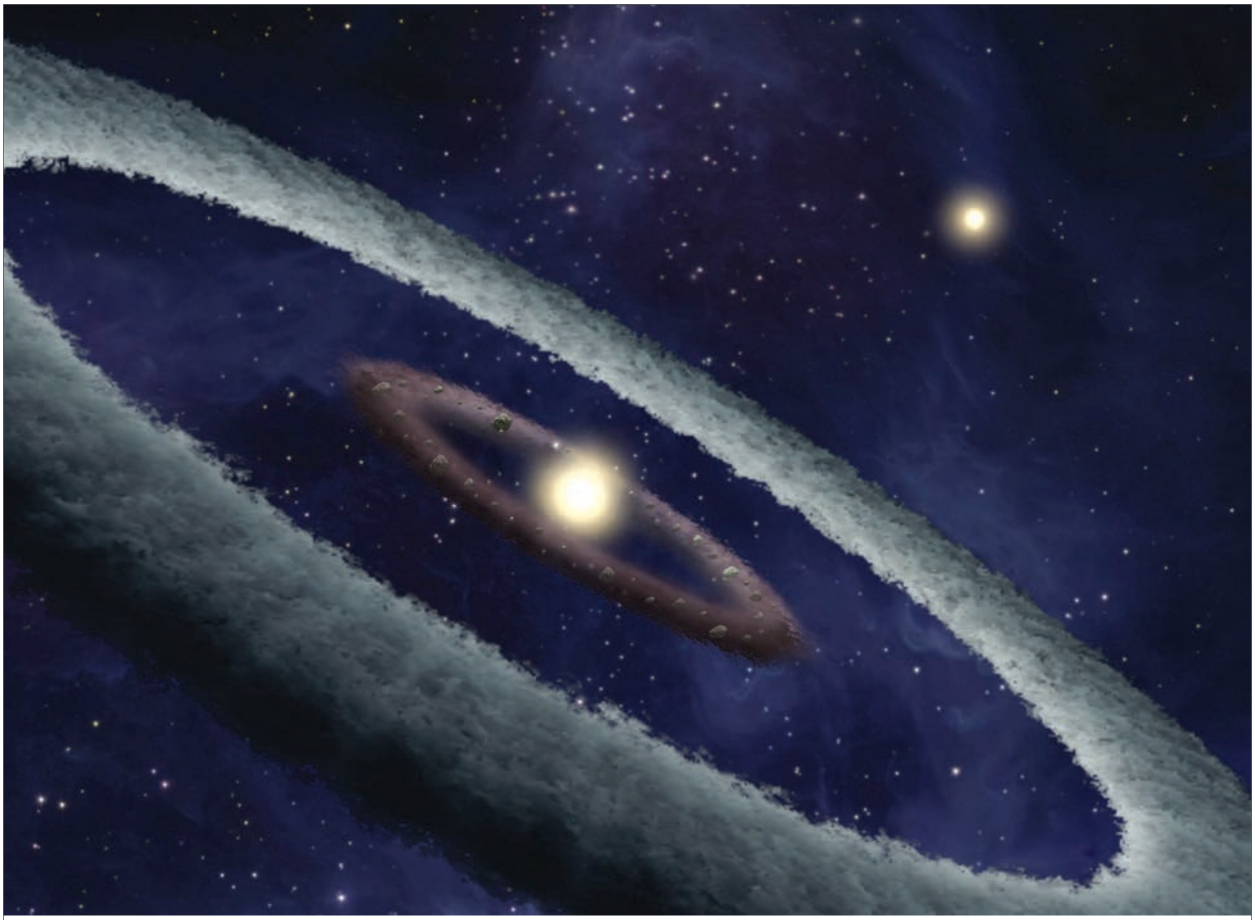

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Optical Propertis of Gallium Antimonide GaSb

