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Studies on temperature variation in semiconductor waveguide through ARDP loss for nanophotonic applications

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ABSTRACT

Studies on temperature variation in InSb and InAs compound semiconductor waveguide through ARDP losses at wavelength 10.6 μm are reported in this work. Here ARDP losses are nothing but absorption, reflection, diffraction and polarization losses, which are frequently encountered as serious problem in optical semiconductors. In this paper these losses are analyzed with respect to different temperatures, which vary from 100 K to 240 K for InSb and 100 K to 220 K for InAs. Plane wave expansion method is used to obtain reflection losses, where Maxwell's curl equation is used to find absorption loss. Simulation is also made for diffraction and polarization efficiencies. Simulation results revealed that reflectance and diffraction efficiency increases with increasing of temperature, where polarization efficiency decreases with same temperature. Finally intensity transmitted through semiconductor decreases from 1.322 mW/m^2 to 1.296 mW/m^2 for InSb, where transmitted intensity increases from 2.218 mW/m^2 to 2.267 mW/m^2 for InAs with respect to above temperatures. Apart from this, it is seen that the variation of transmitted intensity with respect to temperature (100 K to 240 K for InSb and 100 K to 220 K for InAs) is nicely fitted with linear trend line ($R^2 = 0.994$ for InSb and $R^2 = 0.992$ for InAs), which leads to an accurate investigation of temperature in InSb and InAs compound semiconductor.

1. Introduction

In the modern age, semiconductor empowers the technology due to its versatility in many areas including optoelectronics. Both material properties and fabrication process play vital role to design the advanced optoelectronics devices. Apart from this, size of the devices leads to superior properties for manifold applications. Realizing this, it is seen that semiconductor is a right candidate for the age of optoelectronics. As far as intrinsic properties of both optoelectronics and photonics devices are concerned, semiconductor material directly or indirectly depends on their internal characteristics such as temperature, doping concentration, carrier density velocity saturation etc. [1]. Though above parameters are played significant role to envisage advanced photonics devices, we in this paper constrained with temperature only. The reason for choosing the investigation of temperature in this work is that temperature is a suitable parameter to define or control different semiconductor properties such as band gap, conductivity, resistivity speed, output current etc. As far as literature survey on similar sorts of work is concerned, few papers related to same work have appeared [2–7]. In Ref. [2] temperature of various types of semiconductor materials are investigated using optical principle, where in Ref. [3], the computation of concentration of impurities in chalcogenide glass is discussed using plane wave expansion method. Also temperature in polymer waveguide and temperature and pressure of GaN waveguide are explored in Ref. [4,5], respectively. Apart from this, Ref. [6,7] studies the mole fraction in nitride semiconductor and percentage of porosity in porous silicon, respectively. In all above works, absorption and reflection losses are considered during the computation of transmitted intensity. However though above papers discuss similar type of work, here diffraction and polarization losses are cogitated along with absorption and reflection loss. As far as latest article on similar kind of investigation is concerned, Palai et al. have derived an equation which is used for finding the damage ratio of IINDYV nanowaveguide [8].

2. Structure and operational principle

To investigate the temperature in semiconductor, we have considered three layers of semiconductor waveguide, which is shown in Fig. 1.

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Fig. 1. InAs/InSb waveguide.

In Fig. 1, it is seen that the proposed waveguide consists of alternate layers of semiconductor and air, such that two semiconductor layer is separated by air (2nd layer). As far as semiconductor is concerned, here we deal with InSb and InAs semiconductor material. Here thickness of odd and even layer is taken of 10 nm each. Also width of waveguide is taken of 10 nm. The reason for choosing such parameters is that accurate sensing behavior can be realized at these parameters.

As far as operational principle is concerned, here an electromagnetic wave having wavelength of 10.6 μm incident on above said waveguide structure, then various sorts of losses will be accomplished with semiconductor waveguide. In our research we deal with absorption, reflection, and diffraction and polarization losses for investigation of intensity transmitted through above said wavelength. After dealing with these losses, we moved to compute intensity transmitted through structure by using modified equation.

