COMPARAISON ENTRE DIFFERENTES METHODES DE DEFLECTION PHOTOTHERMIQUE POUR DETERMINER LES PROPRIETEES THERMIQUE DES SEMICONDUCTEURS MASSIFS

I. Gaied, M. S. Ghorbel and N. Yacoubi*
Institut Préparatoire Aux Etudes d'Ingénieur de Nabeul IPEIN Merazka 8000 Nabeul-Tunisie
imen.gaied@ipein.rnu.tn
yacoubi20042003@yahoo.fr

RESUME
Dans cette étude, nous allons décrire et comparer différentes méthodes basées sur la Technique de Déflection Photothermique (PTD) permettant la détermination de la diffusivité thermique des semi-conducteurs massifs.
Les deux premières méthodes proposées ici consistent à tracer les variations expérimentales du logarithme de l'amplitude et de la phase du signal photothermique en fonction de la racine carrée de la fréquence de modulation. L'échantillon placé dans l'air est chauffé uniformément grâce à un faisceau de lumière modulé. La seule différence entre ces deux méthodes est que dans la seconde, l'échantillon est recouvert d'une fine couche de graphite.
Nous avons remarqué que la première méthode est seulement sensible à la diffusivité thermique toutefois la deuxième méthode est sensible à la fois à la diffusivité thermique et à la conductivité thermique. Enfin, la troisième méthode qui est purement spectroscopique et où l'échantillon est immergé dans une cellule remplie de CCl_4 consiste à tracer les variations expérimentales de la phase du signal photothermique en fonction de la longueur d'onde pour une fréquence de modulation fixée. La différence de phase entre les deux zones de saturation obtenues pour les grands et faibles coefficients d'absorption optique est sensible à la diffusivité thermique.

COMPARISON BETWEEN DIFFERENT PHOTOTHERMAL DEFLECTION METHODS TO DETERMINE THERMAL PROPERTIES OF BULK SEMICONDUCTORS SAMPLES

I. Gaied, M. S. Ghorbel and N. Yacoubi*
Institut Préparatoire Aux Etudes d'Ingénieur de Nabeul IPEIN Merazka 8000 Nabeul-Tunisie
imen.gaied@ipein.rnu.tn
yacoubi20042003@yahoo.fr

ABSTRACT
In this study we will describe and compare different methods based on the Photothermal Deflection Technique (PTD) which permits the determination of thermal diffusivity for bulk semiconductors. The two first methods proposed here consist in drawing the experimental amplitude and phase variation of the photothermal signal versus square root modulation frequency. The sample placed in air is heated thanks to a modulated uniform light beam. The difference between these two methods is that in the second one the sample is covered by a thin graphite layer. We notice that the first method is only sensitive to the thermal diffusivity however the second method is sensitive for both thermal diffusivity and thermal conductivity. Finally the third method which is a spectroscopic one and where the sample is immersed in a CCl_4 filled cell consists to draw the phase variation of the photothermal signal versus wavelength at a fixed modulation frequency. The phase difference between the two saturated zone (high and low absorption coefficient) is sensitive to the thermal diffusivity.

NOMENCLATURE

ν	Modulation frequency	(Hz)	K_i	Thermal conductivity of i media	($Wm^{-1}K^{-1}$)
n_0	Refractive index of the fluid		D_i	Thermal diffusivity of i media	(m^2S^{-1})
ϕ	Phase of the photothermal deflection	(rad)	α	Sample's optical absorption coefficient	(m^{-1})
z_0	Distance between the probe beam axis and the sample surface	(m)			

1. INTRODUCTION
During the past few years, the application of the photothermal deflection technique which have the advantage of being non destructive has been considerably involved [1-3]. The aim of this technique is in the first time to detect the thermal wave generated by the sample's optical absorption of a modulated light beam which will propagate into the sample and in the surrounding fluid inducing a temperature gradient then a refractive index gradient and in a second time to study the deflection of a laser probe beam skimming the sample surface and crossing the inhomogeneous refractive index region. This deflection may be related to the thermal properties of the sample.
Several methods based on the Photothermal Deflection Technique or the so-called "Mirage Effect" have been developed to determine the thermal diffusivity of materials with high precision [4-6]. The most used technique consists to heat the sample by a modulated laser pump beam and to draw the experimental in phase signal versus the distance x between the pump beam and the probe beam axis at a fixed modulation frequency ν. The obtained curves cut the x axis in two points distant from d. The linear curve $d = f\left(1/\sqrt{\nu}\right)$ whose slope depends on the thermal diffusivity will allow determining it.
In this work, we present and compare three different methods applied to bulk semi conductor such as GaSb samples in order to determine their thermal diffusivity. The two first methods deal with the analysis of the photothermal signal variation versus modulation frequency where the sample is placed in air and heated by a modulated light coming from a Halogen Lamp (uniform heating case).

