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Optical properties and optical parameters of chalcogenide optic fiber material based selenium

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Abstract: *The nonlinear variation of transmission (T) and reflection (R) as a function of wavelength (λ) in the spectral range 200nm – 2500nm for thin film samples of the system $Se_{80}S_{20-x}B_x$ where (x=0, 2.5, 5 and B=In or As) was recorded. The maximum transmission intensity was 85% at visible and infrared regions. The top of the transmission peak was at the wavelength 1500nm for $Se_{80}S_{20}$ sample. The addition of 2.5 at % In on expense of S, leads to the appearance of plateau at a wavelength 1100nm-2500nm. Increasing In content to 5 at %, shift the maximum transmission peaks toward long wavelength (red shift) and located at wavelength 1750nm. Replacing In by As with different ratio, the maximum transmission peak suffered from blue shift. On the other hand, the reflected light intensity was 45 % for the sample $Se_{80}S_{20}$ at the locations 500nm,900nm and 2100nm. The addition of 2.5 at % In increase the reflection to 50% at the location 500nm and change to be 40% at locations 900nm and1400nm. Increasing In content to 5 at %, keep the reflected intensity 40% at locations 900nm,1400nm and 2100nm. Replacement In by 2.5 at % As on expense S, leads to shift the reflected peak intensity to short wavelength (blue shift). Increasing As content to 5 at %, increase blue shift of the reflected peak to appear at locations 700nm and 900nm with intensity 60%.*
The addition Er cover layer leads to appear transmission plateau with intensity 80 % for $Se_{80}S_{20}Er$ and $Se_{80}S_{17.5}In_{2.5}Er$ samples and 60% for the sample $Se_{80}S_{15}In_5Er$.
The absorption coefficient is zero at low photon energy high value at high photon energy and moderate values at visible region. The addition of In or As on expense S, lead to decrease the absorption coefficient. This decrement was more detectable in case of adding As. The addition of Er cover layer leads to decrease the absorption coefficient of all sample. The zero or negative value of the extinction coefficient means that very high smooth surfaces of the samples under test.

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I. Introduction

Chalcogenide glasses were attract special interest due to their benefit applications (1-2). Among the amorphous chalcogenide alloys mostly selenium (Se) based material are preferred due to its commercial use. Thin chalcogenide films have found application in the field of optical technology as novel memory devices (3). These films have a high refractive index, low phonon energy and gradually are transport from visible to the infrared region (3). These materials very promising to be use in fiber optics and wave guide devices integrated optics and optical memories (4-5). Moreover, it can be used as core material for optical fiber, for light transmission (6). This means that, this material will be used in communication systems which depends on high-bit rate of transformed high optical date through ultra-fast optical switches (1-3). The nonlinear switching is the most distinctive chalcogenide glasses due to ultra-fast time interval and compatibility with the future fiber technology (4-6). This glassy material is also insensitive to moisture (7-8). This will lead to the appearance of a new category of optic fiber promising applications in the mid-infrared optics (9-11).

The aim of the present paper is to study the optical properties of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 and B=In or As). The samples were prepared as thin films using the laser ablation technique. The transmission T, reflection R and the optical parameters as function of wavelength will be recorded. The optical band gap E_g^{opt} will also be determined.

