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Study of Some Optical Properties for Different Composition Bismuth -Antimony Thin Films

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

BiSb, Bi_2Sb and $BiSb_2$ alloys were prepared by direct melting of weight from elements, which was followed by quenching then the alloy used to prepared on quartz substrates by using the thermal vacuum evaporation technique at room temperature. The optical characteristics of the prepared thin films have been investigated by UV-VIS spectrophotometer (UV-1650PC Shimadzu) in the wavelength range (200-900 nm), also were determined by FTIR recorder spectrometer model Shimadzu were used to measure the transmission and absorption spectra of (Bi.Sb) alloy thin film deposited on quartz substrate in spectral range (400–4000 cm^{-1}). The films has an indirect allow electronic transitions and optical energy gap (Eg) has increased from 0.063 eV to 0.081eV by modification Bismuth Antimony ratio. The optical properties of the BiSb, Bi_2Sb, $BiSb_2$ thin films were studied which include their absorbance and transmittance. The films were found to exhibit low transmittance, high absorbance in the visible, and near infrared region.

Keywords: Thin films; thermal vacuum evaporation; optical properties; bismuth –antimony; alloy.

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1. INTRODUCTION

Bismuth is easy to combine with antimony [1], both being Group V elements and its alloys are classified as narrow band-gap semiconductors, [2-4] Previously the use of semi-metal BiSb with percentage of Bi and Sb from 8% up to 25% was shown to exhibit a high-sensitivity and small inertia as detectors of Ultra high frequency (UHF) radiation [5].

The present work reports on the optical properties BiSb, Bi_2Sb, $BiSb_2$ thin films have been prepared on quartz substrates by using thermal vacuum evaporation technique at room temperature. Thickness of the deposited films was 60 nm.

2. EXPERIMENTAL DETAILS

2.1 Preparation (Bismuth- Antimony) Alloy

Amount of Bi and Sb powders (each of purity 99.999%; Schuchardt Mfnchen, Germany) have been weighed, mixed and loaded into a quartz ampoule Fig. 1, sealed under vacuum at 10^{-2} Torr. The quartz ampoules containing the powder mixtures are then sintered at 800℃ for 4 h, and quenching into cooled water.

Equation (1) used to determine the weight of each element in the alloy:

$$\mathrm{m_e} = \frac{\mathrm{m_A} \times \mathrm{M_e}}{\mathrm{M_A}} \quad (1)$$

Where $\mathrm{m_e}$ = the first element mass, $\mathrm{m_A}$ = the total mass of alloy, $\mathrm{M_e}$ = Atomic weight of an element in the alloy, $\mathrm{M_A}$ = Atomic weight of an alloy.

X-ray fluorescence (XRF) device (SKYRAY EDX P730) used to Analyzer the alloys powder; the results showed that BiSb Represents $Bi_{50}Sb_{50}$, Bi_2Sb Represents Bi_{66} Sb_{33} and $BiSb_2$ Represents $Bi_{33}Sb_{66}$.

The energy band gaps of the films of various ratios have been determined by concluding the linear portion of the plots of $(\alpha h\nu)^2$ against (hν) to the energy axis.

The extinction coefficient (K_e) refractive index (n), the real and imaginary dielectric constant thin films have been estimated from reflectance using the following formula (2) [6].

$$n = [\frac{4R}{(R-1)^2} - K_e^2]^{1/2} - \frac{(R+1)}{(R-1)} \quad (2)$$

where

$$K_e = {\alpha\lambda}/{4\pi} \quad (3)$$

The real and imaginary parts of the dielectric constant of the Bi-Sb thin films were computed using the relation (4) [5].

$$\varepsilon_r = n^2 - k_e^2 \quad , \quad \varepsilon_i = 2nk_e \quad (4)$$

Fig. 1. The Bi-Sb Alloy and Bi-Sb Alloys in quartz ampoules

3. RESULTS AND DISCUSSION

The values of some important parameters of the studied films (Absorptance, Transmittance, optical band gap energy and refractive index, real and imaginary dielectric constant).

Compared with the absorption of Bismuth and antimony [6] with other ratios conclude three region as shown in Fig. 2.

First: Within the range (200-315) nm, at high percentage of Bismuth clearly showed preponderate Bismuth behavior on the thin film and have high transmittance, while at high percentage of antimony showed antimony preponderate behavior of the thin film and have high absorbency.

Second: All ratios approaching from one value of absorbance (0.54) at a wavelength (315 nm) at UVA.

Third: over (315 nm) the curves exhibits two ways all have a high absorbance, first curve to (Bi_2Sb) continued to increase due to the thin film containing a high percentage of bismuth which has the highest absorbency of antimony in this range of the spectrum, in contrast with the ($BiSb, BiSb_2$)thin films behavior.

