Spectroscopic and Optical Studies of Some Semiconductor Materials

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Abstract

The interest of micro and nano photonics is to identify semiconductor materials which have properties as good as current semiconductors, and also can considerably reduce the size of electronic and optoelectronic structures.
The present work is to study the optical properties of some semiconductor substrates, including spectroscopic properties in the spectral regions of UV, visible and infrared in order to determine optical constants such as the absorbance and transmittance. The spectroscopic behavior of two semiconductor samples, in thin layers form and made from polymers designed for photovoltaic applications, has also been studied.
The results are meaningful and fully satisfactory to be used in technological applications.

Key words: Optoelectronic, semiconductor, spectroscopy, optical properties

1. Introduction

The interest in micro and nanophotonics is to find materials that have good semiconducting properties as current semiconductors (including silicon), and also, to reduce the size of electronic devices. The key parameter for determining the electrical and optical properties of semiconductors is the energy gap, i.e., the "band structure" [1, 2].
The semiconducting polymers have become an area of research and innovation important for emerging technologies; they are widely used in many applications. To make them more attractive in their fields of use, it is necessary to find ways to improve their properties and durability. In recent years, many theoretical and experimental efforts have been made to develop polymer semiconductors for the manufacture of solar cells [3,4]. However, the conventional semiconductors continue to occupy a significant place in the field of optoelectronics.
The present work is to study the optical properties (absorption and transmission) of semiconductor substrates using UV, visible and infrared spectroscopy.

2. UV-visible spectroscopy

The UV-visible spectrophotometry is both qualitative and quantitative analysis method. It's essentially based on the light energy absorption by a given substance. When a light beam with intensity I_0 passes through an absorbing material of thickness l, a portion of the incident light will be absorbed, and the emergent beam is attenuated so that its intensity become I. The mentioned

attenuation is function of the constituents of the analyzed material.
The Beer-Lambert law gives the absorbance A as:

$$A = \ln(I / I_0) = \varepsilon.C.l \tag{1}$$

Where: ε is the absorptivity, C, the molar concentration and l is the material thickness.

The absorption coefficient α can be derived from the transmission spectrum, in the UV-linear region, by the expression:

$$T = \frac{(1-R)^2(1+K^2/n^2)}{\exp(\alpha Z) - R^2 \exp(-\alpha Z)} \tag{2}$$

With: T is the transmittance, R, the reflection coefficient, K, the extinction coefficient, n, the refractive index and Z is the substrate depth.

The absorption coefficient α is then given by:

$$\alpha = 2{,}303 \frac{\log(I_0 / I)}{Z} \tag{3}$$

With:

$$\log(I_0 / I) = \log(1/T) = OD \tag{4}$$

where OD is the optical density.

2.1. The UV-Vis Spectrophotometer:

The spectra were recorded using a spectrophotometer UNICAM 300 (UV-Vis) which operating principle is shown in the following figure:

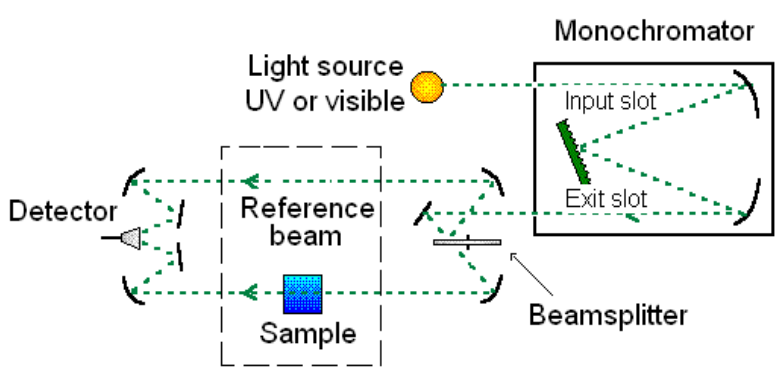


Figure 1. Schematic diagram of a double beam UV spectrophotometer

A light source emits a beam which passing through a monochromator lets emerge a single wavelength. The radiation thus obtained is divided into two parts by a beam splitter, which one serves as a reference beam and the other as an object beam, which crosses the sample.

Thus, the object and reference beams combine and interfere to generate a spectrum expressing the absorbance of the sample, and the intensity at any point is recorded by a photodetector.

