Physica B 485 (2016) 1–5

Contents lists available at ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

Effect of light Si doping on the properties of GaN

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ARTICLE INFO

Article history:
Received 6 June 2015
Received in revised form
24 December 2015
Accepted 4 January 2016
Available online 5 January 2016

Keywords:
Gallium nitride
Si doping
Mobility
Yellow luminescence

ABSTRACT

An obvious increase in electron mobility and yellow luminescence (YL) band intensity was found in light Si doping GaN. For a series of GaN samples with different doping concentration, the dislocation density is almost the same. It is inferred that the abrupt increase in mobility and YL intensity does not originate from the change of dislocation density. The mobility behavior is attributed to the screening of scattering by dislocation and increase of ionized impurity scattering with the increase of Si doping concentration. At lower doping level, the screening of dislocation scattering is dominant, which results in the increase in carrier mobility. At higher doping level, the increase in ionized impurity scattering leads to the decrease in carrier mobility. Higher mobility causes longer diffusion length of nonequilibrium carrier. More dislocations will participate in the recombination process which induces stronger YL intensity in light Si doping GaN.

1. Introduction

GaN-based III-nitrides have been intensely studied owing to their multiple applications in optoelectronic devices, high-temperature and high-power electronic devices. With the improvement of material growth and processing technology, a better understanding of basic properties of GaN has been achieved. N-type conductivity can been obtained using Si as dopant. The effect of Si on the electrical and optical properties of GaN has been investigated recently by several groups [1–3]. Carrier mobility is very important among the parameters characterizing the material quality of n-type GaN films. Electron mobility is decreased by the structural defects such as dislocation and stacking faults. Experimental data of the dependence of electron mobility on temperature and doping concentration have been reported in literature [4–6]. Hall measurement is usually used to characterize these electrical properties and in many reports is performed to assess material qualities. It is well known that there is a yellow (YL) band centered at 2.2–2.3 eV in the photoluminescence (PL) spectra of GaN, and it is normally thought that high-quality GaN materials should have a very weak YL band [7]. However, not only the origin of YL in GaN is under debate, but also the connection between the YL and electrical properties is not well understood. The effect of Si doping on the intensity of YL has been studied extensively, but the results are in controversy. It is worth noting that the ratio of the YL intensity to the near-band-edge emission intensity increases with the increase of doping concentration in some experiments, [8–9] but decreases in others, [10–11] or remains nearly unchanged [12].

In this study, the electrical and optical properties of Si doping GaN films were investigated by Hall and PL measurements. For a large number of GaN samples with different Si-doped concentrations, it was found that the electron mobility of light Si-doped GaN increases obviously with an increment more than twice that of the un-doped GaN and heavy Si-doped GaN. The PL spectrum indicates an obvious YL emission in light Si-doped GaN, while it very weak in un-doped and heavy Si-doped GaN. The results differ from some reports before [13–15].

2. Experiment

The Si-doped GaN films were grown on sapphire by 3×2"wafer metal organic chemical vapor deposition (MOCVD, Aixtron TS300) system. Trimethylgallium (TMGa) and ammonia (NH_3) were used as Ga and N precursors, and H_2 acted as carrier gas. The sapphire was thermally cleaned at 1075 °C under hydrogen for 6 min for the removal of possible impurities. The temperature was then reduced to 570 °C and NH_3 flow was switched on to nitride the sapphire substrate for 360 s. Then TMGa flow was

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http://dx.doi.org/10.1016/j.physb.2016.01.004
0921-4526/

switch on to grow 25 nm GaN low-temperature nucleation layer. The substrate temperature was then ramped to 1080 °C to grow 2.8-μm undoped GaN. Then 1-μm Si-doped GaN was grown at the same temperature with different Silane (SiH_4) flow (0–3 sccm) for different Si doping concentration

The optical, electrical and structure properties were measured by photoluminescence (PL) (RMS2000), Hall (HMS-300), atomic force microscopy (AFM) (SPA-300HV) and high-resolution X-ray Diffraction (HRXRD) (D8 discover) measurement. Room temperature photoluminescence measurements were performed using an Nd-YAG laser, emitting at 266 nm. AFM measurement was carried out at tapping model.

3. Result and discussion

The electron concentration of Si-doped GaN at room temperature as a function of SiH_4 flow and Hall mobility versus carrier concentration are shown in Figs. 1 and 2. The electrical properties were characterized at room temperature by the Van der Pauw Hall measurement method using In electrode for Ohmic contacts. It can be seen that the carrier concentration varies with the flow of SiH_4 approximately linearly. The free carrier concentration of unintentionaly doped GaN films is 4.6×10^{16} cm^{-3} with a mobility about 270 cm^2/Vs. But when the carrier concentration is at the light level, such as 2.37×10^{17} cm^{-3}, the mobility increases to 647 cm^2/Vs which is more than twice that of unintentionally GaN. The mobility decreases to 211 cm^2/Vs when the carrier concentration increases further to 9.73×10^{18} cm^{-3}. For the doped samples, the mobility decreases with the increase of Si doping concentration as a result of the increase in ionized impurities scattering. The increase in mobility for light Si doping indicates reduced the carrier scattering. The carrier scattering centers may come from threading dislocation, point defects, stacking faults, impurity etc [16–17]. There are more ionized impurities in light Si-doping GaN than in unintentionally doped GaN, while the mobility is much higher than that of unintentionally doped GaN. Thus, it is speculated that the increase in mobility may originate from the decrease in dislocation density and defect density.