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ABSTRACT

Knowledge of the optical properties of Gallium Antimonide (GaSb) is important because of the increasing application of GaSb in many optical and electronics applications. We have investigated the optical properties of Gallium Antimonide (GaSb) in the photon energy range 1.5-6.01 eV. We obtained refractive index which has a maximum value of 5.24 at photon energy 2.0 eV, the extinction coefficient which has a maximum value of 4.13 at photon energy 4.2 eV, the dielectric constant, the real part of the complex dielectric constant has a maximum value of 25.6 at photon energy 2.0 eV and the imaginary part of the complex dielectric constant has a maximum value of 25.14 at photon energy 4.0 eV, the transmittance which has a maximum value of 0.20 at photon energy 3.3 eV, the absorption coefficient which has a maximum value of 1.76×10^{8} m^{-1} at photon energy 4.2 eV, reflectance which has a maximum value of 0.67 at 4.3 eV, reflection coefficient which has a maximum value of 0.82 at photon energy 4.3 eV, the real part of optical conductivity has a maximum value of 1.22×10^{16} at 4.1 eV and the imaginary part of the optical conductivity has a maximum value of 5.95×10^{15} at 4.3 eV. The values obtained for the optical properties of GaSb are in good agreement with other results.

Key words: Complex index of refraction, extinction coefficient, complex dielectric constant, transmittance, absorption coefficient, reflection coefficient, reflectance, optical conductivity, semiconductor, photon energy

INTRODUCTION

Gallium Antimonide (GaSb) belongs to antimonide compound semiconductors family which have a smaller band gap among III-V semiconductors, making them suitable for optoelectronic devices operated in the infrared region and electronic devices in the wavelength range 1-5 μm (Kim *et al*., 2006; Kindl *et al*., 2006; Vigil-Galan *et al*., 2006; Kluth *et al*., 2006; Li *et al*., 2004; Hanson *et al*., 2004; Liu *et al*., 2004; Haugan *et al*., 2004; Wei *et al*., 2002; Liu and Zhang, 1999; Dutta *et al*., 1997; Bignazzi *et al*., 1997; Gauneau *et al*., 1993). GaSb has an energy band gap of 0.70 eV (1.77 μm) at room temperature and 0.81 eV (1.53 μm) at 4K (Swaminathan and Macrander, 1991). GaSb-based devices such as near infrared photodetectors, resonant tunneling structure, laser diodes and other quantum devices have been previously reported (Law *et al*., 1981; Menna *et al*., 1991; Choi and Eglash, 1991; Su *et al*., 1992; Bougnot *et al*., 1988; Bedair *et al*., 1984; Cooper *et al*., 1982; Podlecki *et al*., 1996; Allerman *et al*., 1996; Wang and Choi, 1997).

GaSb based structures have shown potentiality for applications in laser diodes with low threshold voltage (Motosugi and Kagawa, 1980; Morosini *et al*., 1993), photodetectors with high quantum efficiency (Hildebrand *et al*., 1981), high frequency devices (Segawa *et al*., 1976; Hilsum and Rees, 1970), superlattices with tailored optical and transport characteristics

(Esaki, 1981), booster cells in tandem solar cell arrangements for improved efficiency of photovoltaic cells and high efficiency thermophotovoltaic (TPV) cells (Fraas *et al.*, 1989). GaSb-based devices are promising candidates for variety of military and civil applications in the 2-5 and 8-14 μm regimes: To mention a few, infrared (IR) imaging sensors for missile and surveillance systems (focal plane arrays), fire detection and monitoring environmental pollution.

GaSb has also proved to be a model material for several basic studies (Dutta *et al.*, 1995). Because of the band structural properties, GaSb has proved to be an ideal material for studying the Auger recombination processes (Benz and Conradt, 1977). Due to low vapour pressures and low melting points, GaSb serve as appropriate model materials to study the effects of convection and diffusion on the solutal distribution under terrestrial and microgravity conditions (Muller, 1990).

In this study, optical properties of Gallium Antimonide (GaSb) have been investigated in the photon energy range 1.5-6.01 eV.

