Ellipsometric Study of Optical Properties of Thin Semiconductors Films

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***Abstract*—the aim of this work is to determine by ellipsometry the optical properties of semiconductor thin films made of gallium nitride, gallium arsenide and gallium phosphide.**
Ellipsometry is an optical method based on the behavior of polarized light. The light reflected on a surface induces a change in the polarization state which depends on the characteristics of the material (complex refractive index and thicknesses of the different layers constituting the device). The paper describes the experimental aspects concerning the semiconductor samples, the SE400 ellipsometer principle, and the results obtained by direct measurements of ellipsometric parameters (Psi and delta) and modeling using "*Sentech Instruments GmbH*",software.

***Index Terms*—semiconductors GaN, GaAs, GaP, ellipsometry, optical properties**

I. INTRODUCTION

The development of semiconductors materials as films has contributed to an increase of performance of electronic, photonic and photovoltaic systems including lower cost of components for mass production. The structure of the deposited films may be monolayer or multilayer with thicknesses which vary from one atomic plane (several Angstroms) to several hundreds of micrometers. Their optical properties depend on their microstructure.

The objective of this work is to determine the optical properties of thin films and semiconductor. The most optical properties are the complex refractive index and thickness, as well as all notions of transmission and reflection. For this goal ellipsometry is adapted as characterization technique of semiconductor sample set on GaAs, GaN, GaP.

Ellipsometry is an optical method based on polarized light. Indeed, the light reflection on a plane surface induces a change in the polarization state which depends on the characteristics of the material (complex refractive index and thickness of the layers).

Advanced applications of thin films have diversified in chemistry and optic fields while the optical layer applications have enabled the development radiation sensors [Bahoura, M., et al., (2008). The intentions of systems produced by films on the substrate are the access to the electrical conductivity of metalized surface for scanning electron microscope, increase or decrease the reflection (anti-reflection coating, metal mirror ...), selecting of reflection or transmission in a certain range of wavelength (selective mirror, interference filters...), fabrication of protective layers. Between the conductors and insulators films, one can classify a number of solids which are semiconductors. The III-V semiconductors are compounds formed from a member of the third column and the fifth column of the periodic table. The study of their properties, and in particular the band structure shows that the lightest elements give wide band gap compounds whose properties be similar to those of insulating compounds including boron, aluminum, nitrogen, and phosphorus, are required by the semiconductor with a high carrier mobility, designed for optoelectronic or a strip structure is necessary for direct optical transitions are effective. The main materials are the III-V compounds type GaAs, GaP, GaN [Duboz, J. Y.(1999)]. The existence of the band gap explains the transparency of semiconductor infrared radiation [Duboz ,J.Y.(1999) , Han, J., at.al. (2007)].

This work shows the measurement principle of ellipsometry and the use of the SE400 ellipsometer to characterize the optical parameters of samples set by two methods: directly (measured) and indirect (modeling).

II. PRINCIPLE OF ELLIPSOMETRY

We consider a surface illuminated at an incidence i0 by a monochromatic plane wave (Fig.1). The polarization direction of the incident wave linearly polarized is identified by the angle α. The field component parallel to Oy component is called S (transverse electric relative to the plane index), and the perpendicular thereto is called P (transverse magnetic) [Azzam, R. M. A. and. Bashara N. M, (1987)].

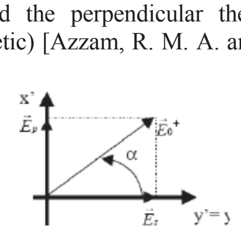

Fig. 1. Direction field in the plane perpendicular to the incident wave vector

The incident wave can be written:

$$\vec{E}_0^+ = \vec{A}_0^+ \exp\left(j\vec{K}_0 \cdot \vec{P}\right)\exp\left(-i\omega t\right) \quad (1)$$

$$\vec{E}_0^+ = \vec{E}_s + \vec{E}_p = E_s\vec{y}' + E_p\vec{x}' \quad (2)$$

$$E_s = E_0^+ \cos\alpha \; ; \; E_p = E_0^+ \sin\alpha \quad (3)$$

To accurately analyze of the change in the state of polarization, a polarizer is introduced into the incident beam, and an analyzer of the reflected beam (Fig.2).

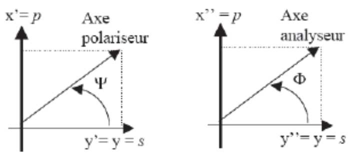

Fig. 2. Definition of angles relative to the polarizer (ψ) and the analyzer (Φ).