2.2. Spectral Measurements

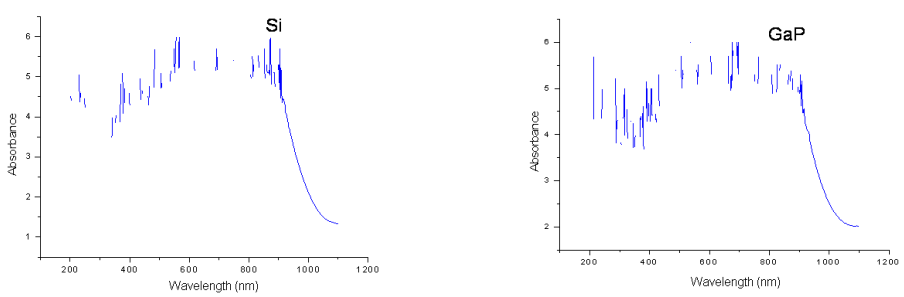
Three groups of semiconductors are studied as shown in table 1: a group with indirect gap, group with direct gap and a group of polymer semiconductors.

Table 1. Semiconductors designation

Semiconductor group	Designation	Z Thickness (µm)
indirect gap	Si	300
	GaP	300
direct gap	GaAs-n	300
	GaAs-p	400
	GaN	500
polymers (P3HT/PCBM)	P3HT (donor)	0,150
	PCBM (acceptor)	0,150

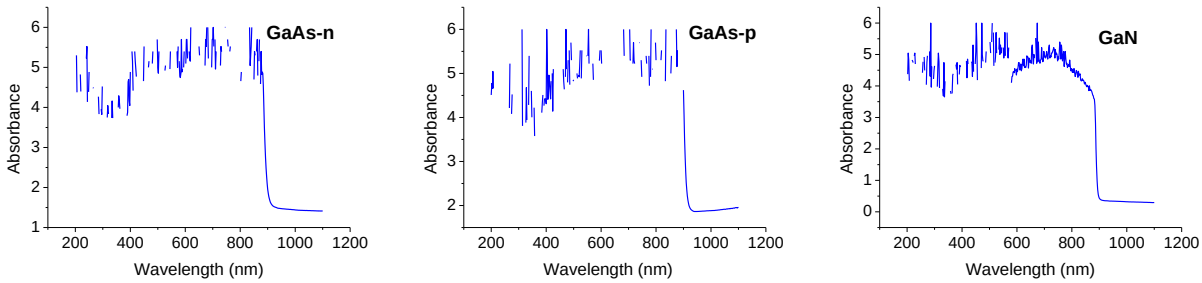
Note that the semiconductors of P3HT/PCBM are thin films on substrate of glass.

The spectra of Figures 2, 3 and 4 shows the absorbance deducted from UV-Vis spectrum, depending on the wavelength, for the semiconductors with indirect gap (Si, GaP), direct gap (GaAs-n, p-GaAs, GaN) and Polymers (P3HT/PCBM) respectively.



(a) (b)

Figure 2. Absorbance versus the wavelength of semiconductors with indirect gap for: (a) Si and (b) GaP



(a) (c) (b)

Figure 3. Absorbance versus the wavelength of semiconductors with direct gap for:
(a) GaAs-n, (b) GaAs-p and (c) GaN

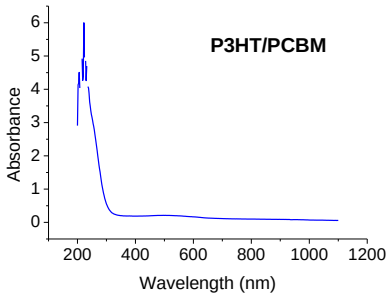


Figure 4. Absorbance versus the wavelength of polymer semiconductor P3HT/PCBM

2.3. Determination of the absorption coefficient versus the gap energy

From the spectra shown in Figures giving absorbance versus the wavelength of the used light, it is possible to determine the absorption coefficient of semiconductors following Eq. (3).

