Advanced Materials Research *Online: 2012-09-28*
ISSN: 1662-8985, Vol. 571, pp 125-128
doi:10.4028/www.scientific.net/AMR.571.125

Influence of electron irradiation on the yellow luminescence in undoped n-GaN

Limin Liang[1a], Xinjian Xie[1b], Qiuyan Hao[1c], Yuan Tian[1d], Weizhong Sun[1e], Caichi Liu[1f*]

[1]School of Materials Science and Engineering, Hebei University of Technology, Tianjin (300130), P. R. China

[a]lmliang117@163.com, [b]xjxie@hebut.edu.cn, [c]haoqiuyan@hebut.edu.cn, [d]ty243399930@yahoo.com.cn, [e]swz@hebut.edu.cn [f]*Corresponding Author: ccliu@hebut.edu.cn

Keywords: GaN; defects; photoluminescence; annealing

Abstract. The yellow luminescence (YL) band in unintentional doped n-GaN irradiated by 10 MeV electrons has been investigated by means of photoluminescence (PL) spectroscopy. The YL intensity increased after electron irradiation and thermal annealing, indicating that the deep level defects are created by electron irradiation and thermal annealing. These deep level point defect complexes arising from the irradiation introduced Ga vacancies and oxygen donor impurities are responsible for the YL.

Introduction

Gallium nitride and its alloys form a class of important semiconductor materials for applications in optoelectronics at blue wavelength and electronic devices operating at high temperature and high voltage [1]. Despite extensive investigation on the III-V nitride materials and related devices, the behavior of various defects, which strongly affects the properties or performances is still obscure. Especially, the yellow luminescence (YL), a broad luminescence band centered around 2.2eV, is usually observed in GaN, and its intensity can vary over a wide range, with good samples exhibiting almost no YL. The origin of the YL is still being debated[2-5]. To clearly confirm the origin of the YL, high-energy electron irradiation was selected as a suitable method for the artificial formation of point defects. Annealing treatment is a very valuable technique to study the diffusion and modification of native point defects at various temperatures.

In this article, the rapid thermal annealing is used to influence the irradiation defects introduced by 10MeV electrons in semiconductor materials and photoluminescence spectroscopy is applied to investigate the thermal induced evolution of YL in unintentional doped n-GaN. And the possible origin of the YL is discussed.

Experimental

Samples used in this study were 2.5μm thick, unintentional doped n-type GaN films grown on c-plane sapphire substrates by metalorganic chemical vapour deposition (MOCVD). The free carrier concentration of the as-grown sample measured by Hall measurement was about $1\times10^{17}cm^{-3}$. Irradiation was performed at room temperature with electrons of 10MeV and beam current of $10\mu Acm^{-2}$ using an electron linear accelerator facility, the irradiation doses was $1.5\times10^{17}cm^{-2}$. Rapid thermal annealing (RTA) treatments were then carried out in nitrogen ambient at temperature ranging from 200 to 800℃ for 1 min. Room-temperature photoluminescence (PL) spectra of the samples were measured by exciting with a He-Cd laser with 325nm excitation line. Besides, PL spectra of the samples were also measured at low-temperature ranging from 25K to 300K, using a closed-cycle refrigerator.

Results and discussions

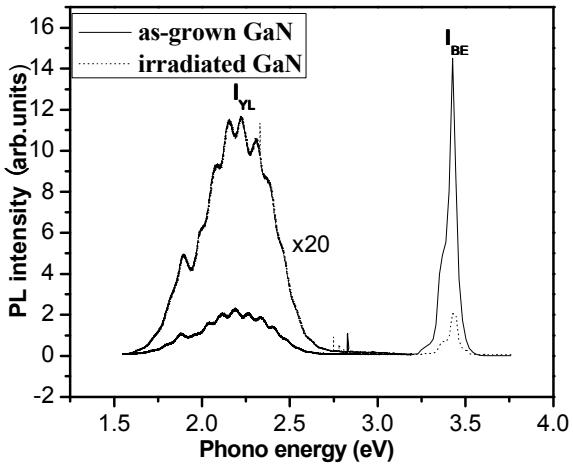

Fig. 1. Room-temperature photoluminescence spectra of the as-grown sample (Solid line) and the irradiated sample (Dot line). The yellow band was multiplied by a factor of 20.

