

Indium-Doping Enhanced Two-Dimensional-Electron-Gas Performance in AlGaN/GaN Heterostructures

Hairong Yuan, Xianglin Liu, Dacheng Lu

Institute of Semiconductors, Chinese Academy of Sciences

P.O. Box 912, Beijing, 100083, People's Republic of China

E-mail: hryuan@red.semi.ac.cn

GaN-based materials with wide band gap and stability at high temperature are suitable for high-temperature and high-power devices. However, large number of threading dislocations (TDs) existing in GaN will perhaps prevent device quality from further improving. These TDs mainly result from mismatch between GaN and substrate. Low temperature buffer technology has greatly improved GaN quality. After that several methods have been experimented to improve further. For example, epitaxial lateral overgrowth, pendeoepitaxy and double buffer layers method exhibited reduction in TDs. In recent years, isoelectronic Indium (In) doping has been used to improve the quality of epilayers^[1,2]. In this paper, we will report the effects of In-doping in GaN on two dimensional electron gas (2DEG) in AlGaN/GaN heterostructures. We found that In-doping is effective for improving electron sheet density of 2DEG. Wet chemical etching indicates that In-doping improved crystalline quality of GaN. It is proposed that In-doping modified growth kinetics and improved quality of GaN.

GaN single layers and AlGaN/GaN heterostructures were grown in our homemade horizontal two-flow metalorganic vapor phase epitaxy, which was designed for group III-nitrides growth. Prior to growth, a 20 nm buffer layer was deposited on sapphire substrate at 550 °C. All samples were grown at 1040 °C under low pressure (100 mbar). The heterostructures were multi-layered, schematically presented in Fig. 1. The doping situations of different heterojunction and thickness of each layer are listed in table 1. The 2DEG confined in each heterojunction can

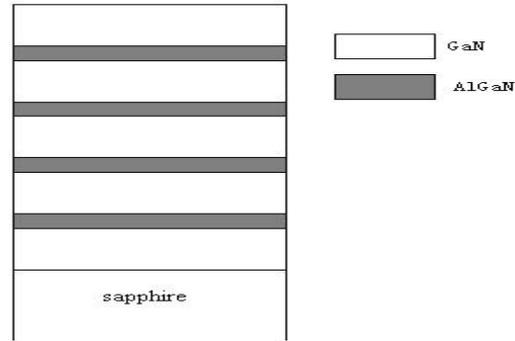


Fig.1. schematic diagram of AlGaN/GaN heterostructure.

Table 1. Doping situation and layer thickness of heterostructures:

sample	A	B	C	D
AlGaN layer	UD*, 40nm	UD, 40nm	Si-MD**, 60nm	Si-MD, 60nm
GaN layer	In-doped, 133nm	UD, 200nm***	In-doped, 133nm	UD, 200nm

Notes: *UD denotes unintentionally doped.

** Si-MD denotes Si modulation doped at middle 20nm of the barrier, upper and lower 20nm barriers act as spacers.

***In-doping reduced growth rate, so that In-doped GaN is thinner than undoped GaN.

contribute to conductance^[3], but the 2DEG in upper heterojunction dominates the conductance. In AlGaN layer, Al content was estimated to be 0.2. Electrical properties of the samples were measured through Hall measurement. Wet chemical etching was performed to investigate crystalline quality of GaN because the etch pit

is related to defects' sites ^[4]. Scanning electron microscope (SEM) was applied to determine etch pit density (EPD) through plan view and growth rate through cross-section view.

Electrical properties of the samples were listed in table 2. We can see from the table that: (1) The mobility of sample B is higher than that of sample A at room temperature and 77 K, while sample A has $1.4 \times 10^{13} \text{ cm}^{-2}$ higher electron sheet density than sample B; (2) Sample C has higher mobility and electron sheet density than sample D. Difference of electron sheet density between C and D is around $1 \times 10^{13} \text{ cm}^{-2}$; (3) Sample A and D has almost the same electron sheet density, while mobility of sample A is higher than that of sample D. All of these results

Table 2. Electrical properties of the heterostructures:

Sample	RT Mobility (cm^2/Vs)	RT Electron sheet density(cm^{-2})	77K Mobility (cm^2/Vs)	77K Electron sheet density(cm^{-2})
A	1132	2.36×10^{13}	4322	2.26×10^{13}
B	1258	9.14×10^{12}	4497	8.72×10^{12}
C	1204	3.4×10^{13}	3583	3.04×10^{13}
D	1166	2.38×10^{13}	2829	2.26×10^{13}

indicate that In-doping in GaN enhanced 2DEG performance through increasing electron sheet density without Si-doping.

Wet chemical etching shows that EPD in In-doped GaN is much lower than that in undoped GaN (Photos not shown here). We can estimate from SEM observation that EPD of In-doped GaN is $4 \times 10^7 \text{ cm}^{-2}$ while that of undoped GaN is $7 \times 10^8 \text{ cm}^{-2}$, and it can be observed that average size of etch pits in In-doped sample seems smaller than that of undoped GaN. These characters show that In-doped GaN is more resistive to etching. This shows that In-doping reduced defects and improved crystalline quality of GaN. And it should be benefit for improving mobility of 2DEG. However, effect of In-doping on mobility is not as significant as reduction of EPD. Mobility is influenced by many factors other than crystalline quality. Perhaps improvement of GaN crystalline quality is counteracted by other factors. This problem is still under investigation.

SEM cross section view shows that In-doping significantly reduced growth rate of GaN from $1.2 \mu\text{m}/\text{hour}$ to $0.85 \mu\text{m}/\text{hour}$. This indicates that In-doping modified growth kinetics. Chung^[1] proposed that In-doping prevents Ga atoms from incorporating and local $V/$ ratio near growth surface is higher than input. This benefits for improving GaN crystalline quality. Chung^[1] also reported that deep levels were reduced by In-doping. So that it is reasonable to assume that electron increasing results from reduction of electron traps. And, increasing of electron sheet density is benefit for screening ionized scattering. So that, mobility improvement may partly resulted from increasing of electrons.

In summary, we found that In-doping enhanced 2DEG performance by increasing electron sheet density. Wet chemical etching shows that In-doping improves crystalline quality of GaN. SEM observation shows that In-doping reduces growth rate of GaN, which could be attribute to modification of growth kinetics of GaN.

References

1. H. M. Chung, *et.al*, Appl. Phys. Lett. **76**, 897 (2000)
2. H. Kumano, *et al*, Appl. Phys. Lett. **75**, 2879 (1999)
3. M. A. Khan, *et al*, Appl Phys Lett, **58**, 2408 (1991)
4. T. Kozawa, *et al*, J. Electrochem. Soc., **143**, L17 (1996)