As the photon energy is calculated using the below equation:

$$h\nu = E(eV) = \frac{1{,}24}{\lambda(\mu m)} \tag{5}$$

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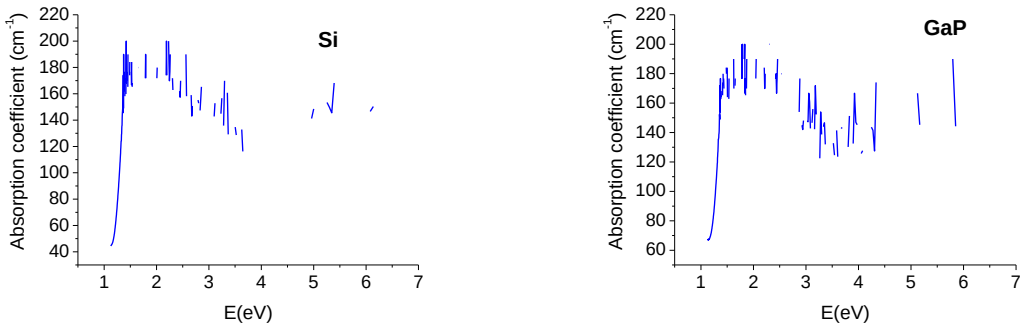
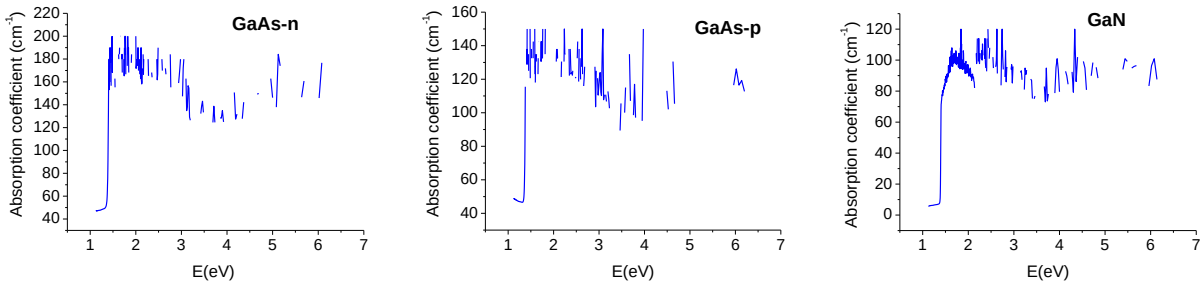
We can represent the spectra making the absorption coefficient as a function of the energy gap for the three groups of semiconductors previously studied, as shown in Figures 5, 6 and 7 respectively.



(a) (b)

Figure 5. Absorption coefficient as function of energy gap of semiconductors with indirect gap for: (a) Si and (b) GaP



(a) (c) (b)

Figure 6. Absorption coefficient as function of energy gap of semiconductors with direct gap for: (a) GaAs-n, (b) GaAs-p and (c) GaN

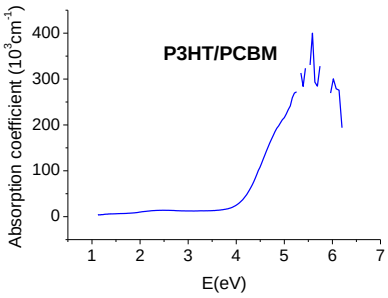


Figure 7. Absorption coefficient as function of energy gap of polymer semiconductor P3HT/PCBM

The graphical results provide information first on the spectral range and the energy gap, which is significant for exploitation of the semiconductor. It is clear that in the visible range, semiconductors have considerable absorption. Limit of the spectra occurs well before the wavelength of 1.1 μm.

The absorption coefficient gets considerable value in the limit of the visible and UV. Moreover, for spectral energies of 5 to 6.5 eV, absorption coefficient can average 3.5×10^{5} cm^{-1}. These results were confirmed by Hoppe and Sariciftci [5].

3. Infrared Absorption Spectroscopy

3.1. Principle and instrumentation

Infrared spectroscopy can detect the presence or absence of functional groups, and for this, we must make a comparison between the spectra of the compound and the synthesized product. Infrared spectra were recorded on a "FTIR" (Fourier Transform InfraRed).
FTIR is a method to obtain an infrared spectrum by first collecting the interferogram signal of a sample using an interferometer, and by performing a Fourier transformation (FT) of this interferogram in order to obtain the spectrum. FTIR spectrometers collect and digitize the interferogram, perform the FT function and display the spectrum. Figure 8 shows the infrared device diagram.

