Influence of Growing Parameters on Optical Band Gap of Gallium Nitride Deposited on Sapphire by Reactive Magnetron Sputtering

Zurab Kushitashvili[1*)], Amiran Bibilashvili[2)], Zurab Jibuti[3)], Zurab Kapanadze[4)]

[1*)] LEPL Institute of Micro and Nanoelectronics, Chavchavadze ave.13, 0179 Tbilisi, Georgia; zurab.kushitashvili@ens.tsu.edu.ge; ORCID: 0000-0001-7140-3438.
[2)] Ivane Javakhishvili Tbilisi State University, Chavchavadze ave.1, 0179 Tbilisi, Georgia, LEPL Institute of Micro and Nanoelectronics, Chavchavadze ave.13, 0179 Tbilisi, Georgia; amiran.bibilashvili@tsu.ge; ORCID: 0000-0002-8153-4498
[3)] LEPL Institute of Micro and Nanoelectronics, Chavchavadze ave.13, 0179 Tbilisi, Georgia; z.jibuti@gmail.com; ORCID: 0000-0002-2084-2139.
[4)] LEPL Institute of Micro and Nanoelectronics, Chavchavadze ave.13, 0179 Tbilisi, Georgia; zuriko1957@yahoo.com; ORCID: 0009-0003-2079-299X.

https://doi.org/10.29227/IM-2026-02-02-029

Submission date: *2026-06-04* | Review date: *2026-03-06*

Abstract

The presented work discusses the preparation of gallium nitride by reactive magnetron sputtering technology and the study of its optical properties. In particular, the dependence of the optical band gap of gallium nitride on technological parameters, such as temperature, UV irradiation and impurity diffusion. The optical band gap was calculated from the emission spectra using the Tauce Plot method. The emission spectra were measured on a UV/VIS/NIR Spectrophotometer Analyzer. The temperature dependence showed an improvement in the band gap with increasing temperature and amounted to 3.37 eV, which is close to the known band gap of gallium nitride of 3.4 eV. The influence of UV irradiation was also studied, which showed a slight improvement in the band gap. In general, UV irradiation improves the structural properties of gallium nitride and, accordingly, was expected to have a positive effect on the optical properties. During magnetron sputtering, silicon as a dopant was mixed, doped. The result showed that doping gallium nitride with silicon reduces the optical band gap by 0.06 eV.

Keywords: *Semiconductor, band gap, technology, magnetron, optical spectrum.*

1. Introduction

Semiconductors with a wide band gap retain their leading positions in the research and production of optoelectronic devices. Their structural, optical and electrical properties determine the areas of application of these semiconductors, as well as the technologies by which these materials are obtained. Gallium nitride (GaN) belongs to this class of semiconductors. Today, it is widely studied in scientific research and has also been successfully implemented in many optoelectronic devices, LEDs, UV photodetectors, HEMTS transistors [1-3]. The development of technologies has contributed to increasing the quality of gallium nitride and, accordingly, improving the parameters of devices that are made on the basis of GaN. The study of optical properties remains one of the challenges in GaN research, since optoelectronic devices are based on optoelectric conversions. It is worth noting that the technologies mainly determine the properties of GaN and its market value. In this paper, the reactive magnetron sputtering technology for obtaining GaN is discussed [4-6]. Compared to other technologies, this technology is a vacuum technology for obtaining thin films, it does not use various exhaust gases, does not require special utilization systems for waste gases. Reactive magnetron sputtering allows the deposition of metals, dielectrics and semiconductors, and most importantly, it is a cheap technology. Based on this technology and by selecting various technological parameters, thin (~2μ) films of GaN have been obtained and its optical properties have been investigated.

2. Experiment

The experiments discuss the influence of technological parameters on the optical bandgap of GaN. Technological parameters include: temperature, ultraviolet irradiation, and doping. The reactive magnetron sputtering setup is a two-stage vacuum system with a maximum base vacuum of 10^{-6} torr. Two parallel magnetrons are located under the vacuum chamber, one of which is a source of pure (99.99%) gallium, and the other (in the experiments under consideration) is a source of silicon (99.995%). The manipulator allows you to move the sample over the desired magnetron and deposit a layer of the desired thickness on the substrate by magnetron sputtering. As a substrate were used 2 inch sapphire wafers with (0006) orientation and 430 μm thickness. A heater is attached to the top of the substrate, which provides a temperature of up to 700^0C. Ultrapure nitrogen (99.9999%) is introduced into the vacuum chamber through a special precession valve with a partial pressure of 4×10^{-3} torr and a plasma is ignited by applying voltage (~400V) between the cathode and anode of the magnetron for reactive magnetron sputtering. As mentioned above, the temperature of the substrate, the effect of ultraviolet radiation, and the alloying of GaN thin films with silicon were technologically varied.

