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Araştırma Makalesi / Research Article

Dielectric Properties of Graded and Non-Graded InGaN/GaN MQWs

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Abstract

In this study, dielectric properties of graded and non-graded InGaN/GaN multi quantum wells (MQWs), grown on sapphire(Al_2O_3) wafer by Metal Organic Chemical Vapor Deposition (MOCVD) technique, are investigated. In order to notice graded layer effect on characteristics of MQWs some of GaN layers are grown by doping In atoms. Dielectric function of films are determined by Swanepoel envelope method. Real and imaginer dielectric coefficient of the films are calculated by using refraction index and extinction coefficient. Differences in refraction index values are discussed for graded and non-graded samples. During determination of dielectric function variations of complex and imaginer dielectric coefficients with photon energy are shown for both samples

Keywords: Swanepoel envelope method, graded, non-graded, InGaN.

Dereceli ve derecesiz InGaN/GaN MQW'lerin dielektrik özellikleri

Öz

Bu çalışmada, Metal organik kimyasal buhar biriktirme(MOCVD) metoduyla safir (Al_2O_3) üzerine büyütülen dereceli ve derecesiz InGaN/GaN MQW'lerin dielektrik özellikleri incelendi. Dereceli tabakanın MQW'nin karakteristikleri üzerine etkisini fark edebilmek için bazı GaN tabakalar In aşılanarak büyütülmüştür. Filmlerin dielektrik fonksiyonu Swanepoel zarf metodu ile belirlenmiştir. Filmlerin gerçel ve imajiner dielektrik katsayıları, kırılma indisi ve soğurma katsayıları kullanılarak hesaplanmıştır. Dereceli ve derecesiz örnekler için kırılma indisi değerlerindeki farklılıklar tartışılmıştır. Dielektrik fonksiyonunun belirlenmesi sırasında, her iki numune için kompleks ve imajiner dielektrik sabitlerinin foton enerjisine göre değişimleri gösterilmiştir.

Anahtar Kelimeler: Swanepoel zarf metodu, dereceli, derecesiz, InGaN.

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1. Introduction

Compounds such as GaN and InGaN formed by nitrite based semiconductors are taking attention since the beginning of ninetees. During growth of GaN layer on sapphire, because of lattice mismatch and the difference between thermal expansion coefficients, defects such as cracks may occur. These defects affects the performance of the device in a bad way but devices formed by nitrite based semiconductors performs well at high temperature and frequency although they have such defects. They are prefered because of this property (Williams et al., 1969).

Today optical thin films play major role in directing light (Willardson et al., 1978). They are used in defence industry, solar cells, high electron mobility transistors and medicine (Straussn et al., 1977., Kroger et al., 1977). In parallel to technological advance, structure of these optical equipments becomes more complex. In order to gain performance desired from optical equipments, applications in optics subject becomes more important. Before making an optical modelling, to have knowledge on optical properties of used materials is also important. Optical properties of thin films forms a research field among classical optics, electrodynamics, solid state physics and quantum mechanics (Gu et al., 1975).

To calculate thickness and optical constants of thin films dependent on wavelength, is important in terms of both basic knowledge and technological development. Even a small change in refraction index makes serious shift in spectral response (reflection and transmission) of optical components of thin films. For this reason, accuracy of complex refraction index and thickness is important in terms of production of optical components successfully (Selim et al., 1977., Anthony et al., 1985). By the help of these parameters mentioned parameters will be calculated; optical energy band gap, defect levels, phonon and plasm frequencies can be determined (Chu et al., 1985). Bilgili et al. determined optical properties of InGaN/GaN MQWs in an earlier study. In this study, dielectric properties of samples are investigated in the light of reference (Bilgili et al., 2019). By the help of optical constants gained from Swanepoel envelope method (1983), dielectric coefficients are calculated.

