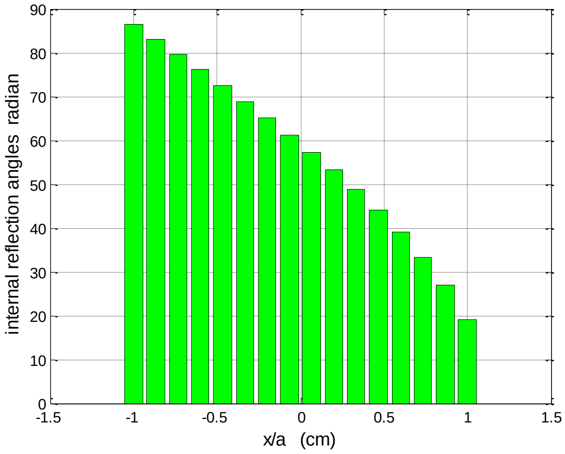

Figure (7) internal reflection angles versus the thickness of silicon material

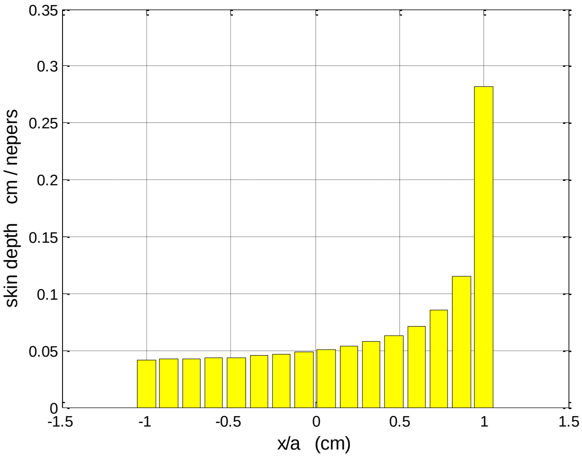

Figure (8) skin depth versus the thickness of silicon material

Conclusion

Silicon semiconductors are strong glasslike substances that will generally have more noteworthy electrical conductivity than protectors. It is remarkable for silicon material that the EM waves could sinusoidal circulated inside material, and dramatically disseminated outside it. Moreover, every one of these electric field designs have common setup. In each example, the electric field sways inside material and transient encompassing it with various spread example for every TE-mode. The result of this work showed that the silicon material center should associate with 1 cm thick for the material to be higher request modes in the symmetric case. Moreover, the quantity of modes thickness in a specific recurrence. As a rule, expanding the thickness of the silicon material builds the remove frequencies. The cut-off wavenumber inside piece increments with expanding the thickness of the material for explicit applied recurrence. Due to expanding the thickness of material, the quantity of modes increments and skin profundity increments, likewise note that higher modes travel. Silicon-on-separator waveguide plans for all the while an accomplishing both low-misfortune optical constrainment and electrical contacts.

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