MATERIALS AND METHODS

Kramers-Kronig analysis of measured data obtained by Schubert (2004) was carried out to obtain reflection coefficient and reflectance of GaSb using Eq. 1 and 2. Reflection coefficient measures the fractional amplitude of the reflected electromagnetic field and it is given by (Fox, 2001):

$$r(\omega)=\frac{n(\omega)-1+ik(\omega)}{n(\omega)+1+ik(\omega)} \tag{1}$$

where, n is the refractive index and k is called the extinction coefficient.

The reflectance R is given by Yu and Cardona (1996):

$$R(\omega)=\frac{(n(\omega)-1)^2+k^2(\omega)}{(n(\omega)+1)^2+k^2(\omega)} \tag{2}$$

The complex dielectric constant is a fundamental intrinsic property of the material. The real part of the dielectric constant shows how much it will slow down the speed of light in the material, whereas the imaginary part shows how a dielectric material absorbs energy from an electric field due to dipole motion. The knowledge of the real and the imaginary parts of dielectric constant provides information about the loss factor which is the ratio of the imaginary part to the real part of the dielectric constant (Bakr *et al.*, 2011; Akinlami and Ashamu, 2013). The real and the imaginary parts of the dielectric constant can be estimated using the relations (Goswami, 2005):

$$E_1 = n^2\text{-}k^2 \tag{3}$$

$$E_2 = 2nK \tag{4}$$

The absorption coefficient (α) can be calculated using the equation (Pankove, 1971; Swanepoel, 1983):

$$\alpha = \frac{4\pi k}{\lambda} \tag{5}$$

where, k is the extinction coefficient and λ is the wavelength.

The transmittance is obtained from the relation:

$$R+T+A = 1 \tag{6}$$

where R, T and A represent the reflectance, transmittance and absorbance, respectively. The sum of these macroscopic quantities which are usually known as the optical properties of the material must equal unity since the incident radiant flux at one wavelength is distributed totally between reflected, transmitted and absorbed intensity. The absorbance A is given by:

$$A = LOG\left(\frac{1}{R}\right) \tag{7}$$

The optical response of a material is mainly studied in terms of the optical conductivity (σ) which is given by the relation (Sharma and Katyal, 2007):

$$\sigma = \frac{\alpha nc}{4\pi} \tag{8}$$

where, c is the velocity of light, α is the absorption coefficient and n is the refractive index. It can be seen clearly that the optical conductivity directly depends on the absorption coefficient and the refractive index of the material (Bakr *et al.*, 2011; Akinlami and Ashamu, 2013).

RESULTS AND DISCUSSION

The refractive index of GaSb increases with increase in photon energy in the energy range 1.5 to 2.0 eV as shown in Fig. 1. It has maximum value of 5.24 at 2.0 eV. The refractive index decreases afterwards in the energy range 2.0-6.01 eV. This decrease in refractive index indicates

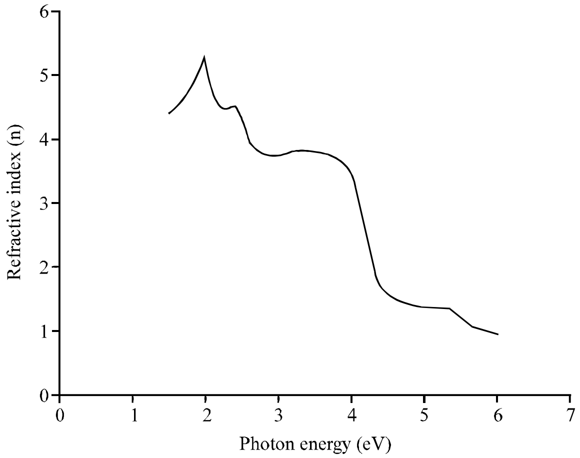

Fig. 1: Refractive index of gallium antimonide (GaSb)