2. Experimental details

InGaN/GaN MQWs are grown on sapphire wafer by MOCVD as In graded and non-graded structures. Samples are cleaned under H_2 atmosphere for 10 minutes at 1100 ºC before epitaxial films are grown. After cleaning procedure, growth operation started by nucleation GaN layer at 575ºC. During growth, TMGa flux ratio is adjusted as 10 sccm, NH_3 flux ratio is adjusted as 1500 sccm and pressure is adjusted as 200 mbars. This nucleation layer has a thickness of 10 nm. After growth of nucleation layer, growth of GaN buffer layer started at 1070ºC. This GaN buffer layer is grown with

15 sccm flux ratio TMGa, 1800 sccm flux ratio NH_3 and 200 mbars pressure conditions. Thickness of GaN buffer layer is 1.6 µm. Growth operation continued by turning on SiH_4 source. SiH_4 source helps growth of n-type GaN layer. In MOCVD SiH_4 is diluted. Flux ratio of SiH_4 source is 10 sccm. Graded and non-graded active layers are grown at 745-760°C with 75 sccm In flux ratio. While the first sample has InGaN graded layer thickness of 20 nm and 200 nm, second sample has an non-graded InGaN layer thickness of 220 nm. Active layers are grown between n-type GaN and p- type InGaN layers with a thickness of 1.9 µm. p-type InGaN layer is grown by using Mg doping source. Flux ratio of this source is 35 sccm. During growth of InGaN layer other sources are kept in off position. To maintain more doping Mg source flux ratio is adjusted as 40 sccm. By making In flux ratio continuous forbidden energy band gap is gained as graded. In Figure.1 schematic diagrams of graded and non-graded InGaN/GaN MQWs can be seen.

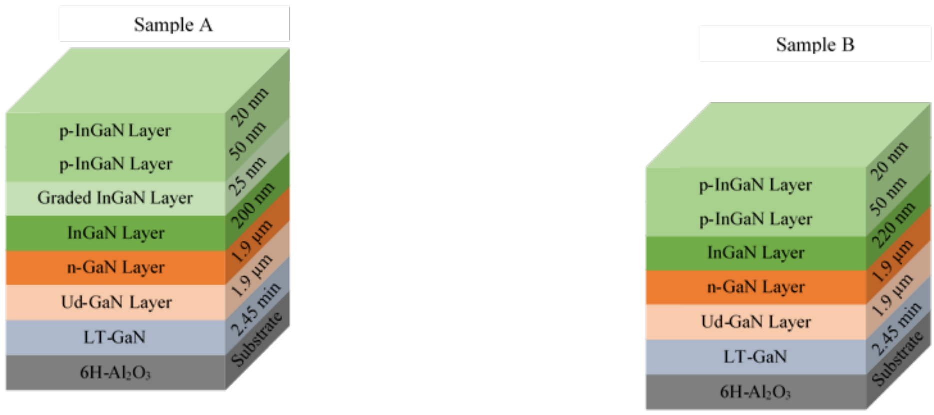

Figure.1 Schematic diagrams of graded and non-graded InGaN/GaN MQWs

3. Results and Discussion

In Swanepoel method, optical constants of mono layer or multi layer thin films grown on a transparent wafer can be determined by analising transmission plot. Heaven's book (Heavens et al., 1965) is a good reference on optical properties of thin films. Transmission spectras of the samples in this study are given in reference (Bilgili et al., 2019). In this reference refraction and extinction coefficients of samples are determined from Swanepoel envelope method. Here in Figure 2 only refraction index and extinction coefficient versus wavelength plots are repeated.

