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Study on the p-type doping of AlGaN/GaN superlattice for blue LED

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Abstract. We studied the relationship of the superlattice structure with the doping efficiency in detail by semi-classic calculation and follow experiment. The results show that period length of about 9nm and Al content of 30% is optimal. The Hall, AFM and PL measurement show that the best annealing temperature under atmosphere is about 540℃ to 580℃. Finally we obtained the sample with resistivity of 0.31Ω·cm. It can be used for fabricating p type ohmic contact and active layer for blue LED.

Introduction

The band gap of GaN and its alloy can be adjusted from 1.9eV of InN to 6.2eV of AlN, which is benefit for the optic and high power devices. To optic devices, the high quality of p and n type GaN material are necessary and critical. While hampered by the Mg-H complex, background carriers and the high active energy of the common acceptor [1] ~ [3], the p-type doping of GaN is still an obstacle to obtain the new optic device, especially the LED and LD devices.

The relationship of hole density p in GaN with activity energy Ea and acceptor density Na can be described as[4]:

$$p = \sqrt{\frac{1}{8} N_A N_V} \exp\left(-\frac{E_a}{2kT}\right). \tag{1}$$

This relation show clearly that hole density p is mainly relies on the active energy Ea. P has the exponential relationship with Ea and just the square root relationship with Na. Thus the p-doping work should focus on decreasing the Ea of the acceptor. The band edge oscillation of superlattice can decrease the active energy of acceptor obviously, then enhancing the doping effect of p-type GaN.
In this paper, the Al content, the barrier and the well width of AlGaN/GaN superlattice are optimized by accounting the strong polarization effect and the incomplete ionize effect. Then the Mg-doped AlGaN/GaN superlattice samples are grown by MOCVD and treated by RTA. The obtained samples are measured by PL, Hall and AFM to determine the doping efficient.

Calculation

GaN has strong polar effect and this character must be accounted at the correspond calculation. The total polar effect P_t is combined by the piezoelectric polarization P_{pi} and spontaneous polarization P_{sp}, which can be write as:

$$P_t = P_{sp} + P_{pi} \tag{2}$$

$$P_{pi} = 2\frac{a_s - a_0}{a_0}(E_{31} - \frac{C_{13}}{C_{31}} E_{33}) \tag{3}$$

Where E_{13}, E_{31} is the pi constant， C_{13}, $C_{31}$is the elastic constant， a_0, a_s is the lattice constant.

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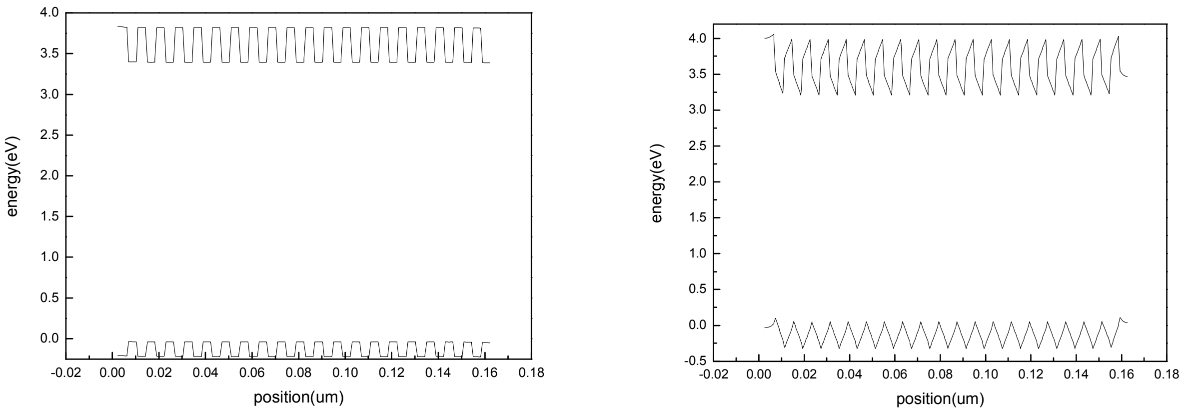

(a) Without polar effect (b) With polar effect

Fig.1. Oscillation of the band edge.

The calculation is performed by Silvaco with Fermi-Dirac model, incomplete ionize model, polar model and the interface stress model. Fig.1 shows the oscillation of the band edge. The amplitude of the valence band oscillation is about 180meV without and 310meV with polar effect. The shape of the oscillation turns from square potential wells to saw potential wells. Fig.2 shows the average hole concentration with and without polar effect. The result shows that the average concentration with polar effect is about $3.2x10^{17}/cm^3$ which is one magnitude higher than the result without polar effect. Fig.3 shows that the relationship of the superlattice period length with average hole concentration. The result shows that the average hole concentration reaches the maximum value around the period length of about 9nm. The above calculation results will guide and be tested at the following experiment.