In the second method the sample is covered with a thin graphite layer where interest will be discussed later. The third method is a spectroscopic one and consists to draw the photothermal deflection signal versus wavelength at a fixed modulation frequency where the sample is immersed in a CCl_4 filled cell. The thermal diffusivity of bulk GaSb samples is obtained by fitting the experimental curves.

2. THEORETICAL MODEL

To obtain the expression of the probe beam deflection ψ, we must know the temperature distribution in the fluid so we have to determine the temperature elevation at the sample surface by resolving the heat diffusion equation in the different media and assuming the continuity conditions of temperature and heat flow at the different interfaces. As the sample surface is uniformly heated so a one dimension heat treatment is sufficient.
In the first method, we have to consider only three media: fluid, sample and backing. We assume that both fluid and backing are optically non absorbing media for the incident light. So the obtained temperature elevation T_0 at the sample surface is given in [7].
When we depose a thin graphite layer on the sample (second method) we must take it into account in our theoretical model. So we have to consider four media which are fluid, graphite layer, sample and backing. In this case, only the graphite layer is considered as an absorbing media of the incident light and so play the role of a heat source.
The periodic temperature elevation T_0 in this case is given in [8]:
By applying the ray equation to calculate the probe beam deflection one can obtain the complex expression of the deflection Ψ [7]:

$$\Psi = \left|\Psi(z_0)\right| \exp(j\Phi) \qquad (1)$$

where $\left|\Psi(z_0)\right| = -\frac{L}{n_0}\frac{dn}{dT_f}\frac{\sqrt{2}}{\mu_f}\left|T_0\right| \exp(-z_0/\mu_f)$ and $\Phi = \frac{-z_0}{\mu_f} + \theta + \frac{\pi}{4}$

are the amplitude and phase of the photothermal deflection signal whereas $\left|T_0\right|$ and θ are respectively the amplitude and phase of the sample's surface temperature.

3. EXPERIMENTAL SET-UP

For the thermal study, the experimental set-up is described in [7]. For the optical study we interpose between the halogen lamp and the mechanical chopper a Monochromator (Jobin Yvon HR250) and we plot the amplitude and phase variation of the photothermal signal versus wave length at a fixed modulation frequency.

4. EXPERIMENTAL RESULTS

The thermal study in the two first methods consists in drawing the logarithm of the amplitude and phase variation versus square root modulation frequency. The best coincidence between experimental and theoretical curves will give the best values of thermal properties.

4.1 First method

If we plot the theoretical logarithm of the amplitude and phase variations versus modulation frequency at a fixed value of the thermal diffusivity and for different values of the thermal conductivity one can notice that the obtained curves are confused so the photothermal signal is insensitive to the thermal conductivity in this case.
However, if we vary the thermal diffusivity at a fixed value of thermal conductivity (figure 1), one can notice that both the logarithm of amplitude and phase variations are very sensitive to D_s. Then increasing the thermal diffusivity of the sample we remark that the theoretical phase maximum moves towards high frequencies. Therefore, the best value of the thermal diffusivity D_s is only

obtained for the best coincidence between the experimental curves and the corresponding theoretical ones.
In figure 2 are represented the experimental logarithm of the amplitude and phase variation obtained respectively for an undoped, Te-doped and Zn-doped GaSb sample. The corresponding theoretical curves which best coincide with experimental ones are obtained for values of thermal diffusivity reported in table 1.

4.2 Second method

Here, the samples of Gallium Antimonide are covered by a graphite layer of thickness 1.6μm for the undoped and Te-doped GaSb and 4μm for the Zn-doped.
To determine the sensitivity of our experimental set-up towards the thermal properties we have plotted in figures 3-a and 3-b respectively the theoretical logarithm of amplitude and phase variations for different couples (K_s, D_s) of an undoped GaSb sample.
We notice from these curves that both the logarithm of amplitude and phase, unlike in the first method, are very sensitive as well as to K_s and to D_s which prove the interest of this method.