The room-temperature photoluminescence spectra of the as-grown and irradiated samples are shown in Fig. 1. The spectra display two distinct features namely near-band-edge emission (NBE) transition at 3.42eV and the yellow luminescence (YL) emission centered around 2.2 eV. The YL exhibits a periodic intensity modulation due to a stronger electron-lattice coupling interaction. Inspection of Fig. 1 reveals that the YL intensity drastically increases after electron irradiation, but the NBE intensity exhibits a marked reduction. The high-energy electron irradiation introduces several defects such as Ga vacancies, and they form several deep-lying defect levels in the band gap of GaN, consequently, leading to the decrease in the NBE intensity and the increase in the YL intensity.

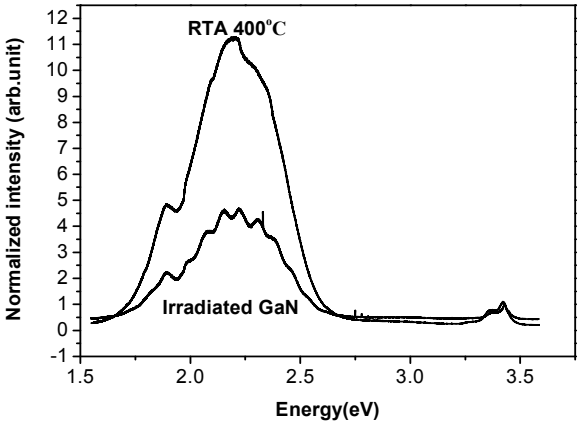

Fig. 2. Room-temperature photoluminescence spectra of the irradiated sample and the rapid thermal annealed sample at 400℃. The YL intensity is normalized to the NBE (3.42eV) intensity.

In order to investigate the origin of YL, the irradiated sample was annealed 400℃. The room-temperature photoluminescence spectra of the irradiated sample and the annealed sample were shown in Fig. 2. The result shows that a significant increase in the YL intensity occurs up to 400℃. It is found that the YL intensity of the sample annealed at 400℃ is about three times larger than that of the irradiated sample, This implies that the concentration of the point defect complex, responsible for YL, increase with increasing annealing temperature.

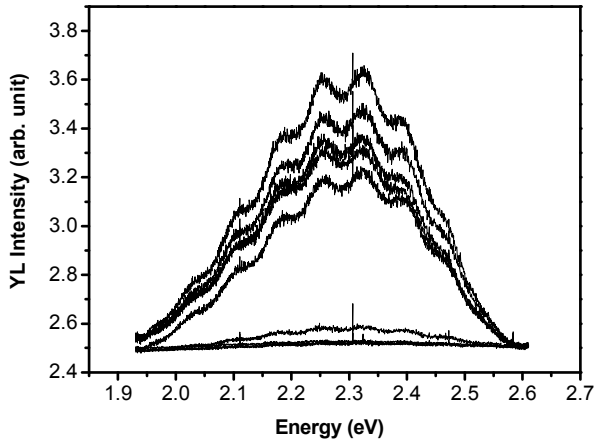

Fig. 3. Temperature dependence of the YL intensity for the sample annealed at 400℃ at measured temperatures ranging from25K to 300K.