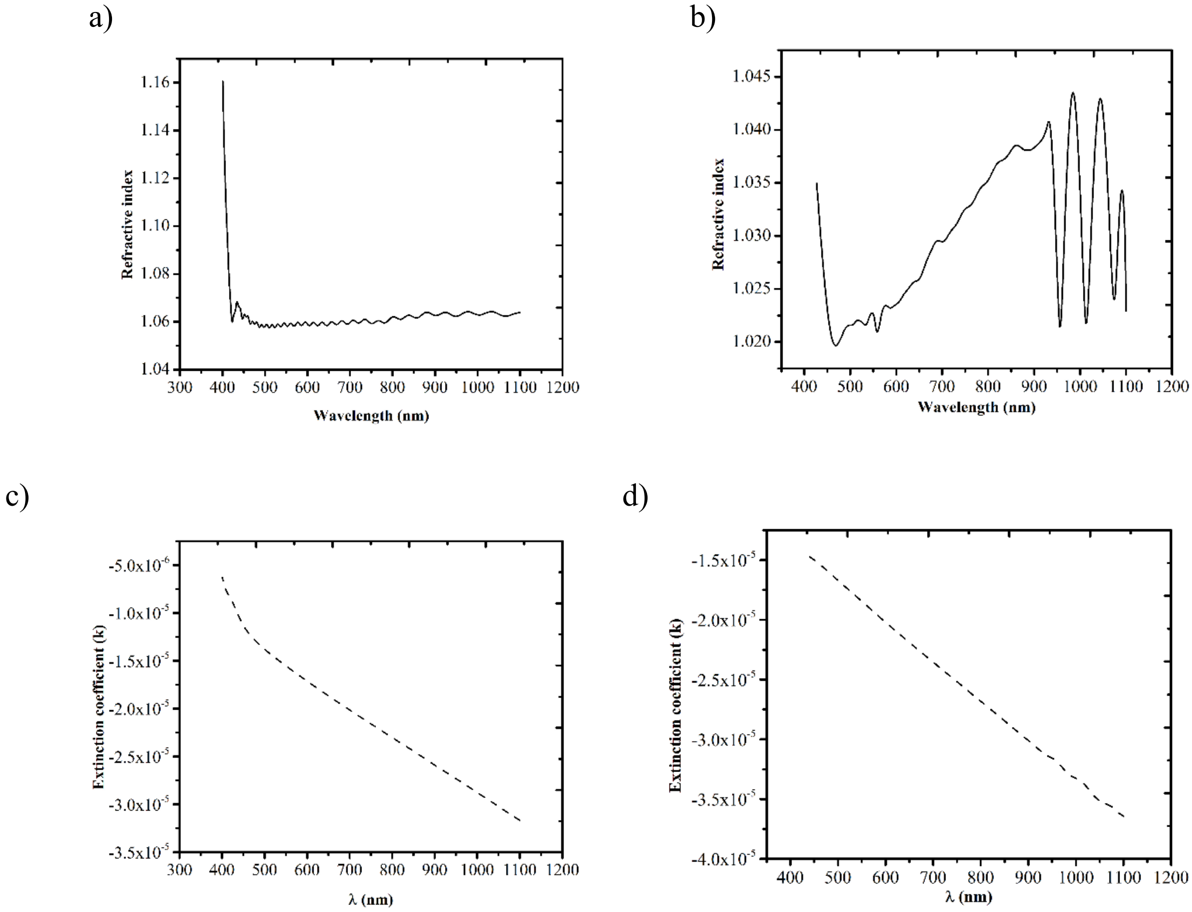

Figure.2 Refractive index and extinction coefficient variations versus wavelength for (a),(c) graded and (b), (d) non-graded InGaN/GaN MQWs[12].

As can be seen in Figure.2 (a) and (b) there is great difference in variations of refractive indexes for graded and non-graded samples. Variation of refractive index for graded layer is more smooth. This is also related with interatomic spaces. There is almost no difference in variation of extinction coefficients for both samples. Negative extinction coefficient implies that there is reflection.

If n_1 and n_2 are two refraction index values corresponding to λ_1 and λ_2 which are consecutive wavelengths for maximum and minimum, thickness can be calculated by equation (1). Thickness values in this study are calculated with a different plotting method and results are found in accordance with reference (Bilgili et al., 2019).

$$d = \frac{\lambda_1 \lambda_2}{2(\lambda_1 n_2 - \lambda_2 n_1)} \tag{1}$$

$$2nd = (m_1 + l/2)\lambda, \qquad l=0,\ 1,\ 2,\ 3\ldots..$$

$$l/2 = 2d(n/\lambda) - m_1 \tag{2}$$

For all extramum points this calculation should be made and mean values for d should be calculated but equation (1) is too sensitive for mistakes during calculation of refraction index. In the calculations made by using this equation, a dispersion especially broadening of fringes at high wavelengths can cause deflections in thickness calculation. As a general rule, thickness values found for the last two maximas should be included in mean value calculation. By using d and n value gained from this thickness calculation m value representing degree of extramum points in equation (1) can be found. For every wavelength, d_2 thickness value can be determined by using n_1 value by taking full or half value of m in equation (1).