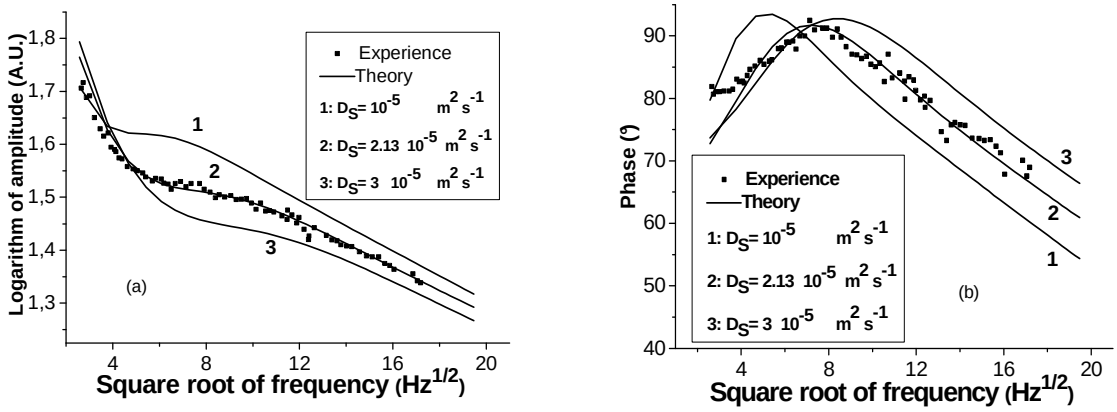

Figure 1: Theoretical and experimental curves giving the variations of the logarithm of the amplitude (a) and phase (b) according to the square root modulation frequency for different values of D_s of an undoped GaSb

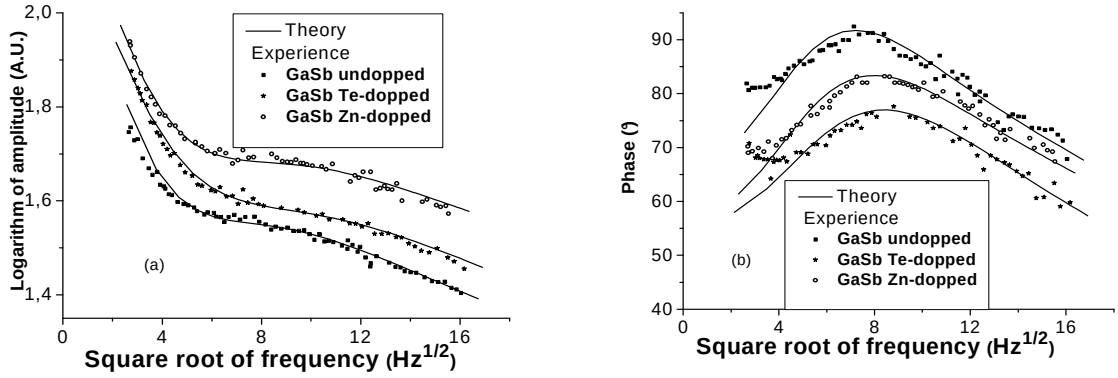

Figure 2: Experimental curves and corresponding theoretical ones giving the variations of the logarithm of the amplitude (a) and phase (b) according to the square root modulation frequency of an undoped, Te-doped and Zn-doped GaSb samples at a same distance z_0=95μm.

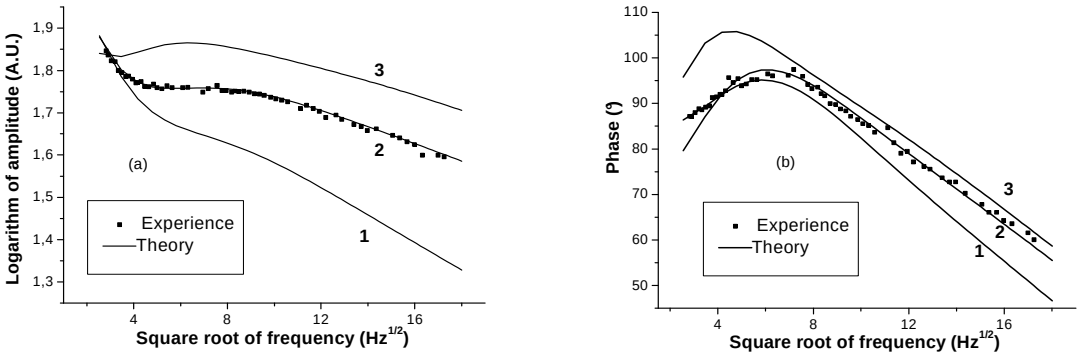

Figure 3: Experimental and theoretical curves giving the variations of the logarithm of the amplitude (a) and phase (b) according to the square root modulation frequency of an undoped GaSb on which we have deposed a thin graphite layer of a thickness 1.6 µm at z_0=215µm for 1: (k_s=5 W.m^{-1}.K^{-1} , D_s = 2.1×10^{-5}m^2.s^{-1}), 2: (k_s=35.2 W.m^{-1}.K^{-1} , D_s = 2.1×10^{-5}m^2.s^{-1}) and 3: (k_s=35.2 W.m^{-1}.K^{-1} , D_s = 10^{-5}m^2.s^{1}).