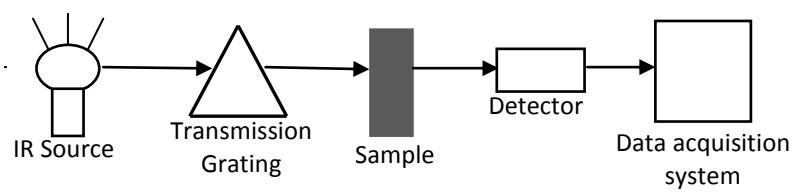
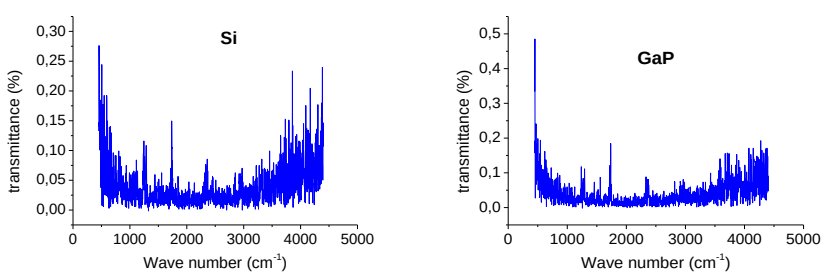


Figure 8. Infrared spectroscopy set-up.

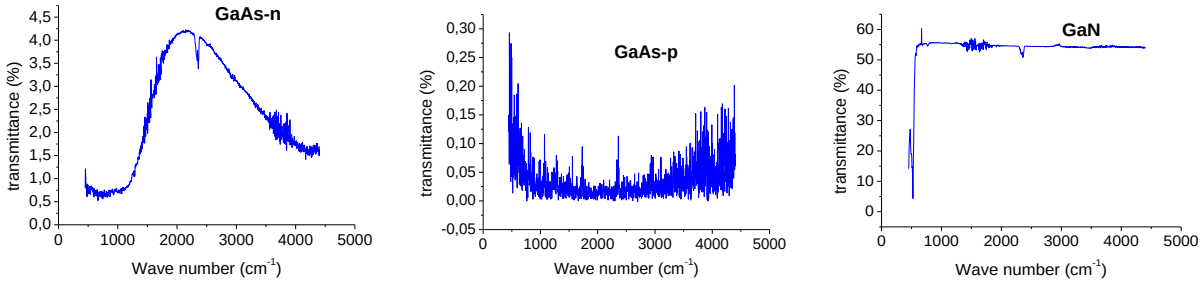
3.2. Spectral measurements:

IR transmission spectra are plotted versus the wave number in Figures 9 and 10 for the both groups of semiconductors with indirect gap and direct gap respectively.



(a) (b)

Figure 9. Transmittance versus wave number for semiconductors with indirect gap for:
(a) Si and (b) GaP



(a) (c) (b)

Figure 10. Transmittance versus wave number for semiconductors with direct gap for:
(a) GaAs-n, (b) GaAs-p and (c) GaN

Concerning silicon (Si) and gallium phosphide (GaP), we note a very low transmission, versus wave number in the range 4000 cm^{-1} to 660 cm^{-1}.

Note that gallium arsenide doped ‘p’ has a very low transmission. This transmission can be increased by doping 'n' the semiconductor, as is confirmed by the graph of Figure 10, where the maximum value is reached between 2000 cm^{-1} and 3000 cm^{-1}.

Gallium nitride is a remarkable semiconductor for its properties that spread out to the infrared. Moreover, a rate of 55% was recorded in almost all the infrared range that extends from 4000 cm^{-1} to 660 cm^{-1}. These exceptional properties are also valid in the infrared than in the visible dominates.

4. Conclusion

The work is based on spectroscopic measurements of some new and classic semiconductors such as polymer semiconductors. The goal is to select the most appropriate semiconductors for the fabrication of receiving and emitting optoelectronic structures.
It appears that spectroscopy is an effective method for the determination of optical properties such as transmission and absorption in the UV-visible and infrared spectral interval.
The purpose is to determine the absorbance, transmission, absorption coefficient and energy of as well some conventional semiconductors (single and complex) as polymer conducting materials.
The objective being achieved therefore, we estimate that the results are significant and may be exploitable.

5. References

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