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Growth and characterization of GaN/AlGaN high-electron mobility transistors grown on p-type Si substrates

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Abstract

In order to grow high-quality GaN, we often choose sapphire as our substrates. However, silicon can be regarded as a new substrate due to its low cost and large wafer size. It is known that the difficulty of growing GaN on silicon is their large lattice mismatch (~17%) and thermal mismatch (~54%) between GaN and silicon. The usual process to reduce such mismatches is to grow an AlN layer as an intermediate layer. In this paper, we inserted a thin SiN layer between GaN and AlN to improve the quality of GaN, and the result showed that such thin SiN layer could greatly enhance the mobility of 2DEG formed at the interface of AlGaN and GaN. This suggests that it is possible to grow high-quality GaN on silicon as well as on sapphire with more studies of growth techniques.

Keywords: HEMT; GaN; Silicon substrate

1. Introduction

Recently, AlGaN/GaN heterostructures have been attracting a great deal of both theoretical and experimental interest because of their applications in high-power microwave devices, in high-frequency field effect transistors, in blue light-emitting diodes and in high electron mobility transistors (HEMTs) [1–11]. The performances of these devices are governed by the electronic properties of the two-dimensional electron gas (2DEG) formed in the AlGaN/GaN quantum well. In addition, there is no doping in AlGaN and GaN, the formation of such a 2DEG results from the polarization of AlGaN and GaN. There are spontaneous polarization and piezoelectric polarization in AlGaN, and there is spontaneous polarization in GaN [1]. The spontaneous polarization is due to the non-coincidence of the centers of cations and anions when they are at their lowest energy positions, and the piezoelectric polarization is due to lattice mismatch strain and thermal strain caused by thermal expansion-coefficient differences between the AlGaN and GaN layers. When these two materials combine together, there are sheet charges formed at the interface of them. If the sheet charges are positive, free electrons will compensate them during the cooling process after growth. Hence, we can observe 2DEG formed at the interface of AlGaN and GaN.

In most cases, GaN/AlGaN HEMTs were grown on sapphire substrates. However, Si can also be regarded as an alternative to commercial sapphire substrates for nitride-based devices owing to its low cost and large wafer size. It is known that good-quality GaN films on a Si substrate are very difficult to achieve due to the large lattice mismatch (~17%) and thermal mismatch (~54%) between GaN and Si [12–16]. It is also known that an AlN layer as an intermediate and nucleation layer can greatly enhance the quality of GaN films [17,18]. In this paper, we report on the growth and measurements of GaN/AlGaN HEMTs on a Si substrate using AlN as an intermediate layer using metal-organic vapor phase epitaxy (MOVPE). In addition, some experiments showed that inserting a thin SiN film can reduce the stress of GaN [19], and hence we insert a thin

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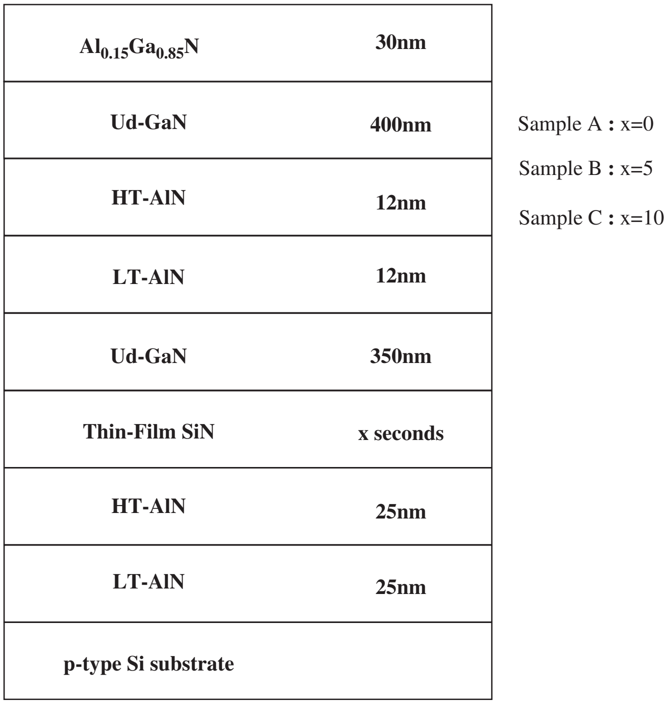
SiN layer between AlN and GaN with 5 and 10 s deposition time. We will report how the SiN thin film can affect our transport properties of 2DEG.

2. Experiment

Fig. 1 shows the schematic diagram of our three samples measured in this thesis. They were all grown by MOVPE and choose Si (1 1 1) as our substrates. Because of the large lattice mismatch and thermal mismatch between Si and GaN [12–16], few AlN layers were grown as intermediate layers between Si and GaN in order to lower down the defects due to such mismatch [17,18]. After that, a SiN treatment was introduced using silance (SiH_4) flow of 50 sccm diluted to 100 ppm with H_2. The growth chamber is kept at a pressure of 100 mbar and a temperature of 1050 °C. The duration of this step was 0, 5, and 10 s respectively to deposite a thin SiN film between GaN and AlN. Hence, we can observe the effect of SiN on the electrical properties of the HEMT structures. In our system, the GaN and AlGaN layers are Ga-polarity. The contacts were grown by evaporating Ti/Al/Ti/Au on the surface, and heated to 500 °C by RAP. There were four contacts on the surface in order to do four point measurements.