II. Experimental

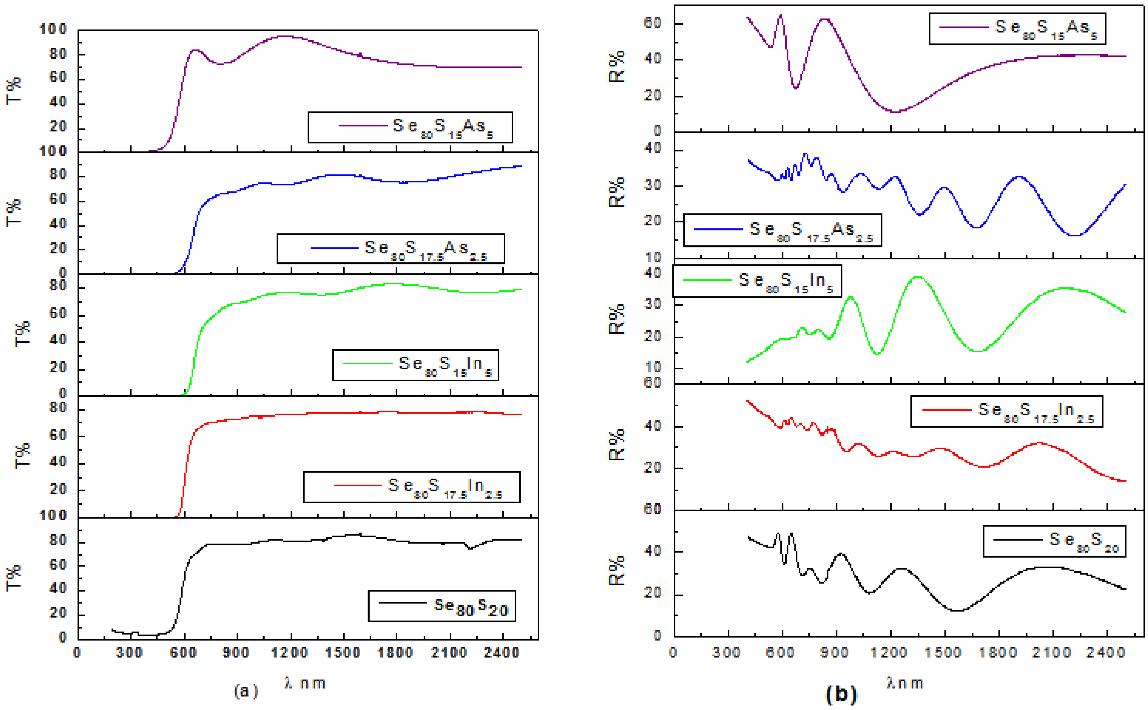
The chalcogenide samples of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 and B=In or As) were prepared by melting quench technique. Elements Se, S, Te, In& As were weighted and well mixed using the ball milling method for each sample alone. The mixture was placed in an evacuated (10^{-4} Pa) and capsulated silica tube. The silica tube containing each sample was heated at fixed temperature for fixed time. The sample $Se_{80}S_{20}$ and each sample contain In on the expense of S were melted at 500^0C for 8 hours and quenched in Ice water.

The samples containing As on the expense of S were melted at 800^0C for 8 hours and quenched in ice water. The thin film samples were prepared from the bulk ingots using laser ablation on glass substrate. This was done using Nd:YAG pulsed laser deposition of wavelength 532nm under $55*10^{-4}$Pa vacuum. Laser ablation was used again under the same condition to cover each sample by Er layer. The thickness of the obtained thin films was determined using interferometric method. The transmittance (T) (ʎ) and reflectance R (ʎ) of the thin films were recorded using spectrophotometer in spectral range200-2500nm.

III. Result And Discussion

1- Transmission (T) and reflection (R) spectra.

The nonlinear variation of transmission (T) and reflection (R) as a function of wavelength (ʎ) in the spectral range 200nm – 2500nm for thin film samples of the system $Se_{80}S_{20-x}B_x$ where (x=0, 2.5, 5 and B=In or As) was recorded in fig [1]. Fig[1a] indicate that as the wavelength exceeds 300nm ,the value of transmission (T) increases gradually up to the wavelength 450nm. Then the transmission increases abruptly to reach maximum intensity around 80 – 85 % for the sample Se80S20 in the spectral range 600nm to 2500nm.