Fig. 3 exhibit energy gap for BiSb, Bi_2Sb & $BiSb_2$ (60 nm) thickness the exponent (n) takes a value of 2 for allowed indirect transitions. The values of the energy gap, E_g (allowed indirect transitions), calculated from the absorption spectra, ranged between (0.063 – 0.081) eV and tabled in Table 1, which is in agreement with previous studies in Table 2.

Table 1. Energy gap

Sample	Optical energy gap (eV)
BiSb	0.073
Bi_2Sb	0.063
$BiSb_2$	0.081

By comparing the energy gaps with the other percentage in comparison Table 2 that the percentage have switched from the replacement process to produce new semiconductor, which are promising for applications in far-infrared devices.

Table 2. Comparative energy gap

Sample	optical energy gap (meV)	optical energy gap (meV)	Sample	optical energy gap (meV)
Bi	155 [7]	150 [10]	$Bi_{x-1}Sb_{x,}$	10.5-20 [12]
Sb	203 [7]	101 [10]	x=[0.103-0.18]	
$Bi_{86}Sb_{14}$	25 [8]	18-20 [9]	$Bi_{x-1}Sb_{x,}$	20-40 [14]
$Bi_{70}Sb_{30}$	7 [10]	-	x=[4-22]	
$Bi_{85}Sb_{15}$	23 [10]	-	$Bi_{0.9}Sb_{0.1}$	< 23 [15]

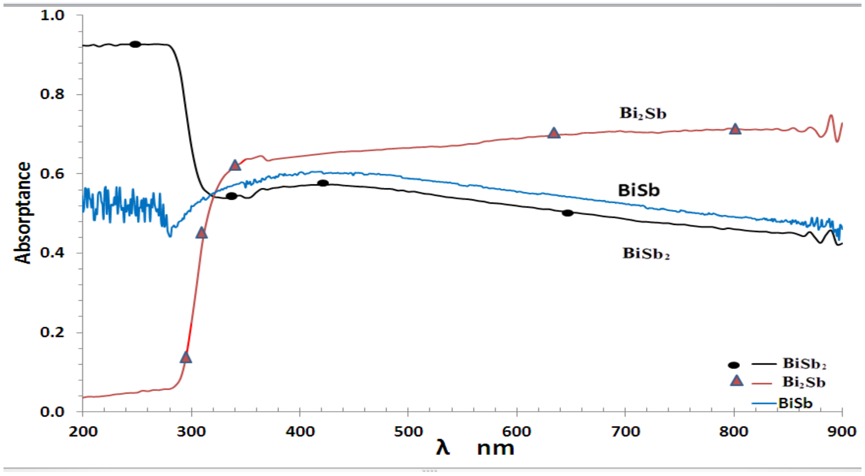

Fig. 2. Absorptance of Bi-Sb thin films

Fig. 4 displays the highest extinction coefficient (K) value for BiSb followed by Bi_2Sb and $BiSb_2$ had lowest value.

Fig. 5 Displays the Fluctuating values of the refractive index as a result of Antimony non-linear behavior, this agrees with [11].

Fig. (6) and Fig. (7) Presents the dependence of the real dielectric constant of the BiSb, Bi_2Sb, $BiSb_2$ thin films on wavelength, it is clearly seen from the Figures that imaginary parts increased as the wavelength increase, where BiSb got the highest value, followed by Bi_2Sb and then $BiSb_2$. Real dielectric results showed a fluctuation in the values.

The difference in the lattice constant as well as the atomic radius of antimony (145 Pico meter) is less than that of bismuth (160 pico meter) made lattice defects, distortion, Interstitial and substitution led to different results for the three samples.