But m and d values can be calculated more sensitively by using graphic method as shown in Figure.3. If degree number is called as m_1 for the first extramum point equation (1) can be written as in equation (2) for extramum points of the spectra (Haochen et al., 2021).

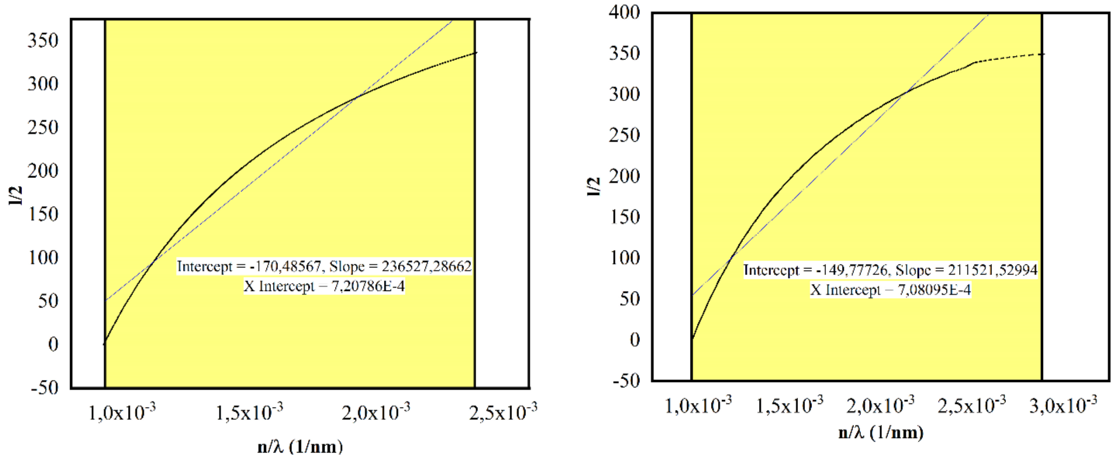

Figure.3 n/λ versus l/2 plots for film thicknesses.

By using the plot in Figure.4 if l/2 versus n/λ is plotted, slope of this plot gives 2d value and y axis intercept gives m_1 value (Rogalski., 2002).

Dielectric coefficient can also be calculated by using optical parameters. Dielectric coefficient is defined as $\varepsilon=\varepsilon_1+i\varepsilon_2$ that is, real and imaginer parts of complex dielectric function. This situation is explained as follows (Fairballs et al., 1997).