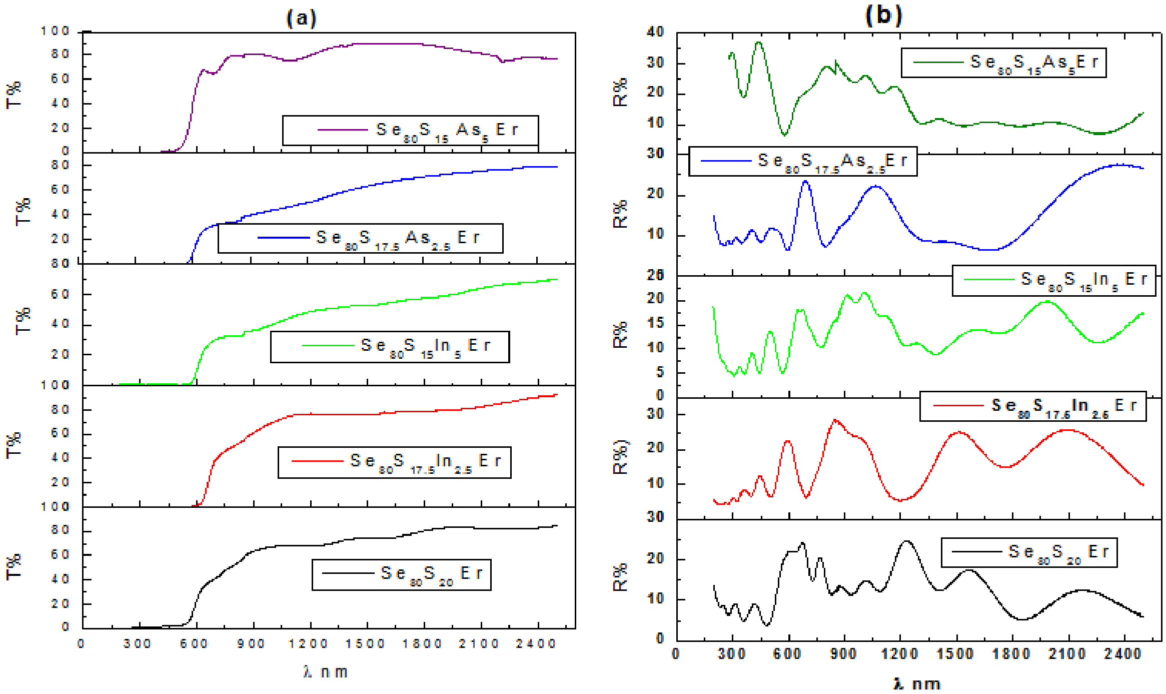


Fig[1] variation of (a) transmission(T) and (b) reflection(R) with wavelength(ʎ) of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) .

These maxima were characterized by three intensity peaks covering the rest of the visible region and all over the infrared region up to 2500nm. The top of the highest peak for the sample $Se_{80}S_{20}$ was located at the wavelength 1500nm. The maximum transmission peak was at 1750nm for the thin film sample $Se_{80}S_{15}In_5$. These transmission peaks were shifted toward long wavelength as In content increases, and shift toward short wavelength as As replacing In and as As content increases.

Figure [1b] shows that the reflected light intensity was 45% for the sample $Se_{80}S_{20}$ at the wavelength locations 500nm ,900nm and 2100nm. The replacement of S by 2.5 at % In leads to increase the reflected light intensity to 50% at wavelength 500nm , keeping in mind that the reflected intensity in the wavelength range 900nm to 2100nm still around the value 45 %. The increase of In content to 5 at % on the expense of S leads to the appearance of the reflected light window at the specific wavelengths 900nm , 1400nm and 2100nm with light intensity 40%. Accordingly, the red shift of these windows will decrease the attenuation and saving the light energy. The replacement of In by As on the expense of S leads to shift the reflected light peaks to short wavelengths(blue shift). The relative intensity of this shifted peaks was 45% for the sample $Se_{80}S_{17.5}As_{2.5}$. Increasing As content to be 5 at %, the blue shift of the reflected peaks becomes more detectable and its relative intensity reaches 60% at the windows 700nm and 900nm respectively. This means that the chalcogenide materials containing In is a good selection to produce optic fiber cables using infrared radiation at the windows 900nm, 1400nm and 2100nm. On the other hand the chalcogenide materials containing As is a good selection to produce optic fiber cables using visible light at 700nm and at 900nm as near infrared. The main conclusion is the use of In or As at the selected windows means low energy losses and in turn low attenuation of light energy.

Figure [2a] shows that, the addition of Er cover layer leads to the gradual nonlinear growth of the transmission(T) as a function of wavelength for all samples of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 and B=In or As).