The angles Φ and ψ define the directions of the axes of the polarizer and analyzer, respectively, compared to the direction S, as shown in fig.2. After the polarizer, S and P components of the field can be written:

$$E_s^+ = E_0^+ \cdot \cos(\psi - \alpha) \cdot \cos\psi$$

$$E_p^+ = E_0^+ \cdot \sin(\psi - \alpha) \cdot \sin\psi \quad (4)$$

Reflection on the sample is written using the complex reflection factors:

$$r_s = \sqrt{R_s} \cdot \exp\left(j\delta_s\right); \; r_p = \sqrt{R_p} \cdot \exp\left(j\delta_p\right) \quad (5)$$

ρ is the ratio of the two reflection coefficients of both directions P and S:

$$P = \tan(\psi) \cdot \exp i\Delta \quad (6)$$

Where $\tan(\psi) = \frac{|r_p|}{|r_s|}$ is the ratio of the amplitudes, and Δ is the phase difference.

Two values are used to describe the optical properties that determine how light interacts with a material. They are usually represented as a complex number. The complex refractive index ň = n+i.k (ň is the index of medium) consists of the index (n) and extinction coefficient (k).

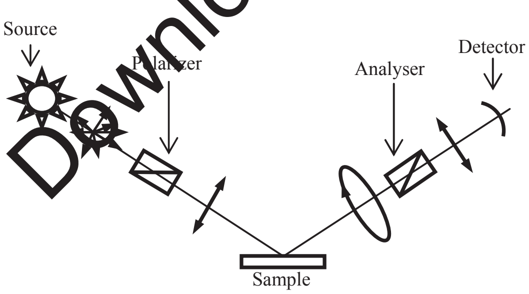

Fig. 3. Ellipsometer operating principle

The modulation of the polarized beam can be obtained by rotation of the polarizer, the analyzer or a compensator.

III. EXPERIMENTAL WORK

A. The ellipsometer SE 400

The ellipsometer SE 400 is mounted on a support module, in which a telescope auto collimator and two arms are attached. The left arm comprises the polarizer and He-Ne laser source, and the right comprises the analyzer. These two arms are pivoted about a common center of rotation (see Fig.4)

Fig. 4. SE400 ellipsometer apparatus

The installed control program can be started automatically or manually. Thus, the computer loads directly from the main menu of the program. From there, the execution can be transferred to one of the following programs; "Application", and "Setup". The "Application" contains an interactive menu giving access to any extent by the work of the ellipsometer. The "Setup" is used for diagnostics and especially measures of ellipsometric parameters: the ellipsometric pair (ψ, Δ), the refractive index and the thickness of the layer according to the model.

B. Samples and measures

The table 1 shows the different types of samples that we have measured and characterized using ellipsometry.

TABLE I. SAMPLES DESCRIPTION

Samples	Description
Ech 1	GaAs-p (gallium arsenide)
Ech 2	GaAs-n (gallium arsenide)
Ech 3	GaP (gallium phosphide)
Ech 4	GaN (gallium nitride)

Measurements are taken for an incidence angle of 70°, and five measurements are done at different positions on the surface of each sample. Table 2 shows the mean values for each sample, as well as calculation of errors.

TABLE II. MEAN VALUES OF PSI AND DELTA

Ellipsometric parameters	Ech 1	Ech 2	Ech 3
$\overline{\psi}$ [°]	8.52	8.20	8.56
$\pm\delta\psi$ [°]	0.54	0.10	0.86
$\overline{\Delta}$ [°]	324.90	325.70	335.00
$\pm\delta\Delta$ [°]	10.64	4.24	15.80

Curve tracing is carried out by setting the values ns, Ks, λ, and φ in the case of a monolayer on substrate and ns, Ks, n1, K1, d1, λ, and φ in the case of two layers on substrate by varying the parameters to be determined for two layers on substrate. Once found the global range of the index and the thickness, and then each sample is treated separately.