We notice also and as in the first method that the theoretical phase maximum moves towards high frequencies when the thermal diffusivity increases.
The theoretical curves which fit best the experimental ones are obtained for the couple (k_s=35.2 W.m^{-1}.K^{-1} , D_s = 2.1×10^{-5}m^2.s^{-1}).
Now in order to verify that the couple (K_s , D_s) which we have founded is unique, we have plotted respectively in figures 4-a and 4-b the logarithm of the amplitude and the phase versus square root modulation frequency for two fixed values of z_0. The coincidence between the theoretical curves and the experimental ones is obtained for the same couple (K_s , D_s) which prove its uniqueness.
A similar study was made for the Te-doped and the Zn-doped.
In figures 5-a and 5-b are represented the experimental and the corresponding theoretical curves of respectively the logarithm of the amplitude and the phase versus square root modulation frequency for each samples at a same distance z_0=95μm. We notice from these figures the good agreement between the experimental and the theoretical curves for both the logarithm of amplitude and phase variation. The three samples thermal diffusivity and thermal conductivity values so deduced are reported in Table 1.

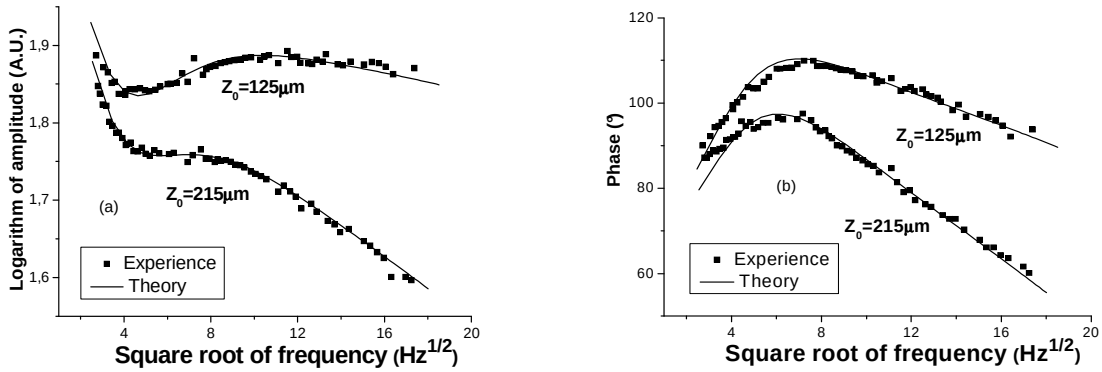

Figure 4: Experimental curves and corresponding theoretical ones giving the variations of the logarithm of the amplitude (a) and phase (b) according to the square root modulation frequency for two values of z_0 of an undoped GaSb covered by a graphite layer of thickness 1.6µm

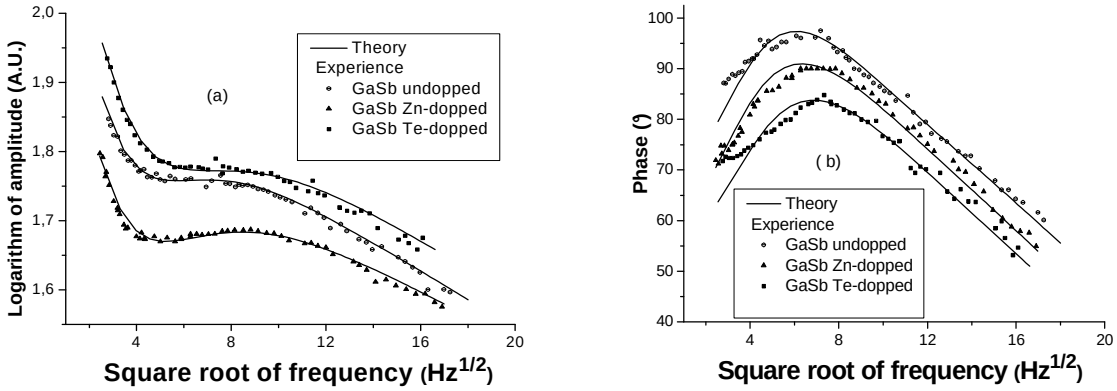

Figure 5: Experimental curves and corresponding theoretical ones giving the variations of the logarithm of the amplitude (a) and phase (b) according to the square root modulation frequency of an undoped, Te-doped and Zn-doped GaSb samples at a same distance z_0=215µm.