3. Results and Discussions

3.1 Temperature Influence

The dependence of the optical band gap of GaN on the deposition temperature is one of the clearly observed experimental results in the study of the optical properties of GaN. In various experiments, the temperature of the sapphire layer during the GaN deposition

process varies in the range of 300 ÷ 700 ^{0}C. Table 1 shows various technological parameters for obtaining samples.

Tab. 1. Temperature vs Band gap

Sample #	Growing Temperature, ^{0}C	Optical Bandgap, eV
GaN-69d	**300**	**2.96**
GaN-16S	**480**	**3.19**
GaN-17S	**570**	**3.33**
GaN-19S	**670**	**3.37**

The optical band gap of GaN was calculated from the analysis of the transmission spectra. The optical transmission spectrum was analyzed using the Tauce Plot method.

The dependence of the band gap on the GaN deposition temperature is clearly visible from the graphs in Fig. 1-4. The band gap increases with increasing temperature. At 300 ^{0}C it is 2.96 eV and at 670 ^{0}C it is 3.37 eV, which is very close to the GaN band gap (3.4 eV).

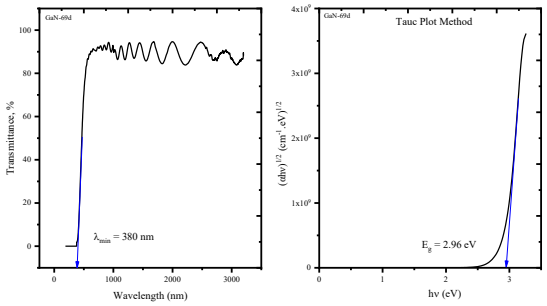

Fig. 1. Transmission spectra, deposition Temperature 300 ^{0}C.

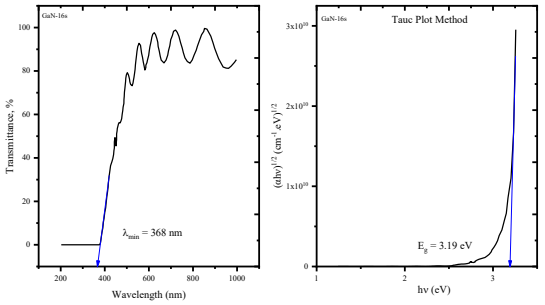

Fig. 2. Transmission spectra, deposition Temperature 480 ^{0}C.

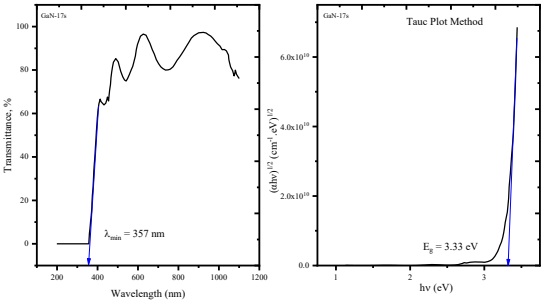

Fig. 3. Transmission spectra, deposition Temperature 570 ^{0}C.

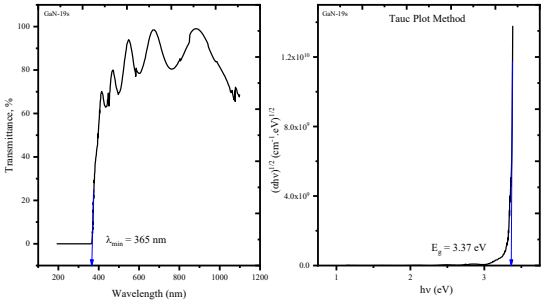

Fig. 4. Transmission spectra, deposition Temperature 670 ^{0}C.

3.2 UV Irradiation Influence

To determine the influence of ultraviolet radiation, samples with and without UV exposure were investigated and compared in experiments. The UV lamp is placed above the sample and is a lamp with a power of 400 W and a wavelength of 365 nm. The UV lamp is turned on when depositing GaN. Since the substrate is a sapphire wafer, UV passes through the sapphire without hindrance (the band gap of sapphire is 9.1 eV) and acts directly on the thin film of GaN deposited on the surface. Fig. 5-8 show the transemission spectra and the band gap values calculated by the Tauc Plot method, as well Table 2 shows the technological parameters.