Fig[2] variation of (a) transmission(T) and (b)reflection(R) with wavelength(λ) of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) with Er cover layer .

The maximum transmission (T) was detected at 2000nm for all samples. These maxima were 80% for $Se_{80}S_{20}$ and $Se_{80}S_{17.5}In_{2.5}$. This value was reduced to 65% for the samples $Se_{80}S_{15}In_5$. The maximum recorded transmission (T) as As replacing In was 70%. This means that, using Er as cover layer leads to decreasing the intensity value of transmission (T) for both chalcogenide materials containing In or As.

The reflected light intensity from the surface of the sample $Se_{80}S_{20}Er$ was 25 % at the wavelengths 700nm and 1200nm. These values become around 20% for same sample at the wavelengths 1500nm and 2100nm. The intensity of the reflected light at the wavelengths 700nm, 900nm, 1400nm and 2200nm was around 30% for the sample $Se_{80}S_{17.5}In_{2.5}Er$ and $Se_{80}S_{15}In_5Er$. The intensity of the reflected light from the surface of the sample $Se_{80}S_{17.5}As_{2.5}Er$ was 25% at the windows 700nm,1100nm and 2200nm. The intensity of the reflected light from the surface of the sample $Se_{80}S_{15}As_5Er$ was in the range 30-35% at the locations 500nm and 700nm. Generally, the red shift for the samples containing In and the blue shift for the samples containing As still the same after Er cover layer was added.

2- The absorption Coefficient (α) and Urbach tail :

The absorption coefficient (α) (8) of the thin film samples was calculated. The nonlinear variation of the absorption coefficient (α) as a function of photon energy (hυ) is shown in Fig [3].

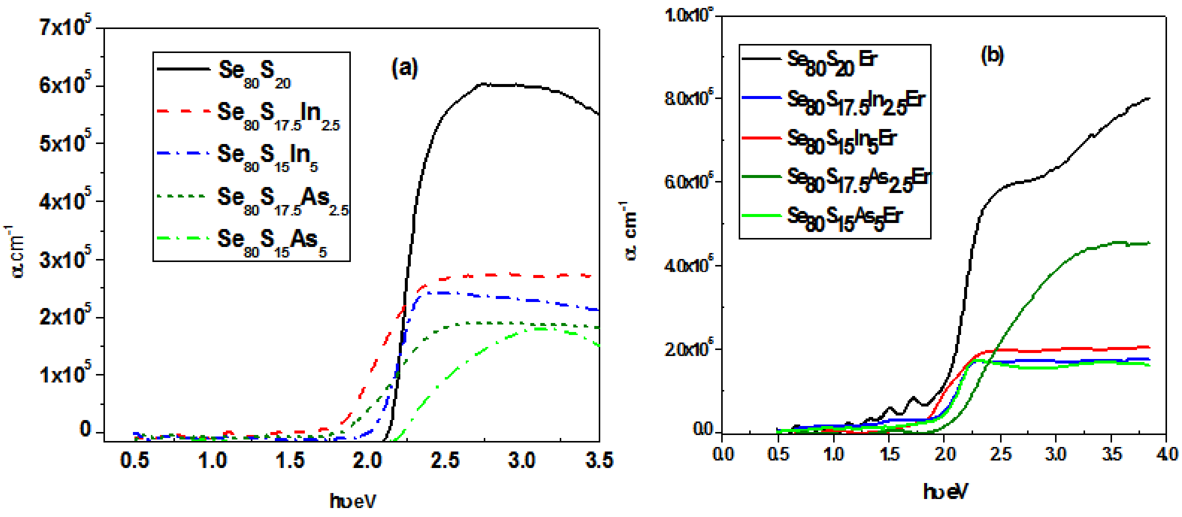


Figure [3] Variation of absorption coefficient (α) with photon energy (hυ) of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) (a) uncovered Er layer and(b) cover Er layer.

Figure [3a] shows that the absorption coefficient (α) is nearly zero during the low light energy. The value of α starts to increase as the photon energy increase. As photon energy exceed 2.0 eV, the absorption coefficient of the sample $Se_{80}S_{20}$ increases abruptly to reach maximum value of $6.5*10^5$ cm^{-1}. The addition of In or As on the expense of S leads to decrease the absorbed light energy. This was revealed as threshold energy at which α increases was decreased to be below the value 2.0 eV.