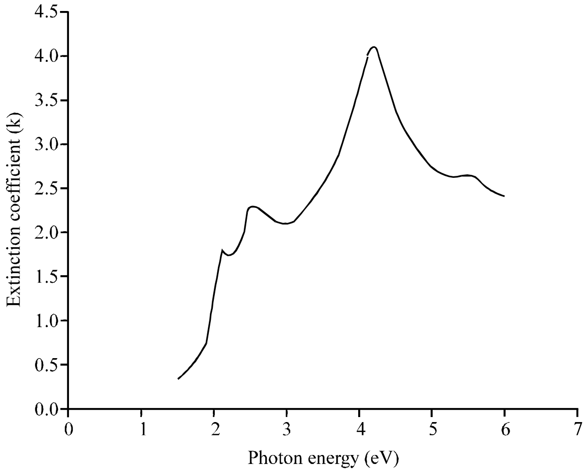

Fig. 2: Extinction coefficient of gallium antimonide (GaSb)

that GaSb shows normal dispersion behaviour. Four peaks were observed at 2.0, 2.3, 3.8 and 5.3 eV. The result for refractive index is in good agreement with that reported by Adachi (1989) (5.3), Aspnes and Studna (1983) (5.24) and Dutta *et al.* (1997) (5.24).

The extinction coefficient of GaSb increases with increase in photon energy in the energy range 1.5-4.2 eV as shown in Fig. 2. It rises to a maximum value of 4.13 at 4.2 eV and then decreases to a value of 2.42 at 6.01 eV. The increase in extinction coefficient with increase in photon energy in the energy range 1.5-4.2 eV shows that the fraction of light lost due to scattering and absorbance increases in this energy range and the decrease in the extinction coefficient in the photon energy range 4.2-6.01 eV shows that the fraction of light lost due to scattering and absorbance decreases in this energy region. Four peaks were observed at 2.1, 2.5, 4.2 and 5.4 eV.

The real part of the complex dielectric constant ε_1 of GaSb increases with increase in photon energy in the energy range 1.5-2.0 eV as shown in Fig. 3. It rises to a maximum value of 25.6 at 2.0 eV which is in good agreement with that reported by Aspnes and Studna (1983) (25.55). The increase in dielectric constant with increase in photon energy in the photon energy range 1.5-2.0 eV shows that the loss factor increases with increase in photon energy in this energy range. The real part of the complex dielectric then decreases with increase in photon energy in the photon energy range 2.0-6.01 eV with a minimum value of -11.4 at 4.3 eV. This shows that the loss factor decreases with increase in photon energy in this energy range.

The imaginary part of the complex dielectric constant, ε_2, of GaSb increases with increase in photon energy in the energy range 1.5-4.0 eV as shown in Fig. 4. It rises to a maximum value of 25.1 at 4.0 eV which is in good agreement with that reported by Aspnes and Studna (1983) (25.14). The increase in imaginary part of the complex dielectric in the photon energy range 1.5-4.0 eV shows that the loss factor increases with increase in photon energy in this energy range. The imaginary part of the complex dielectric constant decreases with increase in photon energy in the photon energy range 4.0-6.01 eV which shows that the loss factor decreases with increases in photon energy in this energy range.

The Transmittance (T) of GaSb has a maximum value of 0.20 which is constant in the energy range 1.5-3.3 eV, it then decreases with increase in photon energy in the energy range 3.3-4.3 eV

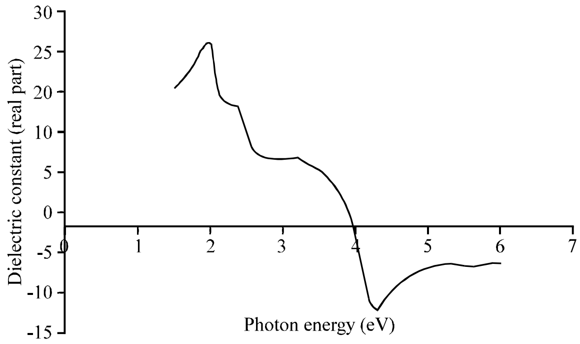

Fig. 3: Complex dielectric constant (real part) of gallium antimonide (GaSb)

