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 hundred micrometers. Their optical properties depend on their microstructure.

The objective of this work is to determine the optical properties of thin films of a 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 samples set on GaAs, GaN, GaP.

Ellipsometry is an optical method based on polarized light and 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) and selecting of reflection or transmission in a certain range of wavelength (selective mirror, interference filters, utilization of protective layers). Between the conductors and insulators films, one can classify a number of systems 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 i_0 by a monochromatic plane wave (Fig.1). The polarization direction of the incident wave linearly polarized is identified by the angle $\alpha$. The field component parallel to Oy is called $E_y$ (transverse electric relative to the plane index), and the perpendicular thereto is called $E_x$ (transverse magnetic) [Azzam, R. M. A. and. Bashara N. M, (1987)].

![Fig. 1. Direction field in the plane perpendicular to the incident wave vector](image)

The incident wave can be written:
\[ E_x = E_x^0 \cos \alpha; \quad E_y = E_y^0 \sin \alpha \quad (3) \]

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

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

\[ r_s = \sqrt{R_s \cdot \exp(i\delta_s)}; \quad r_p = \sqrt{R_p \cdot \exp(i\delta_p)} \quad (5) \]

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 \( n+i.k \) (where \( n \) is the index of medium) consists of the index of refraction and extinction coefficient of the sample.

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.
Curve tracing is carried out by setting the values $n_s$, $K_s$, $\lambda$, and $\phi$ in the case of a monolayer on substrate and $n_s$, $K_s$, $n_1$, $K_1$, $d_1$, $\lambda$, and $\phi$ 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: $2.8 \leq n_1 \leq 2.9$;
- Ech. 2: $2.9 \leq n_1 \leq 3$;
- Ech. 3: $2.9 \leq n_1 \leq 3$;
- Ech. 4: $2.8 \leq n_1 \leq 2.9$

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.

<table>
<thead>
<tr>
<th>Modeled data at incidence angle of 70°</th>
<th>Samples</th>
<th>Refractive index $n$</th>
<th>Thickness [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ech 1</td>
<td>2.91</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Ech 2</td>
<td>2.92</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Ech 3</td>
<td>2.905</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Ech 4</td>
<td>2.905</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

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 110 nm, on the other hand the index of gallium phosphate is equal to 2.905 and its thickness is about 100 nm.
<table>
<thead>
<tr>
<th>Samples</th>
<th>Refractive index n</th>
<th>Thickness [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ech 1</td>
<td>2.53</td>
<td>86.3</td>
</tr>
<tr>
<td>Ech 2</td>
<td>2.11</td>
<td>86.34</td>
</tr>
<tr>
<td>Ech 3</td>
<td>2.10</td>
<td>86.26</td>
</tr>
<tr>
<td>Ech 4</td>
<td>2.52</td>
<td>86.00</td>
</tr>
</tbody>
</table>

According to the table 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.

REFERENCES