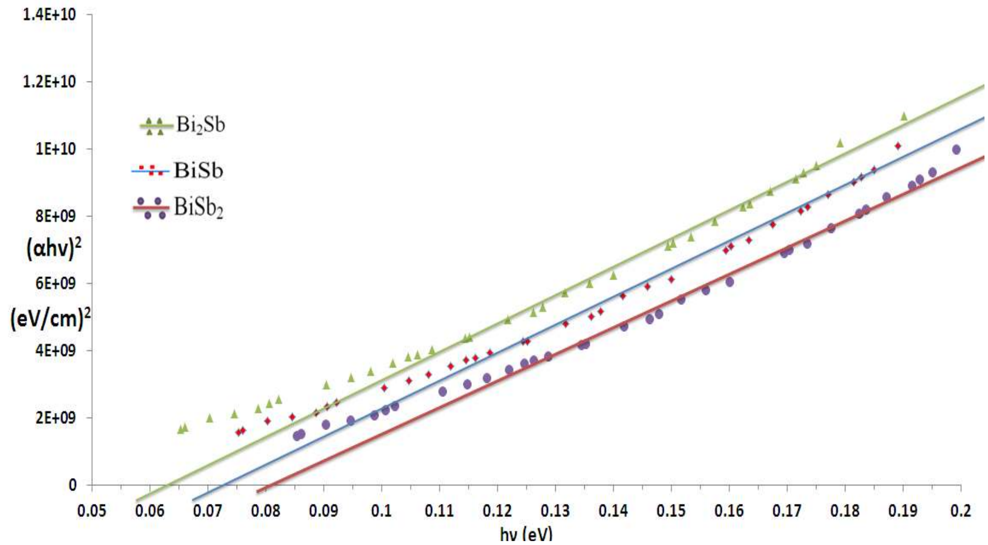

Fig. 3. Energy gap for Bi_2Sb, BiSb, $BiSb_2$

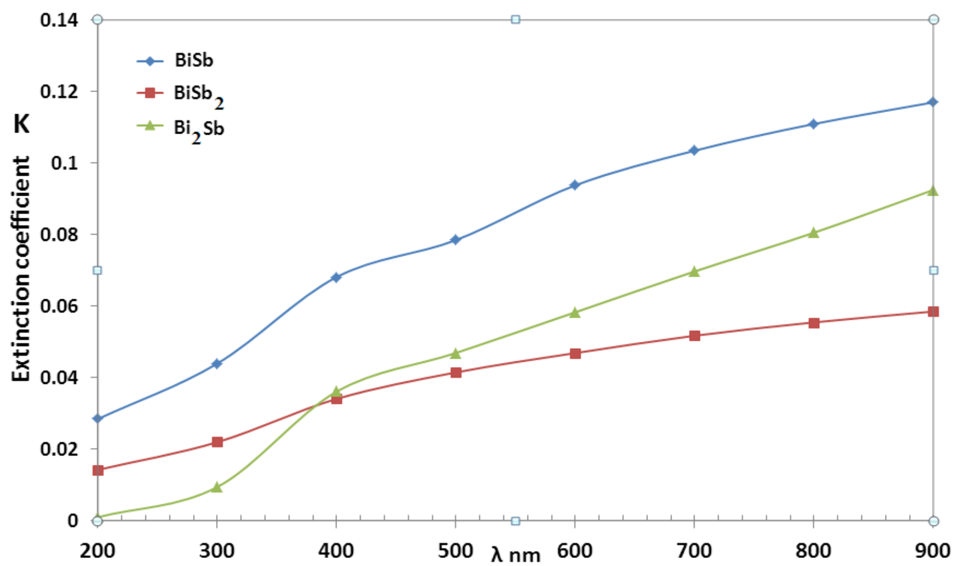

Fig. 4. Extinction coefficient (K) for BiSb, Bi_2Sb, $BiSb_2$ thin films

Table 3. Variation of refractive index and extinction coefficient as a function of wavelength (500 nm – 1000 nm)

Sample	Refractive index	Extinction coefficient
Bi	1.565-1.568 [10]	0.178-0.221 [10]
Sb	1.568-1.601 [10]	0.069-0.207 [10]
BiSb	2.24-2.49	0.028-0.116
Bi_2Sb	1.53-2.64	0.001-0.092
$BiSb_2$	2.53-2.61	0.014-0.058