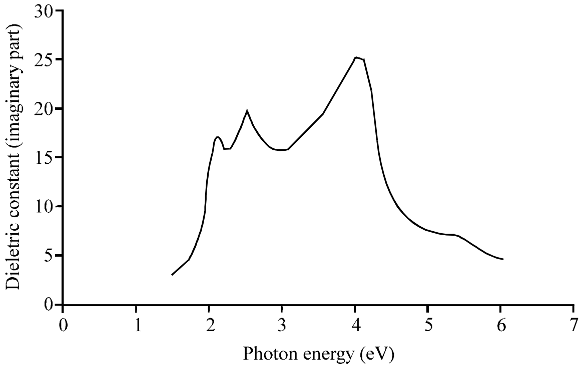

Fig. 4: Dielectric constant (imaginary part) of gallium antimonide (GaSb)

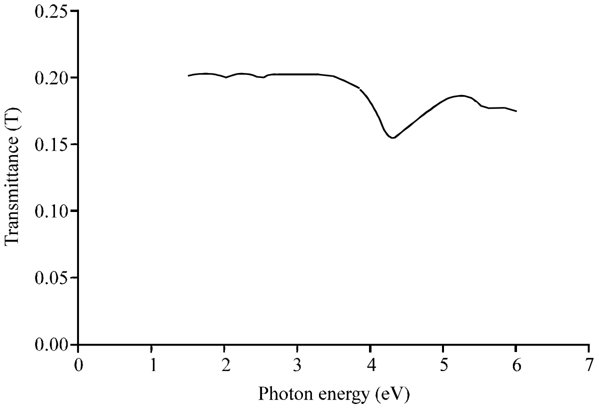

Fig. 5: Transmittance of gallium antimonide (GaSb)

and afterwards increases with increase in photon energy in the energy range 4.3-6.01 eV as shown in Fig. 5. With a maximum of 0.20 for transmittance it means that GaSb is not a good transmitter of electromagnetic wave in this energy region.

The absorption coefficient, α of GaSb increases with increase in photon energy in the energy range 1.5-4.2 eV as shown in Fig. 6. It rises to a maximum value of 1.76×10^{8} m^{-1} (1.76×10^{6} cm^{-1})

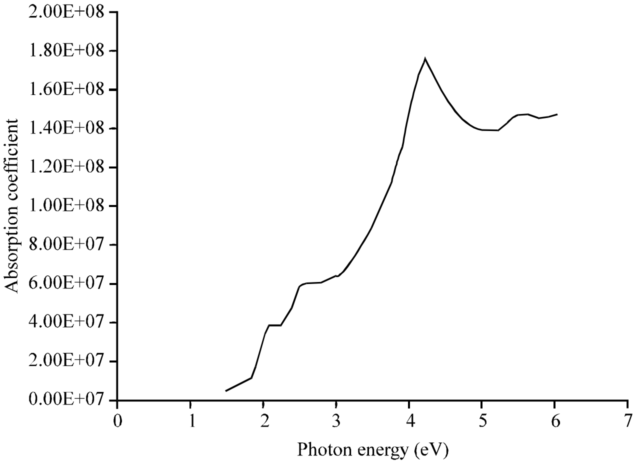

Fig. 6: Absorption coefficient of gallium antimonide (GaSb)

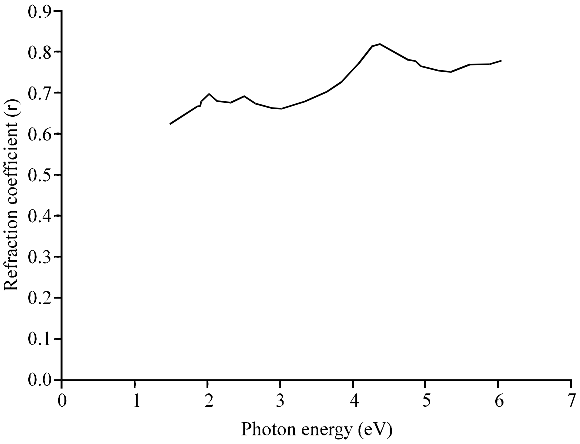

Fig. 7: Reflection coefficient of gallium antimonide (GaSb)

at 4.2 eV which is in agreement with that reported by Qiao *et al.* (2009) (1.0×10^5 cm^{-1}). The value of absorption coefficient then drops to a value of 1.47×10^8 m^{-1} at 6.01 eV. This high value of the absorption coefficient is typical for interband absorption in semiconductors (Sturge, 1962). GaSb shows no absorption below its band gap 0.70 eV (Swaminathan and Macrander, 1991).