Analyzing Refs. [2–8] and using simple definition of overall transmitted efficiency, we can write

$$\eta = \frac{I_T}{I_O} \qquad I_T = \eta I_O \tag{1}$$

where I_T is output transmitted intensity and I_O be the input intensity corresponding to wavelength 10.6 μm.

Similarly η is overall transmitted efficiency and can be expressed as [8],

$$\eta = \underbrace{(1-R)}_{\text{Reflectance}} \; \underbrace{e^{-(2\beta_1 t_1+\beta_2 t_2)}}_{\text{Absorbance}} \; \underbrace{\sin^2\left(\frac{\pi n d}{\lambda}\right)}_{\text{Diffraction Efficiency}} \; \underbrace{\frac{\mathrm{N}}{\mathrm{N}+\dfrac{2n}{n^2-1}}}_{\text{Polarization Efficiency}} \tag{2}$$

where R be the reflectance, β_1 and β_2 are the absorption coefficient of odd and even layer, respectively, t_1 and t_2 are thickness of odd and even layer, respectively. N is the number of layer, n is the effective refractive index, which is $(n_1 - n_2)/2$.

From literature, it is found that β_1 and β_2 are zero for proposed structure at wavelength 10.6 μm.

3. Result and discussions

As far as result and discussion for computation of output transmitted intensity is concerned, this paper deals with absorption, reflection and diffraction losses including polarization. As far as absorption loss for proposed semiconductor structure is concerned, it is found that it is zero for all waveguide structure at wavelength 10.6 μm [9]. Then plane wave expansion method is used to carry out simulation to find out reflectance from semiconductor waveguide structure [10]. The reflectance from such structure depends on different parameters such as refractive indices and thickness of odd and even layer, which is shown in Table 1.

Table 1
Input parameters of semiconductor waveguide.

Temperature in K	Refractive index (InSb)	Refractive index (InAs)	Thickness t_1 and t_2 (nm)	Wavelength in μm
100	3.832	3.432	10	10.6
110	3.837	3.434		
120	3.841	3.436		
130	3.845	3.437		
140	3.849	3.441		
150	3.859	3.444		
160	3.860	3.448		
170	3.864	3.451		
180	3.869	3.453		
190	3.875	3.455		
200	3.879	3.458		
210	3.885	3.460		
220	3.889	3.462		
230	3.891			
240	3.894			

Table 1 gives the information about the variation of refractive indices of InSb and InAs semiconductor materials with respect to temperatures at wavelength 10.6 μm [11]. In this paper we have chosen t_1 and t_2 as the thickness of odd (semiconductor) and even (air), respectively. The reason for choosing such thickness is that accurate sensing behavior can be realized at above parameters.

Using data from Table 1 and employing plane wave expansion method, simulation is done for reflectance with respect to wavelength for different temperatures (Temperature from 100 K to 240 K for InSb and 100 K to 220 K for InAs). Considering above techniques, simulation result for temperature 100 K of InSb and InAs are shown in Fig. 2(a) and (b), respectively. Simulation for other temperatures are done but not shown here. Fig. 2(a) represents simulation result for reflectance of InSb semiconductor at temperature 100 K. From this figure it is seen that reflectance (Arbi Unit) is taken along vertical axis, where wavelength in μm, is taken along horizontal axis. It is also seen that reflectance are different for different wavelengths. Though different reflectance can be computed corresponding to wavelengths, we have concentrated on reflectance value at wavelength 10.6 μm. only and also seen that. From Fig. 2(a), it is found that reflectance is 0.00406 at wavelength 10.6 μm. Similarly, Fig. 2(b) reflectance is found to be 0.006527 for InAs semiconductor at above wavelength.

Using similar method, reflectance's for other temperatures of InAs and InSb are computed. After finding reflectance's corresponding to each temperatures of InSb and InAs semiconductor, we moved to compute diffraction efficiency with respect to temperatures of above said semiconductors using Eq. (2). After finding reflectance and diffraction efficiency, polarization efficiency for all temperatures of InSb and InAs are investigated. All the computed values of reflectance, diffraction efficiency and polarization efficiency are mentioned in Table 2.