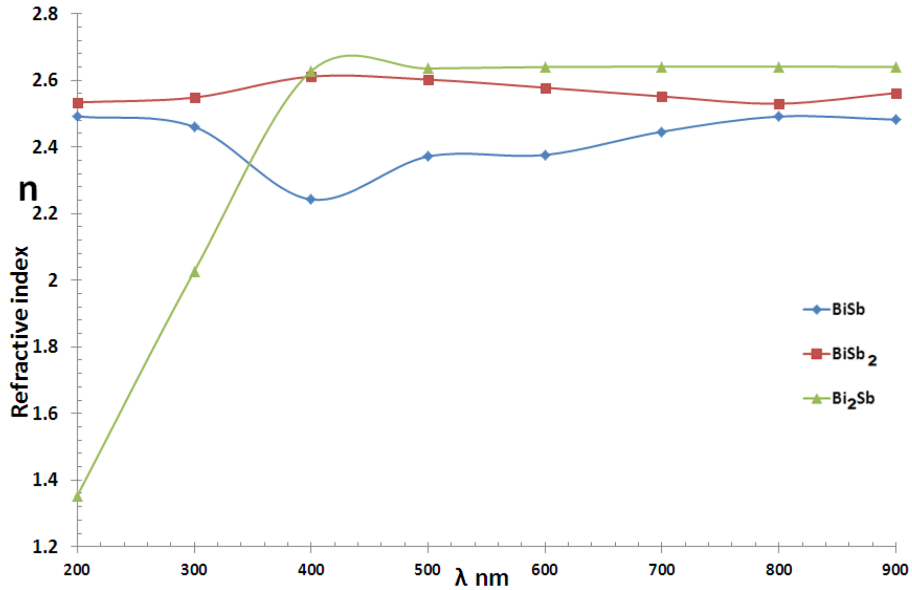

Fig. 5. Refractive index (n) for BiSb, Bi_2Sb, $BiSb_2$ thin films

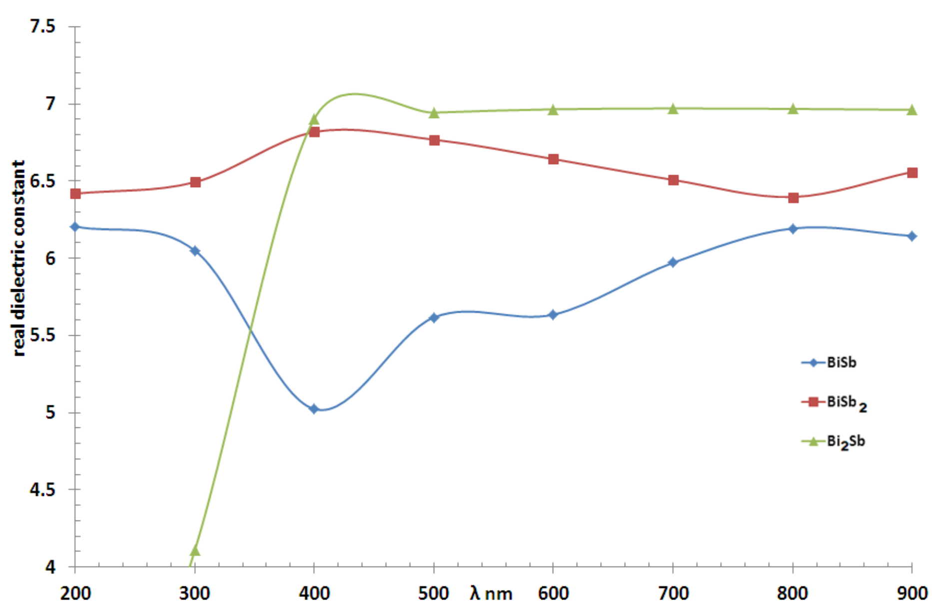

Fig. 6. Real dielectric for BiSb, Bi_2Sb, $BiSb_2$ thin films

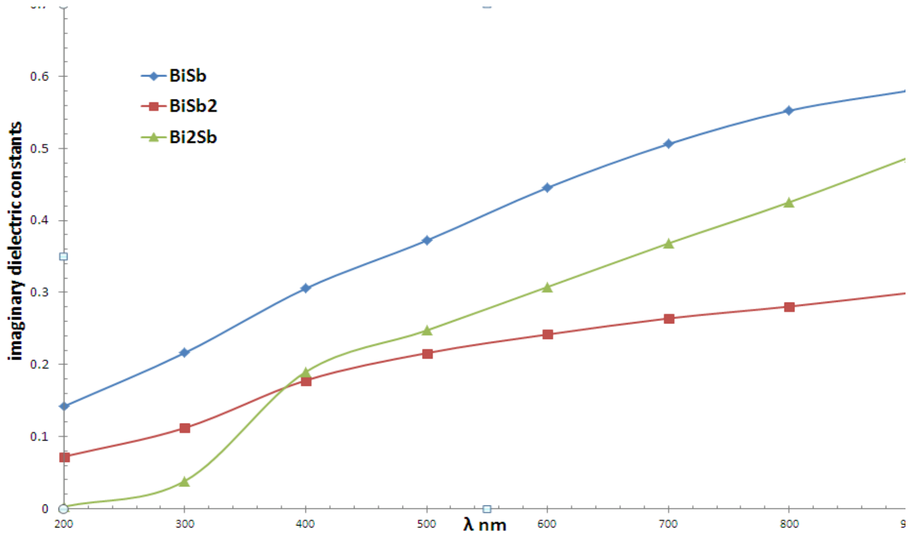

Fig. 7. Imaginary dielectric for BiSb, Bi_2Sb, $BiSb_2$ thin films

4. CONCLUSIONS

Thin films of BiSb, Bi_2Sb, $BiSb_2$ were deposited on quartz substrates by thermal evaporation technique. Bi-Sb thin films are found new values of (Absorptance, Transmittance, absorption coefficient, optical bandgap energy and refractive index, real and imaginary dielectric constant) can be modified with the changing percentage of the elements in the alloy.

The dependence of $(E_g)_{opt}$ obtained in this way on the composition of the samples. It is evident that $(E_g)_{opt}$ increases with the antimony concentration, this agrees with [12].

The value of the energy gap in this work more than doubled in [13-15] and it was due to the different method of work and percentage of the elements.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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