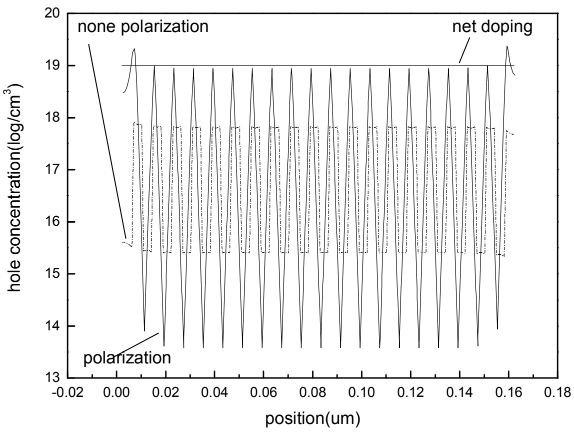

Fig.2. Average hole concentration.

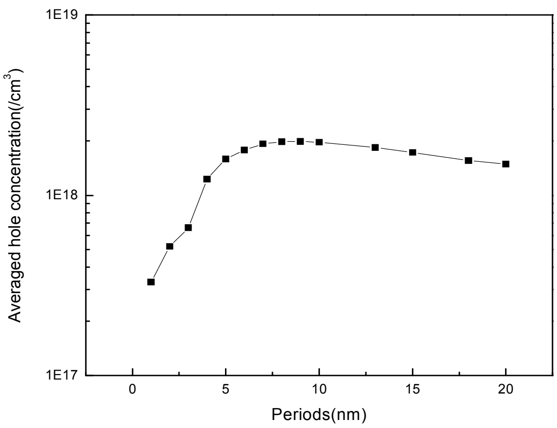

Fig.3. Relationship of the hole concentration with the period length.

Experiment

Figure 1. Experiment condition

sample	Well (nm)	Barrier (nm)	Pressure (Torr)	Temperature (℃)
1	3	3	40	950
2	4.5	4.5	40	950
3	6	6	40	950
4	4.5	4.5	100	950
5	4.5	4.5	100	850
6	4.5	4.5	40	850

The samples are obtained by the MOCVD method, the TEGa, NH_3, CP_2Mg are used as the Ga source, N source and the Mg source separately. The grown process can be concluded as follow steps: Firstly, a LT-GaN buffer layer is deposited at 550℃; Secondly an un-doped HT-GaN layer about 2um thick is deposited at 950℃ as the base layer, on which the superlattice will fabricated; Then forty pairs AlGaN and the GaN layer will be grown alternatively, at the same time the Mg source will be induced to obtain the p type material. Totally six samples are grown to study the affect of the period length, the temperature and the chamber pressure to the doping efficiency. All the samples are annealed at different environment to active the acceptors. The Hall, AFM and the PL are operated to measure the doping efficiency.

Test and discussion

The Hall results of sample 1, 2, 3 are shown at Fig.4. The resistivity of period length 6nm, 9nm and 12nm are 2.2Ω·cm, 0.72Ω·cm and 0.81Ω·cm separately. This result is coincidence with the former calculation. In Fig.5, The resistivity of sample 2, 4, 6 after annealing at atmosphere about 10 minutes descends about 1.9 times at high chamber pressure 100Torr than 40Torr. Fig.6 shows the relationship of the grown temperature with the sample resistivity. It shows clearly that high temperature benefit to the low resistivity.

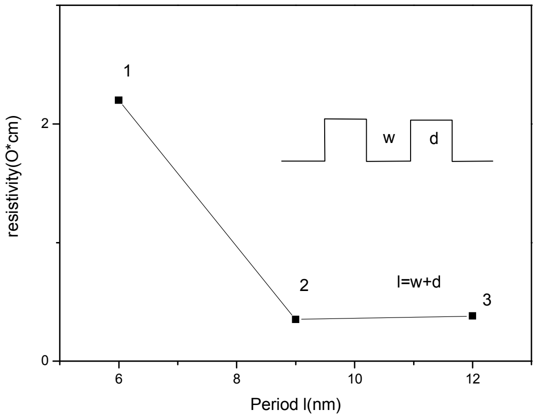

Fig.4. Resistivity to period length.

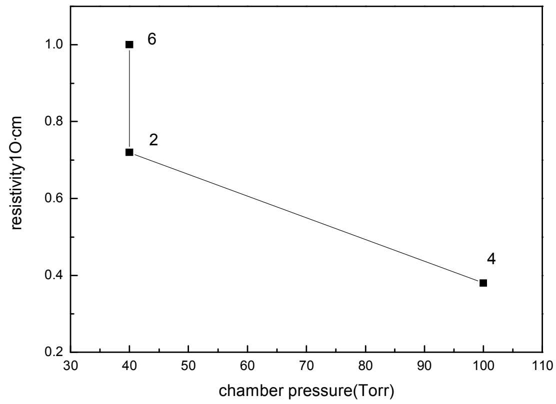

Fig.5. Resistivity to chamber pressure.