The reflection coefficient of GaSb increases with increase in photon energy in the range 1.5-4.3 eV as shown in Fig. 7. It rises to a maximum value of 0.82 at 4.3 eV. The high value of the reflection coefficient means that GaSb is highly absorbing.

The reflectance of GaSb increases with increase in photon energy in the energy range 1.5-4.3 eV as shown in Fig. 8. It rises to a maximum value of 0.67 at 4.3 eV which is in agreement with that reported by Aspnes and Studna (1983) (0.61), Dutta *et al.* (1997) (0.61) and Qiao *et al.* (2009) (0.64). Four peaks were observed at 2.0, 2.5, 4.3 and 5.6 eV.

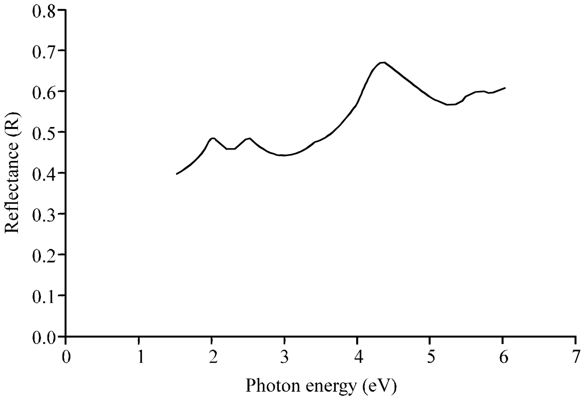

Fig. 8: Reflectance of gallium antimonide (GaSb)

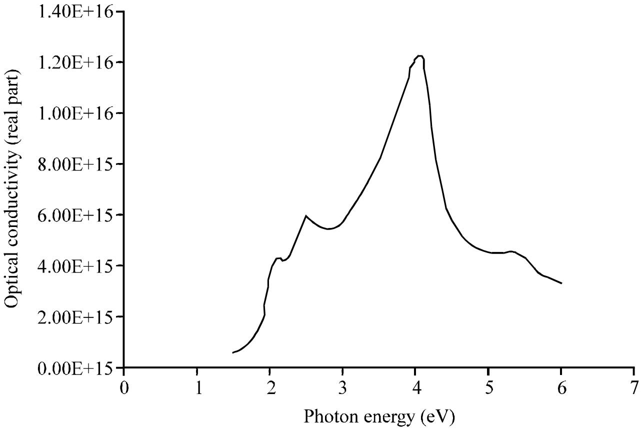

Fig. 9: Optical conductivity (real part) of gallium antimonide (GaSb)

The real part of the optical conductivity of GaSb increases with increase in photon energy in the energy range 1.5-4.1 eV as shown in Fig. 9. It rises to a maximum value of 1.22×10^{16} at 4.1 eV. The increase in the real part of optical conductivity in the photon energy range 1.5-4.1 eV can be attributed to the increase in absorption coefficient in this energy range. The real part of the optical conductivity shows four peaks at 2.1, 2.5, 4.1 and 5.3 eV. The real part of optical conductivity of GaSb decreases with photon energy in the photon energy range 4.1-6.01 eV.

The imaginary part of the optical conductivity of GaSb first decreases with increase in photon energy in the energy range 1.5-2.0 eV from a value of -3.47×10^{15} at 1.5 eV to a minimum value of -6.18×10^{15} at 2.0 eV as shown in Fig. 10. The negative value of the imaginary part of the optical conductivity is due to the increase in extinction coefficient and it implies that there is reduction in the conductivity of GaSb in this energy range. It then increases with increase in photon energy in the photon energy range 2.0-4.3 eV with a maximum value of 5.95×10^{15} at 4.3 eV and then drops to a value of 3.60×10^{15} at 6.01 eV.