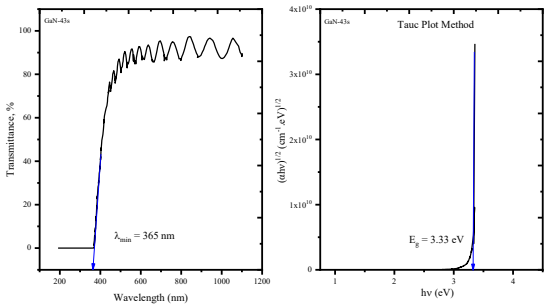

Fig. 5. Transmission spectra, deposition Temperature 300 ^{0}C.

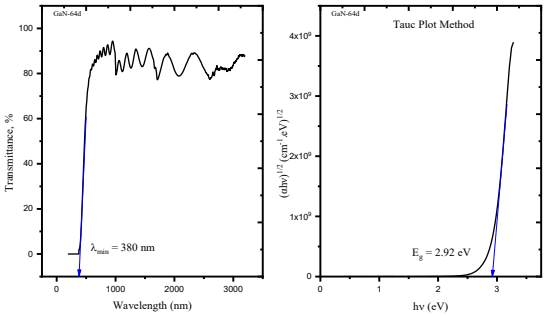

Fig. 6. Transmission spectra, deposition Temperature 480 ^{0}C.

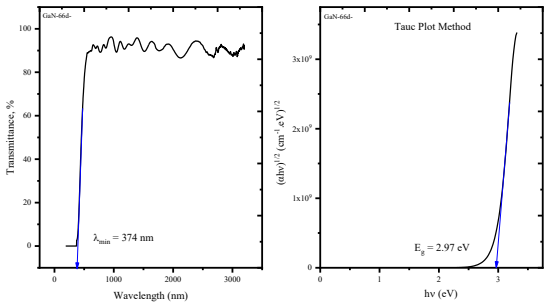

Fig. 7. Transmission spectra, deposition Temperature 300 ^{0}C.

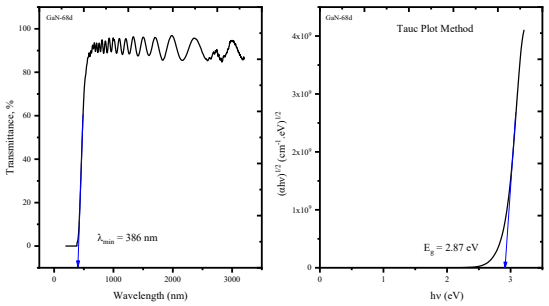

Fig. 8. Transmission spectra, deposition Temperature 480 ^{0}C.

Tab. 2. UV irradiation vs Band gap

Sample #	Growing Temperature, ^{0}C	Optical Bandgap, eV	UV Irradiation
GaN-43S	**630**	**3.33**	**-**
GaN-64d	**632**	**2.92**	**+**
GaN-66d	**284**	**2.99**	**+**
GaN-68d	**291**	**2.87**	**-**

High temperature is already a favorable condition for obtaining good quality GaN [7-8], so the research interest was to check the effect of UV exposure at relatively low temperatures. As can be seen from Table 2, the two samples (GaN-66d and GaN-68d) were obtained at almost the same temperatures. The band gap of GaN obtained with UV exposure (GaN-66d) is 0.12 eV larger than that of the sample obtained without UV (GaN-68d). Due to the relatively low temperature, the stimulating effect of UV is well expressed and the improvement of the band gap is also obvious. As for GaN obtained at high temperatures, the situation is the opposite. In particular, UV exposure is even a somewhat hindering factor, and the band gap of GaN decreases by 0.42 eV to 2.92 eV.

3.3 Doping Influence

One of the factors that was used to evaluate the dependence of the GaN band gap on technological parameters was doping. In the experiment considered silicon doping in GaN (Lith). Table. 3 shows some technological parameters.