The detected maximum value of α after the addition of 2.5 at % In on the expense of S was $2.5*10^5$ cm^{-1}. This value was decreased to be $2.0*10^5$cm^{-1} as the In content become 5 at % on the expense of S.

Also, the maximum value of the absorption coefficient for the sample containing As was decreased to the value of $1.5 *10^{-5}$ cm$^{-.1}$

Generally, the recorded behavior of the absorption coefficient (α) as a function of photon energy (hυ) during the ultraviolet region, the absorption is very high. This may confirm, the use of these samples as a ultraviolet filter (9).

Fig [3b] shows that the absorption threshold energy of the absorption coefficient (α) decreases mostly as the Er cover layer added to each sample. The threshold energy for samples of the system $Se_{80}S_{20-x}$ B_x where (x=0,2.5,5 and B=In or As) were found to be below 2.0eV. The value of α in case of $Se_{80}S_{20}$Er becomes $8*10^5$ cm^{-1}. The values of α for the samples containing In or As also, increased after Er cover layer was added, but still less than its $Se_{80}S_{20}$Er.

Generally, the Er cover layer increases the values of α for all samples of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 and B=In or As) during the ultraviolet region. This result, direct the application of chalcogenide optic fiber to use the IR spectra, as the value of α very low or nearly zero.

The samples of the system $Se_{80}S_{20-x}$ B_x where (x=0,2.5,5 and B=In or As) were formed in the amorphous state (10,11), and some defects are expected to be exsit. Among this defects is the Urbach tail, which normally extended in the optical energy gap of the given sample. The relation (12) holding the Urbach tail with absorption coefficient α is,

$$\alpha=\alpha_0 \exp(h\upsilon/E_{e)}$$

Where αo is a constant and Ee is width of Urbach tails.

Table [1]

S.No.	Sample	Ee degree of disorder(meV) Before Er layer	Ee degree of disorder(meV) after Er layer	Optical Band Gap (Eg) before Er layer in eV	Optical Band Gap (Eg) in eV after Er layer
1	$Se_{80}S_{20}$	56.95	11.85	2.17	1.9
2	Se_{80} $S_{17.5}$ $In_{2.5}$	41.19	11.71	2.12	1.75
3	Se_{80} S_{15} In_5	58.43	9.83	1.87	1.5
4	$Se_{80}S_{17.5}As_{2.5}$	44.07	14.92	2.05	1.75
5	$Se_{80}S_{15}As_5$	58.6	15.65	2.25	2.1

The addition of Er cover layer leads to decrease the values of Urbach band tails for all samples.

3- The optical energy gap (Eg):-

The absorption coefficient α can be used to calculate the optical energy gap (13,14).

The results of table (1) illustrate that, the Er cover layer leads to decrease the optical energy gap of all samples Finally, this reduction in the optical energy gap as well as in the Urbach tail length means the increase of material purity from defects. The industrial and technological conclusion of the pure and narrow optical energy gap is to keep the launched light energy through the produced optic fiber under control.