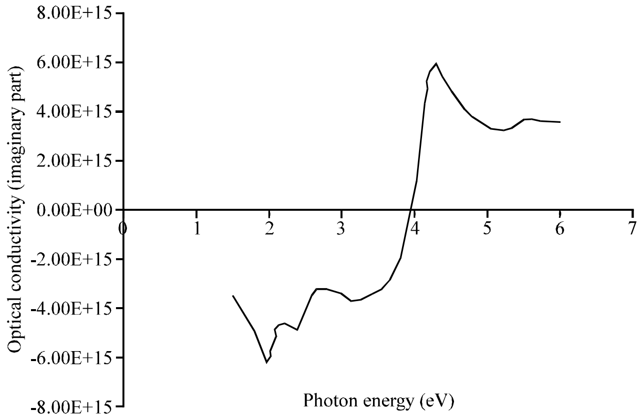

Fig. 10: Optical conductivity (imaginary part) of gallium antimonide (GaSb)

CONCLUSION

In conclusion, we have investigated theoretically the optical properties of Gallium Antimonide (GaSb) in the energy range 1.5-6.01 eV. The refractive index has a maximum value of 5.24 at 2.0 eV which is in good agreement with that reported by Adachi (1989), Aspnes and Studna (1983) and Dutta *et al.* (1997). The refractive index decreases with increase in photon energy in the energy range 2.0-6.01 eV. This decrease in refractive index indicates that GaSb shows normal dispersion behaviour.

The increase in extinction coefficient with increase in photon energy in the photon energy range 1.5-4.2 eV shows that the fraction of light lost due to scattering and absorbance increases in this energy range and the decrease in the extinction coefficient in the photon energy range 4.2-6.01 eV shows that the fraction of light lost due to scattering and absorbance decreases in this energy region.

The real part of the complex dielectric constant has a maximum value of 25.55 at 2.0 eV. The increase in dielectric constant with increase in photon energy in the photon energy range 1.5-2.0 eV shows that the loss factor increases with increase in photon energy in this energy range. The decrease in the real part of the complex dielectric with increase in photon energy in the photon energy range 2.0-6.01 eV shows that the loss factor decreases with increase in photon energy in this energy range. The imaginary part of the complex dielectric constant has a maximum value of 25.1 at 4.0 eV. The increase in imaginary part of the complex dielectric in the photon energy range 1.5-4.0 eV shows that the loss factor increases with increase in photon energy in this energy region. The decrease in the imaginary part of the complex dielectric constant with increase in photon energy in the photon energy range 4.0-6.01 eV shows that the loss factor decreases with increase in photon energy.

The transmittance has a maximum value of 0.20 at 3.3 eV which shows that GaSb is not a good transmitter of electromagnetic wave in this energy region. The absorption coefficient has a maximum value of 1.76×10^{8} m^{-1} (1.76×10^{6} cm^{-1}). This high value of the absorption coefficient is typical for interband absorption in semiconductors. GaSb shows no absorption below its band gap. The reflection coefficient has a maximum value 0.82 at 4.3 eV. With a value of 0.82 for reflection coefficient it means GaSb is highly absorbing. The reflectance has a maximum value of 0.67 at 4.3 eV which is in good agreement with that reported by Aspnes and Studna (1983), Dutta *et al.* (1997) and Qiao *et al.* (2009).

The real part of the optical conductivity has a maximum value of 1.22×10^{16} at 4.1 eV. The increase in the real part of optical conductivity in the photon energy range 1.5-4.1 eV can be attributed to the increase in absorption coefficient in this energy range. The imaginary part of the optical conductivity has a minimum value of -6.18×10^{15} at 2.0 eV and a maximum value of 5.95×10^{15} at 4.3 eV. The negative value of the imaginary part of the optical conductivity is due to the increase in extinction coefficient and it implies that there is reduction in the conductivity of GaSb in this energy range.

The values obtained for the optical properties of GaSb over the energy range 1.5-6.01 eV indicate promising device applications such as the fabrication of optoelectronic devices such as photodetectors, Light Emitting Diodes (LED) and Lasers and high frequency devices.

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