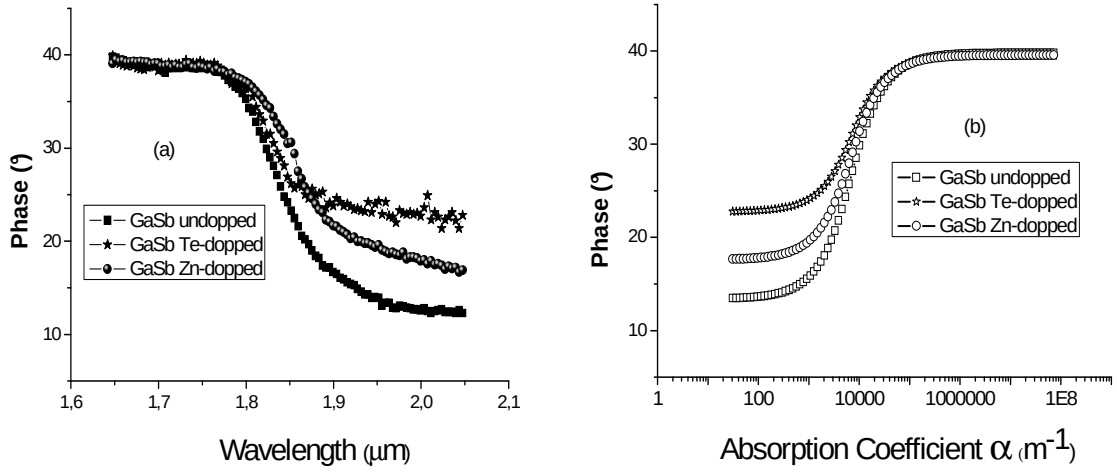

Figure 6: Experimental (a) curves giving the variations of the phase according to wavelength and corresponding theoretical one (b) according to absorption coefficient of an undoped, Te-doped and Zn-doped GaSb samples at a fixed modulation frequency ν =18.5 Hz.

4.3 Third method

Our study in this method consists to plot the phase variation of the photothermal signal near the band gap region versus wavelength. The experimental corresponding curves obtained for each sample are shown in figure 6. From this figure, one can notice that the phase saturates above and below the gap energy. The phase difference $\Delta\Phi$ between this two saturated zones is a function of the thermal diffusivity which may be determined by comparison of the theoretical phase difference with the corresponding experimental ones. The obtained thermal diffusivity values are listed in table1

Table 1: Experimental thermal diffusivities and thermal conductivities values from the three methods

	Samples	*Ds* (10^{-5} x $m^2.S^{-1}$)	*Ks* ($W\,m^{-1}\,K^{-1}$)
First method	undoped GaSb	2.13 ± 0.05	---
	Te-doped GaSb	3.15 ± 0.05	---
	Zn-doped GaSb	2.67 ± 0.05	---
Second method	undoped GaSb	2.10 ± 0.03	35.2 ± 0.5
	Te-doped GaSb	3.10 ± 0.03	48.4 ± 0.5
	Zn-doped GaSb	2.71 ± 0.03	23.1 ± 0.5
Third method	undoped GaSb	2.07 ± 0.10	---
	Te-doped GaSb	3.90 ± 0.20	---
	Zn-doped GaSb	2.70 ± 0.15	---

5. CONCLUSION

In this work, we have investigated the thermal diffusivity for an undoped GaSb, Te-doped and Zn-doped using three different methods based on the photothermal deflection technique by fitting the experimental curves and we have compared their sensitivity to the thermal properties especially the thermal diffusivity. In fact: while the first and the third methods are sensitive only to the thermal diffusivity, the second method depends on both thermal diffusivity and thermal conductivity. By depositing a thin graphite layer on the sample (second method), we have shown one simple and chip method applied for bulk semiconductors which allow to determine simultaneously the thermal diffusivity and the thermal conductivity with good precision.

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