Spectroscopic Ellipsometry of Compound Semiconductors: $Al_xGa_{1-x}N$ / GaN Hetero-Structures

Roland Seitz - Application Scientist - Thin Film Division

Introduction

Group III-Nitrides and their alloys are the most promising materials for short-wavelength optoelectronic devices such as LEDs, injection lasers, photodetectors, full colour displays and electronic devices like HFETs, HEMTs, etc.
For their design and optimization a detailed knowledge of both the layer thickness and the optical properties are essential. Spectroscopic Ellipsometry is a non-destructive optical characterization method that allows determination of these required material parameters.

Materials

A typical AlGaN / GaN heterostructure as used for LEDs and transistors is shown in figure 1.

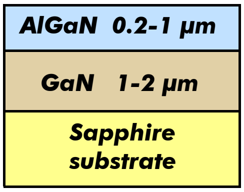


Figure 1: Typical AlGaN / GaN heterostructure

The GaN and AlGaN films were deposited by MOCVD (metal-organic chemical vapour deposition) on sapphire substrates.

The following samples were analyzed:

Sample	Structure	Al Content in AlGaN %
1	GaN / Sapphire	-
2	GaN / Sapphire	-
3	AlGaN / GaN / Sapphire	7
4	AlGaN / GaN / Sapphire	16
5	AlGaN / GaN / Sapphire	25
6	AlGaN / GaN / Sapphire	5
7	AlGaN / GaN / Sapphire	9

Results

The work was performed using the HORIBA Jobin Yvon MM-16 spectroscopic ellipsometer which provides significant advantages in terms of speed, high resolution measurement and experimental versatility. Ellipsometric measurements were performed at an angle of incidence of 70° in the spectral range 500nm-800nm. Both the thicknesses and optical properties were extracted simultaneously from the SE data analysis.
When compared to conventional ellipsometer platforms, the Liquid Crystal Modulation Ellipsometer delivers exceptionally high accuracy for the ellipsometric angles (Ψ, Δ) across their full range in one measurement, without any dead spots.

Figure 2 shows the Ψ *and* Δ spectra of sample 1.

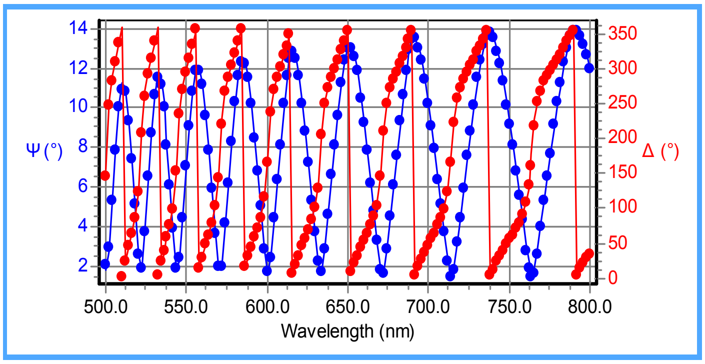


Figure 2: Ψ and Δ spectra of sample 1

The thickness and the dispersion of the GaN layer were determined by appropriate modelling. For this sample the result is the following:

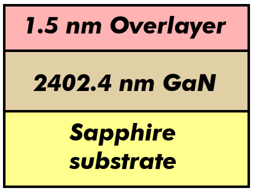


Figure 3 shows the Ψ *and* Δ spectra of sample 6.

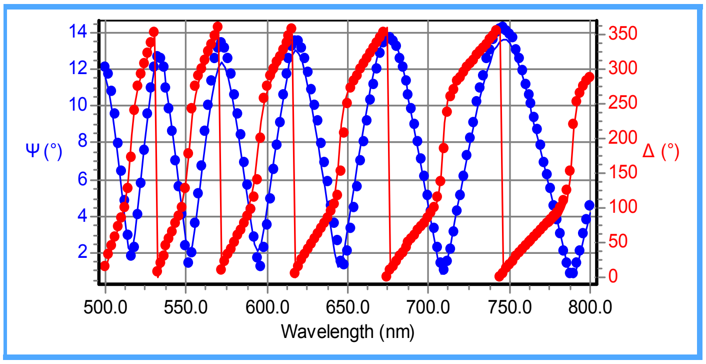
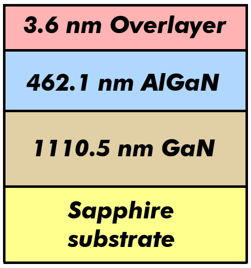


Figure 3: Ψ and Δ spectra of sample 6

The thickness and the dispersion of both the AlGaN and the GaN layer were determined by appropriate modelling. For sample 6 the result is the following:



For the modelling of the optical dispersions a classical Lorentz oscillator dispersion formula was used:

$$\varepsilon(\omega) = 1 + \frac{(\varepsilon_S - 1)\omega_t^2}{\omega_t^2 - \omega^2 + i\Gamma_0\omega} = \varepsilon_1(\omega) + \varepsilon_2(\omega)$$

where $E=h\omega$ is the photon energy.