3. Results and discussion



$Al_{0.15}Ga_{0.85}N$	30nm
Ud-GaN	400nm
HT-AlN	12nm
LT-AlN	12nm
Ud-GaN	350nm
Thin-Film SiN	x seconds
HT-AlN	25nm
LT-AlN	25nm
p-type Si substrate	

Sample A : x=0
Sample B : x=5
Sample C : x=10

Fig. 1. The schematic diagram of our samples, where x is 0, 5, 10, respectively.

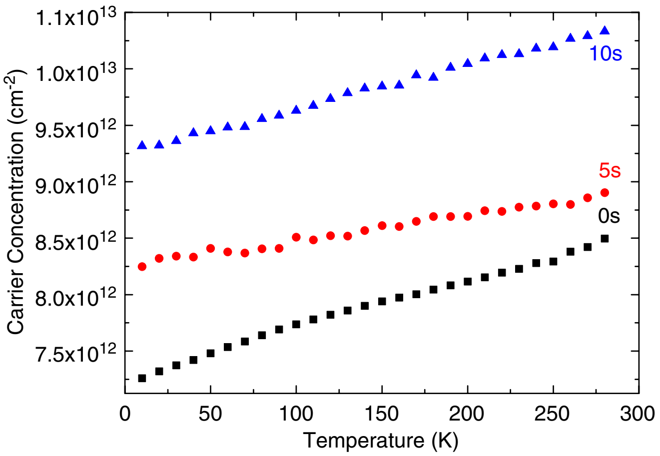


Fig. 2. The carrier concentration as a function of temperature.

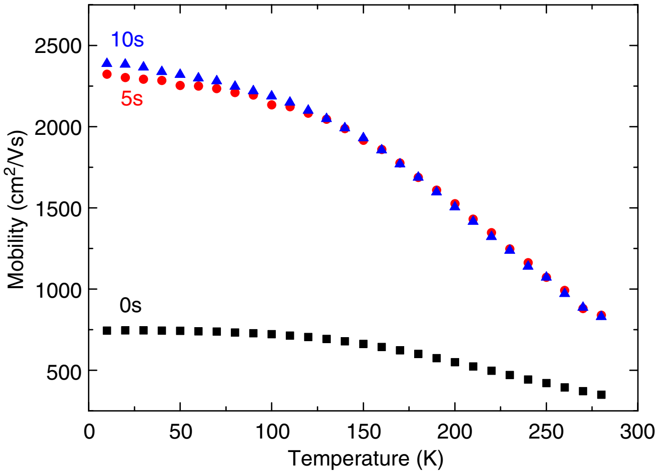


Fig. 3. Mobility as a function of temperature. We could observe that SiN deposition could greatly enhance sample mobility.

Fig. 2 shows the measured carrier concentration as a function of temperature for three different samples A, B, and C. We can see that within the experimental errors, the carrier concentrations show very little variation (about 15%, 7.4%, and 9.8% for sample A, B, and C, respectively) over a wide range of temperature ($10\,K \leqslant T \leqslant 280\,K$). This demonstrates the formation of a 2DEG in our system even at room temperature.

In order to provide further understanding of the transport properties of our three samples, we have measured the mobilities of them. This is the quantity, which is generally used in semiconductors because it can directly reflect the sample quality. Fig. 3 shows the measured mobilities as a function of temperature. We can see that the mobility decreases with increasing temperature. This is consistent with the fact that electron–phonon scattering increases with increasing temperature. We can find out that sample quality is greatly enhanced after SiN thin film was grown. The mobility of 5 and 10 s at 10 K is almost three times larger than that without a SiN thin film. We note that the insertion of the SiN layer results in a small increase of the electron concentration in our HEMT.

However, such an increase ($<30\%$) cannot cause a dramatic increase (>3 times) in the measured mobility. According to the seminal work of Dadgar et al., PL spectra shows SiN treatment can cause a reduction of tensile stress in the GaN layer [19].

4. Conclusions

In conclusion, we have performed transport measurements on AlGaN/GaN heterostructures on silicon substrates over a wide temperature range. Our results show that the carrier concentrations, within the experimental error, show little variation from room temperature to low temperatures. This demonstrates the formation of a 2DEG in our system even at room temperature. And the mobility was greatly enhanced after either 5 or 10 s SiN was deposited. This is consistent with the fact that SiN can reduce the stress of GaN on a silicon substrate, and hence we are able to grow good-quality GaN to form a high-mobility 2DEG at the interface of AlGaN and GaN. This great enhancement of the mobility demonstrates the usefulness of our technique. With optimization of our growth temperature, HEMT structure, and most importantly, SiN treatment technique, it is expected that the quality of HEMTs grown on silicon substrates can be as high as those grown on conventional sapphire substrates. This paves way to a possible experimental realization of integration of GaN/AlGaN HEMTs with the very mature silicon technology in industry.

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