Fig. 3 shows the full width half maximum (FWHM) of X-ray rocking curves (XRCs) obtained from (002) and (102) measurement, as a function of carrier density. The FWHMs of the (002) and (102) XRCs keep almost unchanged with different carrier density. In order to determine the dislocation density exactly, chemical etching was carried out in a mixture of H_2SO_4 and H_3PO_4 with a

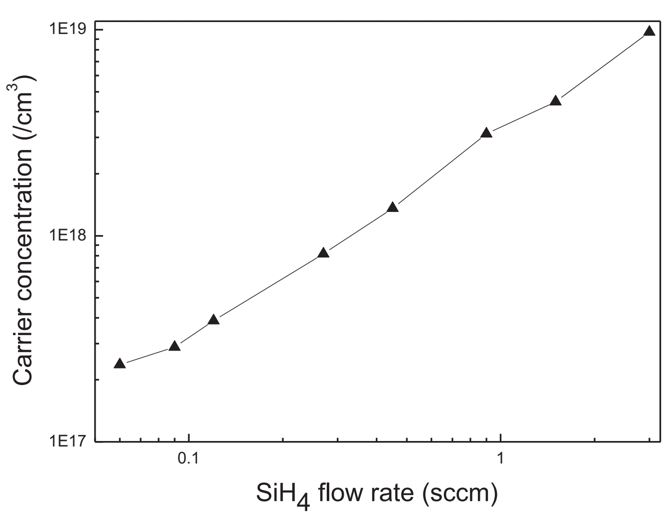

Fig. 1. Carrier concentration as a function of SiH_4 flow rate.

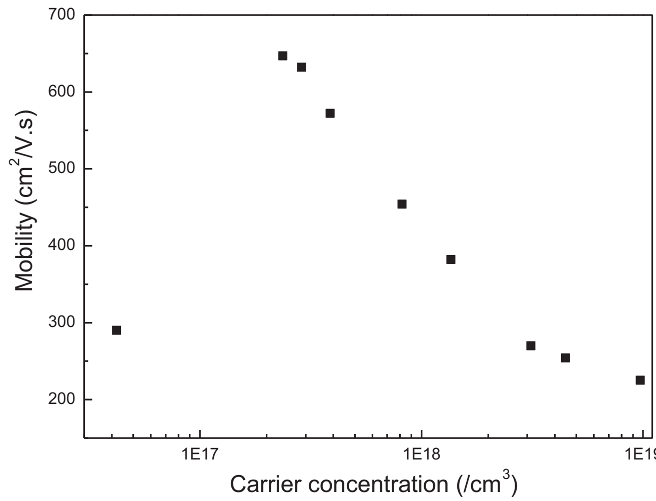

Fig. 2. The relationship of carrier concentration and mobility at room temperature.

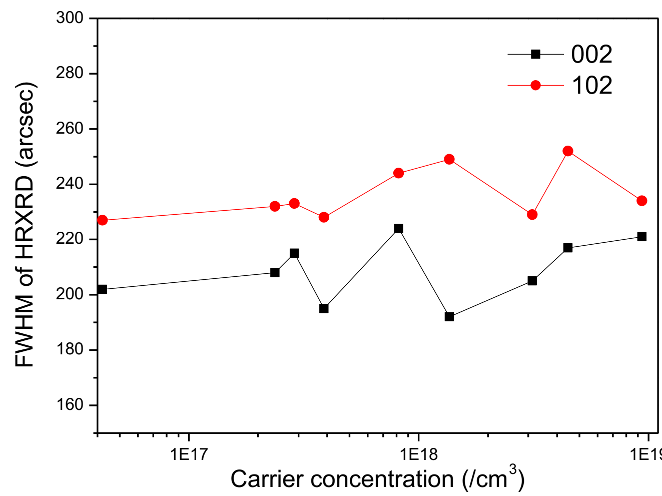

Fig. 3. The FWHMs of (002) and (102) plane as a function of carrier concentration.

ratio of 1:3 at 240 °C for 5 min. Fig. 4 shows the AFM images revealing etch pits on GaN surface. These etch pits might be produced by threading dislocations propagating to the top surface of GaN [18–19]. The etch pits' densites of un-doped GaN, light Si-doped GaN(2.37×10^{17} cm^{-3}), and heavy Si-doped GaN (9.73×10^{18} cm^{-3}) are very close to the value 1.6×10^8 cm^{-2}. The results indicate the dislocation density does not decrease in the light Si-doped GaN.

From the analysis above, the result does not agree with predicted one. In order to analyze GaN property further, the PL measurement with a 266 nm Nd-YAG laser as the excitation source was carried out at room temperature and the slit width is 4 mm. Fig. 5 shows the PL spectrum of GaN with different carrier concentrations (4.6×10^{16}, 2.37×10^{17}, 1.36×10^{18}, 4.47×10^{18}, 9.73×10^{18} cm^{-3}). All the spectra were measured at the same condition. Near-band-edge emissions at 360 nm were detected from all samples. It is important to notice there is an obvious broad luminescence band centered at 550 nm for the light Si doped GaN, known as YL, and the light interference as the undulations in the YL band [20]. However, the light Si doping GaN shows an obvious YL compared with un-doped GaN and heavy Si doping GaN. Fig. 6 presents the integrated intensity ratio of YL to the band edge emission at room temperature, which is 0.58, 12, 3.03, 0.67, and 0.41 for the five samples separately. The integrated intensity ratio decreases with increasing doping concentration. This result is