The relation of ε_1 and ε_2 with n and k is: $\varepsilon_1 = n^2 - k^2$ and $\varepsilon_2 = 2nk$

The following table summarizes the results found for the samples in the wavelength range 500-800nm:

Sample	thickness GaN/nm	thickness AlGaN/nm	n at 633nm	ε_S	ω_t	Γ_0
1	2402	0	2.361	5.19	6.76	0.1
2	2466	0	2.353	5.16	6.78	0.1
3	1283	332	2.331	5.07	6.85	0.2
4	1180	254	2.299	5.00	7.56	0.3
5	1128	401	2.292	4.93	7.11	0.5
6	1111	462	2.340	5.09	6.68	0.2
7	1124	602	2.336	5.08	6.75	0.2

The refractive index as a function of wavelength is shown in figure 4 for different Al concentrations.

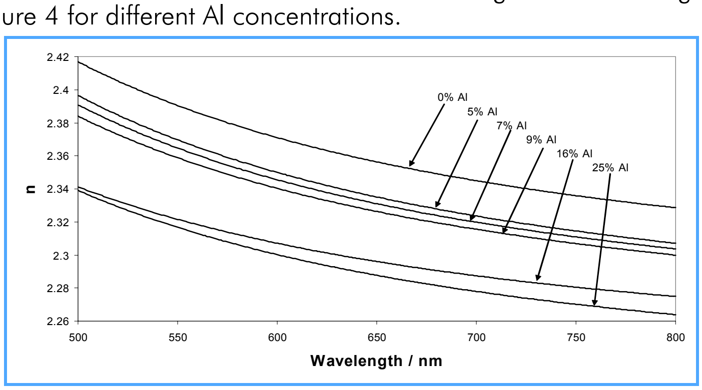


Figure 4: Refractive index for various Al concentrations in AlGaN

From these data a calibration curve can be set-up that allows the determination of the Al content in the AlGaN layer by evaluating the optical dispersion of the material (figure 5):

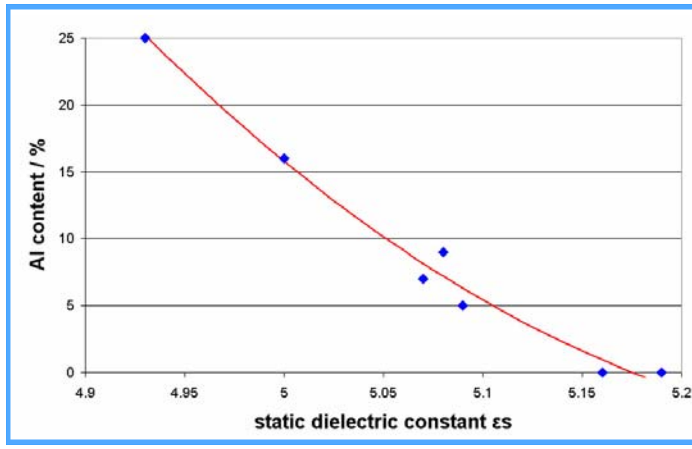


Figure 5: Calibration curve for Al concentration in AlGaN

The Al concentration can be calculated by the following formula:

$$Al - content(\%) = 182\varepsilon_S^2 - 1943\varepsilon_S + 5180$$

Conclusion

Liquid Crystal Modulation Spectroscopic Ellipsometry is an excellent technique for the highly accurate characterization of the compound semiconductor heterostructure AlGaN / GaN.
Using the MM-16 spectroscopic ellipsometer it is a straightforward procedure to determine the film thickness and optical dispersions of the complete structure even where the film is several microns thick.
The detailed knowledge of the optical parameters of AlGaN alloys is crucial for example for the design of opto-electronic devices.
Furthermore, from the optical parameters a calibration curve could be constructed to provide a rapid and efficient determination of the Al content in the AlGaN layers. Thus Spectroscopic Ellipsometry also proves a non-destructive technique for AlGaN alloy composition determination.
This method can be equally applied to other compound semiconductors such as SiGe, II-VI semiconductors or classical III-V semiconductors.