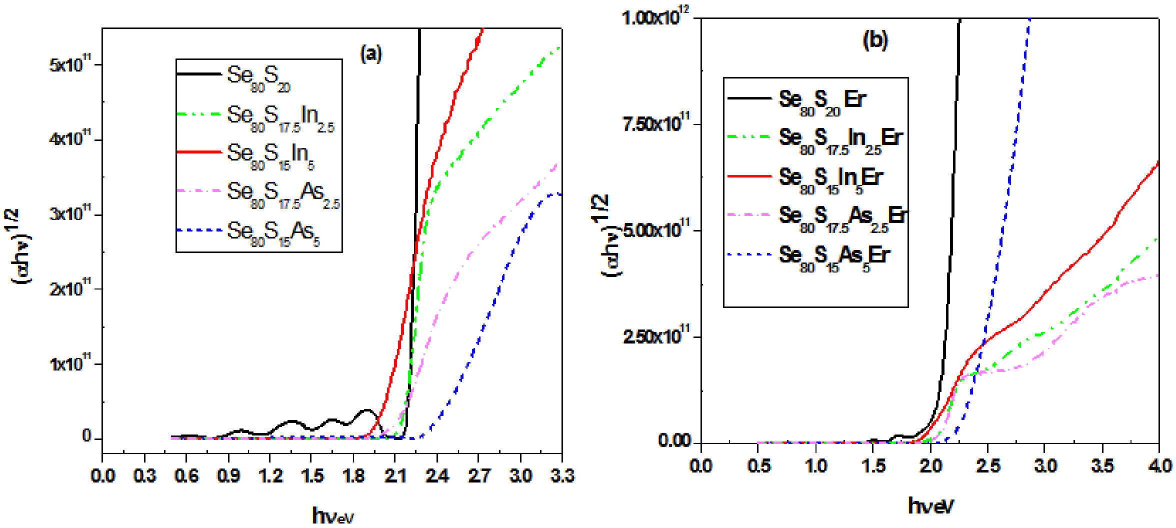
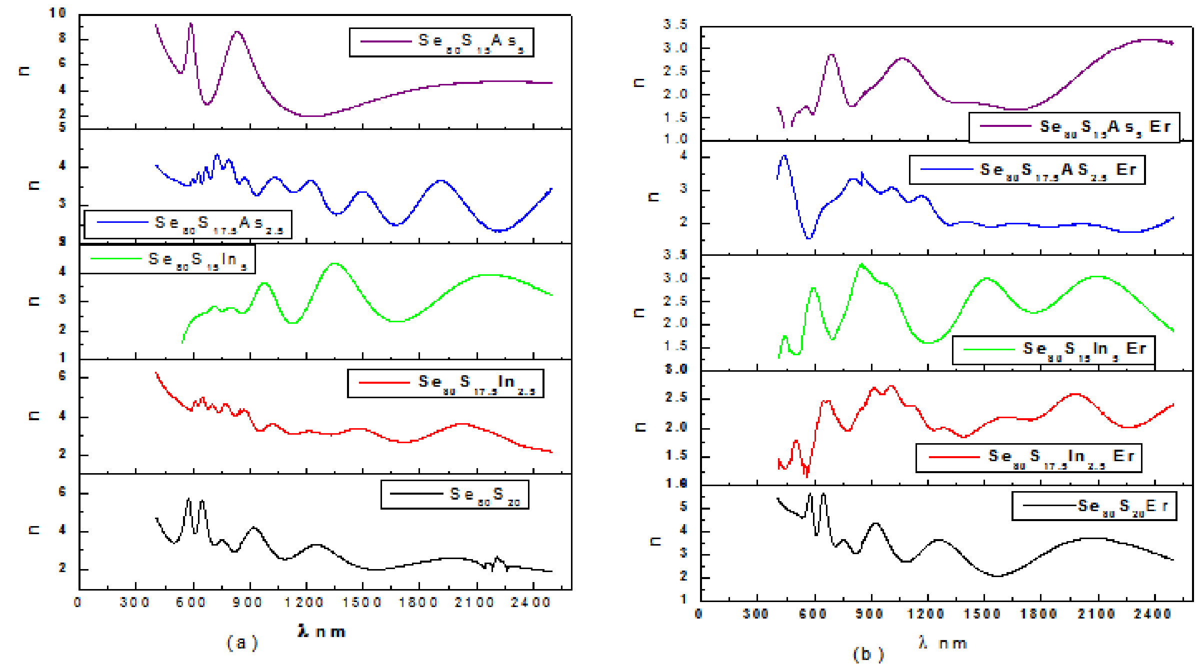


Figure [4] Variation of (αhν)1/2 with (hυ) of the system Se80S20-x Bx where (x=0,2.5,5 B=In or As) (a) uncovered Er layer and (b) with Er cover layer.

4-**Refractive index**

The nonlinear variation (12,15) of the refractive index as a function of wavelength is shown in fig [5].



Figure[5] Variation of refractive index (n) with wavelength (λ) of $Se_{80}S_{20-x}$ B_x where (x=0,2.5,5 B=In or As) (a) uncovered Er layer and (b) with Er cover layer.