After modeling with "*Sentech Instruments GmbH*" software and introducing the measured values we get the curves in Fig.5. According to this graph, we can determine the intervals of the index and the thickness of each sample as following:

Ech. 1: 2.8 ≤ n1 ≤ 2.9; Ech. 2: 2.9 ≤ n1 ≤ 3; Ech.3: 2.9≤ n1 ≤ 3; Ech.4: 2.8 ≤ n1 ≤ 2.9

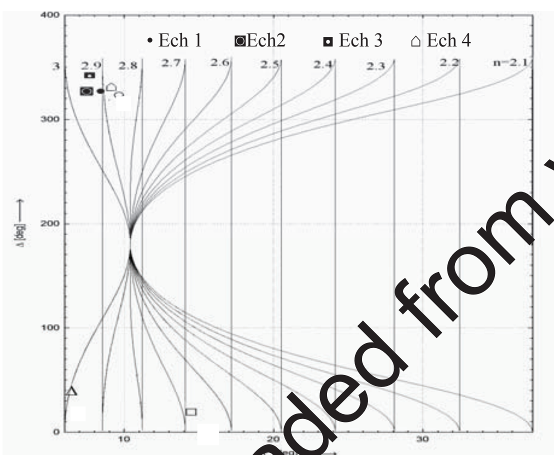

Fig. 5.Measured values represented as Δ = f (ψ) for an angle of 70°

C. Results and discussion

The results are shown in Figure 6. The graph shows that the index of gallium arsenide doped p is equal to 2.91 and its thickness is about 110nm, on the other hand the index of gallium nitride is equal to 2,905 and its thickness is about 100nm.

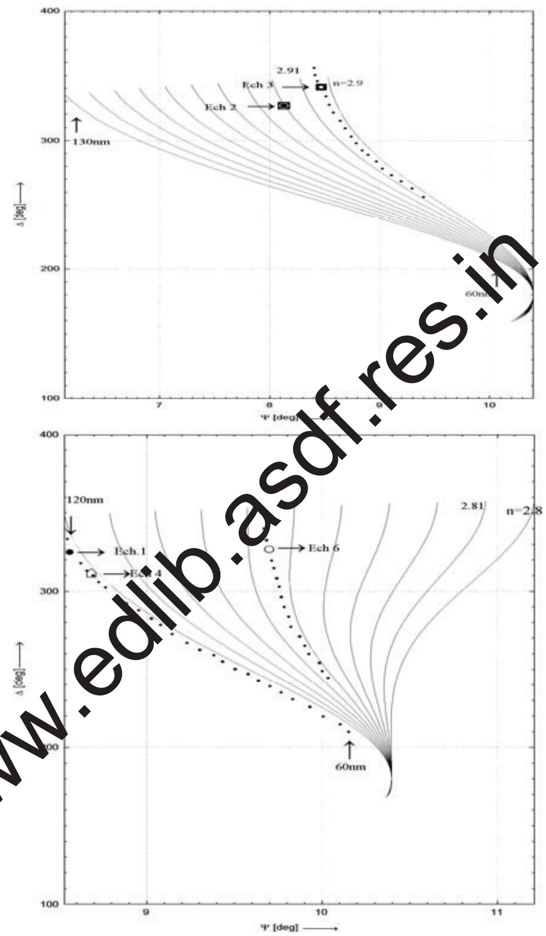

Fig. 6.Determination of n and the thickness d of the layer from Δ = f (ψ) at 70 °

For gallium arsenide doped n, the index is equal to 2.92 and the thickness is about 110 nm, and the gallium phosphide refractive index is equal to 2.905 and its thickness is equal to 120 nm.

TABLE III. REFRACTIVE INDEX AND THICKNESS FOR MODELED AND MEASURED DATA RESPECTIVELY

Modeled data at incidence angle of 70°		
Samples	***Refractive index n***	***Thickness [nm]***
Ech 1	2.91	110
Ech 2	2.92	110
Ech 3	2.905	120
Ech 4	2.905	100

Measured data at incidence angle of 70°		
Samples	***Refractive index n***	***Thickness [nm]***
Ech 1	2.53	86.3
Ech 2	2.11	86.34
Ech 3	2.10	86.26
Ech 4	2.52	86.00

According to the table3 of refractive index and thickness by modeled data and measured values at incidence angle of 70°, the following comments can be given:

For the refractive index: the direct measurements with a 70° angle are closer to the values of the indirect method of modeling. For the thickness we find that there is a difference between the two methods. The sources which influence on the results are the reference adjustment, the roughness of the surface and the sensor sensitivity. Because the receiving surface don't capture the entire reflected beam, so the change in the intensity of the beam influence on the measurements.

IV. Conclusion

Optical properties and mainly the refractive index, and the thickness are obtained by ellipsometry. We have shown that these properties can be obtained directly by ellipsometry and modeling. The results show an acceptable error range for the average direct measurements. We consider that the error range compared to modeling is nevertheless lower.

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 ISBN : 978-81-925233-8-5