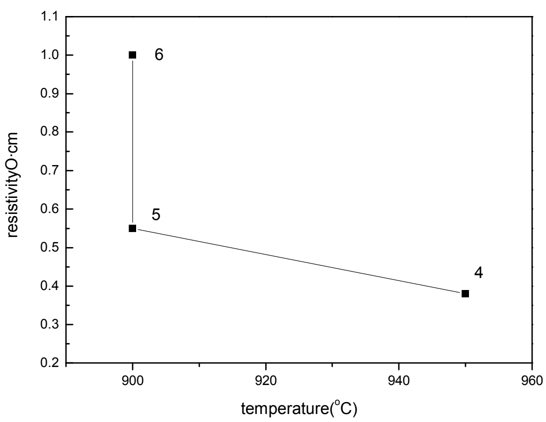

Fig.6. Resistivity to chamber temperature.

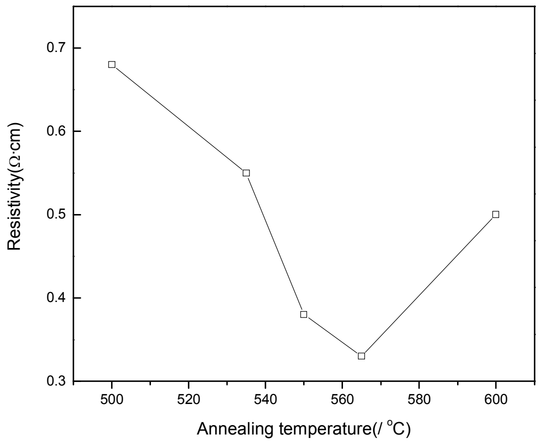

Fig.7. Resistivity to anneal temperature.

Furthermore the relationship of the annealing temperature at atmosphere with the resistivity is studied to find the optimal annealing condition. Sample 4 is annealed at 500°C, 535°C, 550°C, 565°C and 600°C about 10 minutes directly under atmosphere. The results are shown at Fig.7. All the resistivity are less than 1Ω·cm, the minimize resistivity of 0.31Ω·cm is reached about 565°C. From these results the optimal temperature is proved at about 540°C to 580°C.

$$E = 1240 / \lambda \tag{4}$$

Fig.8 is the PL results of sample 4, the dark line is the PL result before annealing and the light line is the result after annealing. The relationship of the wavelength with the photo energy can be described by Eq.4. The peaks of the PL spectra are 3.46eV, 3.28 eV, 3.18 eV, 3.02 eV and 2.91 eV. The 3.46 eV is the peak from the band border; 2.8eV is the peak from Mg acceptor to the donor. The peak strength of 2.8eV after annealing is about 5.2 times stronger than that of before annealing. This result shows clearly that our annealing process under atmosphere at about 565℃ is very efficient. Fig.9 shows the 1×1um AFM topography result of sample 4. The RMS of the topography result is about 0.38 nm, which indicate the good quality of the surface and the 2D grown mode.

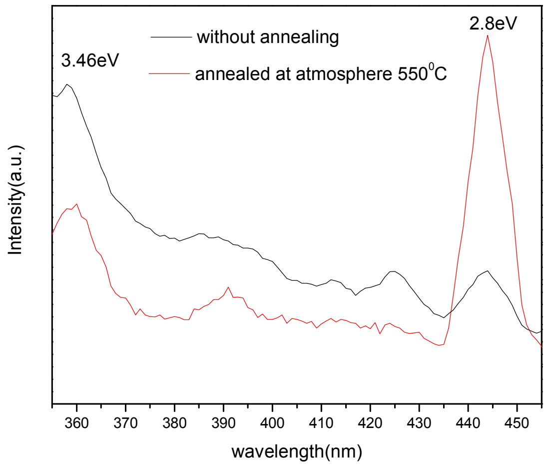

Fig.8. Room temperature PL spectra of sample 4.

Fig.9. AFM topography of sample 4.

Summary

Firstly, we optimize the superlattice structure by theoretic calculation and follow experiment. The structure with about 9nm period length and 30% Al content is proved to be optimal. Furthermore the proper chamber pressure of 100Tor and grown temperature of 950°C are obtained by the experiments. The Hall and PL measurement show that the best annealing temperature under atmosphere is about 540°C to 580°C. Finally, sample with resistivity of 0.31Ω·cm is obtained.

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