The strat values of the refractive index of the system $Se_{80}S_{20-x}$ B_x where (x=0,2.5,5 and B=In or As) were high. These values were decreased as the radiation energy decreases. The smallest value of refractive index (n) was for the sample $Se_{80}S_{20}$ at the infrared range. The addition of In or As on the expense S leads to increase the values of refractive index.

The addition of Er cover layer leads to decrease the values of the refractive index (n) for all samples. This may be employ to control possibility of obtaining graded refractive index for the optic fiber.

5- Extinction coefficient (K):

The nonlinear variation of the extinction coefficient (16) as a function of wavelength, in the spectral range 400nm – 800nm for system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) is shown fig [6].

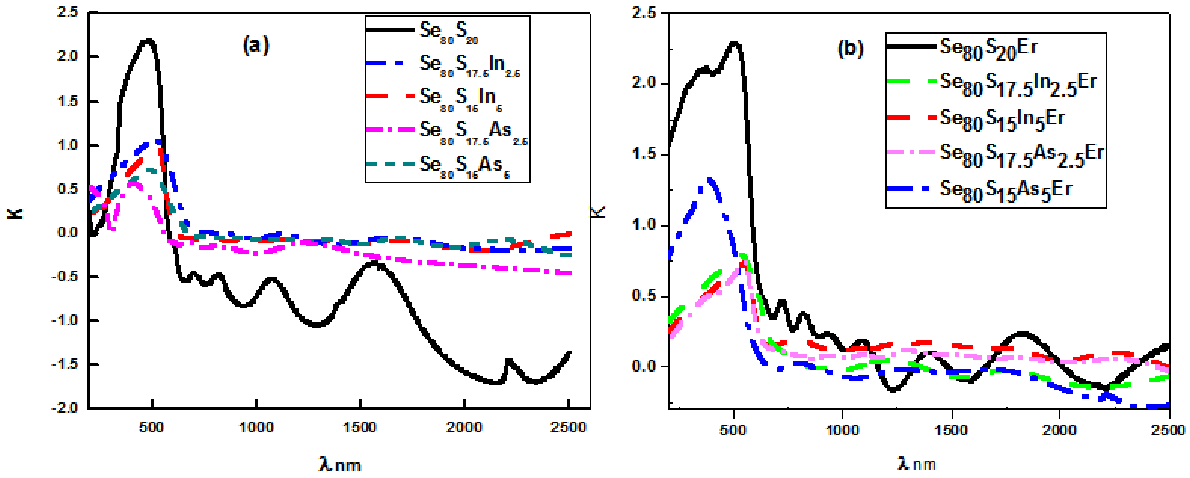


Figure [6] Variation of extinction coefficient (k) with wavelength (λ) of $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) (a) uncovered and (b) covered with Er layer.

The extinction coefficient (k) were started as low values and increased abruptly to reach maximum values at the visible region. The maximum K value was 2.25 for $Se_{80}S_{20}$. This value decreased to zero at λ=600nm and decreased more to reach -1.75 at λ=2500nm. The addition of In or As on the expense of S, leads to decreases the values of extinction coefficient (K) all over the spectral range.

The addition of Er cover layer to the surface of samples of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) lead to increase the start values of K and keep the end saturated values as the same as before the Er cover layer. The reducing of the K values during IR region means a high degree of smoothing of the surface of the sample and this in turn reduces the attenuation as the smooth surface of less scattering.

IV. Conclusion

The nonlinear variation of transmission and reflection with the wavelength give chance to determine the possible windows for the visible and infrared regions. These windows were determined to be in the infrared region as the sample of the system $Se_{80}S_{20-x}B_x$ where (x=0,2.5,5 B=In or As) contain In on the expense of S. These windows were found to be in the visible and near infrared regions as the samples of this system contains As. The obtained values of the absorption coefficient were high at ultraviolet region, moderate at the visible region and low at the infrared. The obtained extinction coefficient K was high at ultraviolet and very low or zero during the visible and infrared regions. This means the possible total internal reflection as the sample surfaces are very smooth.

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