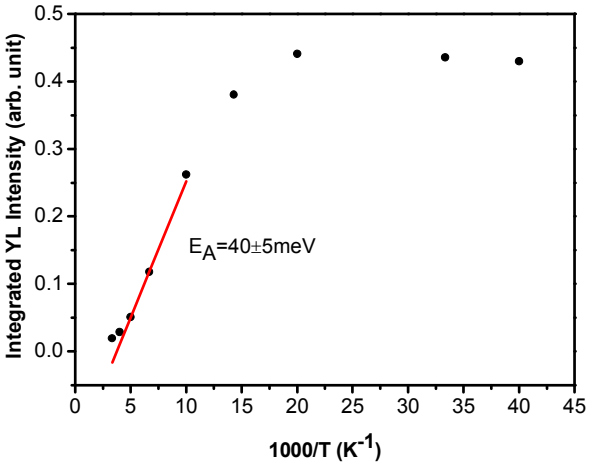

Fig. 4. The temperature dependence of the integrated YL intensity, the defect ionization energy E_A is extracted from a fit to the linear region.

PL measurements for the sample annealed at 400℃ were performed at various ambient temperatures from25K to 300K, as shown in Fig.3. Fig.4 gives the temperature dependence of the integrated YL intensity, the integrated YL intensity values are determined by single-Gaussian curve fits. The defect ionization energy E_A extracted from a fit in the linear region is found for 40±5meV, which is close to the 35 meV estimated for the shallow donor impurity in the earlier works [6,7]. This shallow donor impurity is possibly related to oxygen.

To understand the nature of the YL, the mechanism involved in the electron irradiation and the diffusion of irradiation induced defects in the annealing processes are needed to take into account. Ga Frenkel-pairs are the most likely defects induced by electron irradiation. According to the first-principles calculation [8], the predicted migration barriers for the 3- charge state of the isolated Ga vacancy is 1.8eV, the temperature needed to migrate for the isolated Ga vacancy is about 600K, it is in good agreement with the value estimated by experiment [9]. The isolated Ga vacancies introduced by electron irradiation become mobile at 400℃. The isolated Ga vacancies are very likely to combine with the oxygen impurities that are incorporated during growth by forming energetically stable vacancy-impurity complexes. Therefore, the forming of V_{Ga}-O_N complexes driven by the annealing kinetics is responsible for the increase of the YL intensity in the annealing temperature range of 400℃.

Summary

In conclusion, the effect of 10MeV electron irradiation on the undoped n-type GaN was studied by means of photoluminescence spectroscopy. The intensity YL increased with the electron irradiation, which is attributed to the introduction of insolated Ga vacancies by electron irradiation. The YL at 400℃ annealing was attributed to the point defect complex arising from the combination of the irradiation introduced Ga vacancies and the mobile residual oxygen donor impurities driven by high temperature annealing.

Acknowledgements

This work was financially Supported by the Hebei Natural Science Foundation (F2012202083) AND Tianjin Natural Science Foundation (10JCYBJC03000).

References

[1] S. Pimpukar, J. S. Speck, S. P. DenBaars, and S. Nakamuro, Nat. Photonics 3 (2009), p. 180

[2] J.Neugebauer and C. Van de Walle, Appl. Phys. Lett. 69 (1996), p. 503

[3] A. Aumstong, C Poblenz, D. S. Green, U. K. Mishra, J. S. Speck, and S. A. Ringel, Appl. Phys. Lett. 88 (2000), p. 2761

[4] T. Ogino and M. Aoke, Jpn. J. Appl. Phys. 19 (1980), p. 2395

[5] A. Sedhain, J. Li, J. Y. Lin and H. X. Jiang, Appl. Phys. Lett 96 (2010), p. 151902

[6] C. B. Soh, S. J. Chua, and H. F. Lim, J. Appl. Phys. 96 (2004), p. 1341

[7] H. Morkoc, S. Strite, G. B. Gao, M. E. Lin, B. Sverdlov, and M. Burns, J. Appl. Phys. 76 (1994), p. 1363

[8] S. Limpijumnong and C. G. Van de Walle, Phy. Rev. G 69 (2004), p. 035207

[9] F. Tuomisto, V. Ranki, D. C. Look, and G. C. Farlow, Phys. Rev. B 76 (2007), p. 165207