Tab. 3. Doping vs Band gap

Sample #	Growing Temperature, ^{o}C	Optical Bandgap, eV	Si doping
GaN-18S	**665**	**3.32**	**-**
GaN-45S	**670**	**3.26**	**+**

As can be seen from the Table 3, the band gap of the samples, deposited at the same temperature, decreases that was doped with silicon. This decrease is 0.06 eV. This decrease may not be large, but the effect of doping, i.e. the presence of silicon atoms in the GaN lettice, changes the crystallographic structure, and this changes the band gap. Fig. 9 and Fig. 10 show the transmission spectra and the corresponding band gap values.

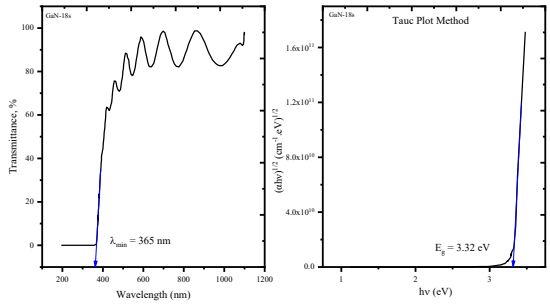

Fig. 9. Transmission spectra, without Si doping.

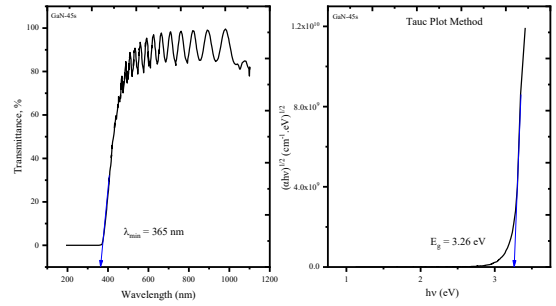

Fig. 10. Transmission spectra, with Si doping.

4. Conclusion

The article discusses the dependence of technological parameters on the optical band gap of GaN. The GaN band gap values were calculated from the transmission spectra using the Tauce Plot method. Analysis of the experimental results showed that the optical band gap of GaN depends strongly on some factors and less on others. Temperature has a strong influence on the structural formation of GaN. The band gap values obtained at low temperatures (300 ^{0}C) and high temperatures (670 ^{0}C) differ by 0.41 eV in favor of the higher temperature. The effect of UV irradiation is clearly visible at relatively low temperatures (~300 ^{0}C) the difference was 0.12 eV. The effect of doping with silicon was also evaluated. The results showed that doping with silicon reduces the band gap of GaN by 0.06 eV.

Acknowledgments

This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) [#YS-24-973, Project Title: „Study of Doping and Activation Processes in GaN.“].

References

1. C. Guo, X. Sun, D. Li and K. Jiang “AlGaN photonics: recent advances in materials and ultraviolet devices”, Adv. Opt Photon, 10 (1) (Mar. 2018), pp. 43-110, 10.1364/AOP.10.000043 Vol. 10, Issue 1, pp. 43–110.
2. Z. Alaie, S.M. Nejad and M.H. Yousefi “Recent advances in ultraviolet photodetectors”, Mater. Sci. Semicond. Process., 29 (Jan. 2015), pp. 16-55, 10.1016/J.MSSP.2014.02.054
3. B. Mounika, J. Ajayan, S. Bhattacharya and D. Nirmal “Recent developments in materials, architectures and processing of AlGaN/GaN HEMTs for future RF and power electronic applications: a critical review” Micro Nanostruct., 168 (Aug. 2022), Article 207317, 10.1016/J.MICRNA.2022.207317.
4. Abe Y, Takamura K, Kawamura M and Sasaki K 2005 J. Vac. Sci. Technol. A 23 1371–4.
5. Andersson J and Anders A 2008 Appl. Phys. Lett. 92 221503.
6. Andersson J, Ni P and Anders A 2014 IEEE Trans. Plasma Sci. 42 2856–7.
7. Zurab Kushitashvili, Amiran Bibilashvili, Revaz Guliaevi, Ana Kurtanidze „ Structural Properties of III-Nitrides Received by UV Stimulated Technology’’, Nanotechnology Perceptions, Vol. 20, Issue: 1, pp. 72-79, 2024. https://doi.org/10.56801/nano-ntp.v20i1.337
8. Z.Kushitashvili, A.Bibilashvili, Nugzar Dolidze, Givi Skhiladze and Revaz Guliaevi „Reactive Magnetron Sputtering Technology for Receiving III Nitrides’’, 8th World Multidisciplinary Earth Sciences Symposium, Inzynieria Mineralna: Vol. 1, Issue: 1, pp. 675-680, 2024. https://doi.org/10.29227/IM-2024-01-78