$$\varepsilon_1 = n^2 - k^2 \tag{3}$$

$$\varepsilon_2 = 2nk \tag{4}$$

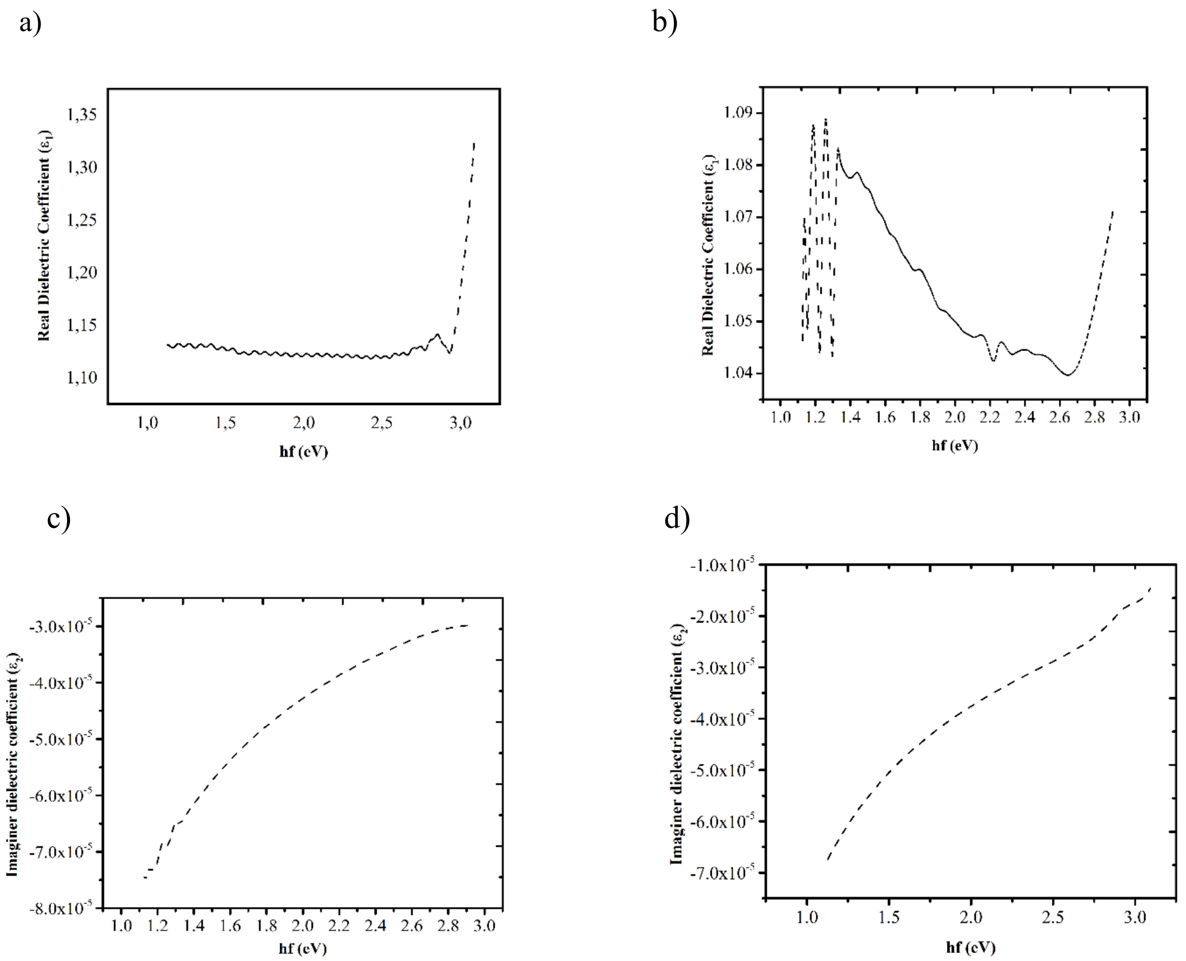

Figure.4 Real and imaginer dielectric functions dependent on energy.

Dielectric dependency is shown in Figure.4. Optical dielectric coefficient is calculated for InGaN/GaN MQWs. Variation of complex and imaginer dielectric coefficients with photon energy is shown. According to Figure.4 (a) and (b) it is noticed that being non-graded or graded effects real dielectric coefficient. But in Figure.4 (c) and (d) it can be seen that absorbtion starts about 1 eV for both samples. This means that being graded or non-graded does not effect imaginer dielectric function (Kars et al., 2017).

4. Conclusion

In this study dielectric properties of graded and non-graded InGaN/GaN MQWs are investigated. Swanepoel envelope method is employed on transmission spectra. By using graphic method, thickness of films are determined as 1.0050 and 1.0150 nm approximately. Real and imaginer dielectric coefficients are also determined and shown on Figure.5. As a result of this study, being graded improves optical properties also it helps conductivity. On the other hand, being graded or non-graded does not effect some properties such as extinction coefficient and imaginer dielectric function. Refractive index variations shows fluctiative behaviour for graded sample but, in non-graded sample variation of refractive index versus wavelength is almost smooth. This behaviour may be attributed to inhomogeneous structure of graded layers along the sample. Also variation of real and imaginer dielectric coefficients versus photon energy are symmetric to refractive index variations. This may be because of similarities in mathematical functions used to determine these two parameters. Real dielectric coefficient values variate between nearly 1.04 and 1.09 for both samples. Imaginer dielectric coefficients change in the range of -8 and -1 ($x10^{-5}$).

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Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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