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Characterization of AlInN Layer Grown on GaN/Sapphire Substrate by MOCVD

(Pencirian Lapisan AlInN yang Ditumbuh di Atas Substrat GaN/Nilam Menggunakan MOCVD)

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ABSTRACT

The AlInN layers have been grown with different growth parameters on GaN/sapphire substrates by metal-organic chemical vapor deposition (MOCVD). The effects of growth parameters such as pressure and temperature on the Al incorporation during AlInN material growth have been investigated. The results showed that lower pressure provides a tendency for higher Al incorporating in the AlInN layer. Besides, as the temperature was increased from 700°C to 780°C, an estimation of 4% reduction on the indium composition has been observed for each 20°C increment. XRD analysis showed that the best crystal quality of AlInN occured at 80% Al composition because of the higher lattice matching with GaN. Based on the above criteria, an $Al_{0.8}In_{0.2}N$*/GaN HEMT device with 2 µm gate length has also been fabricated. The DC characteristics showed a saturated current,* I_{dss} *of 280 mA/mm and transconductance of 140 mS/mm.*

Keywords: AlInN layer; GaN; MOCVD

ABSTRAK

Lapisan AlInN telah ditumbuh dengan menggunakan pelbagai parameter di atas substrat GaN/nilam dengan menggunakan pemendapan wap kimia organik logam (MOCVD). Kesan bagi parameter-parameter seperti tekanan dan suhu terhadap percampuran Al di dalam lapisan AlInN telah dikaji. Kajian menunjukkan bahawa tekanan yang lebih rendah memberi kecenderungan untuk percampuran Al yang lebih tinggi di dalam lapisan AlInN. Selain daripada itu, untuk suhu yang meningkat daripada 700°C ke 780°C, pengurangan komposisi indium sebanyak 4% telah diperhatikan bagi setiap pertambahan suhu sebanyak 20°C. Melalui analisis XRD, kualiti AlInN yang paling baik diperhatikan apabila lapisan mempunyai 80% komposisi Al kerana pemadanan kekisi yang paling baik dengan GaN pada komposisi ini. Berdasarkan kepada kriteria di atas, satu peranti HEMT $Al_{0.8}In_{0.2}N$*/GaN dengan panjang get 2 µm telah difabrikasi. Ciri-ciri DC menunjukkan arus tepu,* I_{dss} *pada 280 mA/mm dan bacaan transkonduksi sebanyak 140 mS/mm.*

Kata kunci: GaN; lapisan AlInN; MOCVD

INTRODUCTION

Recently, the emergence of III-nitride such as GaN, AlN, InN and their alloys family (InGaN, AlGaN, InAlN) as materials for high frequency devices has channeled plenty of researches to focus into this area. Currently, the major III-nitride device is AlGaN/GaN high electron mobility transistor (HEMT) for microwave frequency application (Lee et al. 2011, 2011a). One special phenomenon for this device is the presence of spontaneous polarizations in the AlGaN layer. It forms a two dimensional electron gas (2DEG) layer at the interface of AlGaN/GaN without the presence of doping layer. Two factors that will affect the carrier density of the 2DEG layer, are the thickness of AlGaN layer and the composition of Al in it. By increasing the thickness of the layer, the carrier density of 2DEG could be increased. The increase in Al content will improve the polarization-induced surface charge density and the carrier confinement (Ambacher et al. 2000). However, there is a limiting point where further increment of those parameters would result in higher lattice strain and reduce the crystal quality. This will cause the decrease in electron mobility in the channel (Morkoç 2009).

In order to overcome this problem, the use of AlInN to replace AlGaN has been proposed (Kuzmik 2001). AlInN not only has the advantage of lattice matching to GaN layer but also provides higher polarization effect (Dadgar et al. 2005; Gonschorek et al. 2006; Neuburger et al. 2004). However, the growth parameters (pressure and temperature) for AlN and InN are in opposite direction. For both pressure and temperature, the value favor to one's growth will depress the other growth. To combine them into ternary compound of AlInN is a big challenge. An optimized value needed to be obtained. To resolve this problem, we have done a series of work to grow the best AlInN layer on GaN by using metal-organic chemical vapor deposition (MOCVD). In this paper, the effect of crystal quality dependency on the growth parameters such as chamber pressure and growth temperature has been investigated. After a set of optimized value has been obtained, an AlInN/GaN HEMTs was fabricated and characterized for the electrical properties.

EXPERIMENTAL DETAILS

GaN/sapphire substrates were used for the growth of AlInN layer by VECCO D-180 MOCVD system. First, the pressure of the growth chamber was altered to 50, 100 and 200 torr in separate samples by keeping the temperature and flow rate of all the other parameters as constants. High resolution X-ray diffraction (XRD) has been used to characterize the grown AlInN layer. Based on the XRD data, an optimized chamber pressure was obtained and used for the optimization process for temperature. In this second step, the growth temperature was changed from 700 to 780°C in a step of 20°C. The AlInN layers with different indium incorporations were obtained under different growth temperatures. HRXRD was used to determine the percentage of the indium incorporation in the AlInN layer. The optimized growth parameters for the AlInN layer were used to fabricate a AlInN/GaN HEMT device.

RESULTS AND DISCUSSION

The XRD spectra of AlInN materials deposited at three different growth pressures (50, 100 and 200 torr) are shown in Figure 1. According to the published data, the best lattice matching of $Al_xIn_{1-x}N$ is at x~0.80 (Morkoç 2009). We know that the lower growth pressure is more suitable for the formation of AlN in $Al_xIn_{1-x}N$ layer, but the formation of InN needs higher pressure. At 200 torr, the grown layer showed no peak at the right of the GaN (002) peak in the HRXRD spectrum. This shows that the value of x in the $Al_xIn_{1-x}N$ layer was less than 0.5. An x value of ~0.80 is needed for this purpose. A lower pressure (100 torr) was therefore selected to grow the layer with higher Al content, where a peak for AlInN started to appear at the right of the GaN (002) peak in a ω-2θ HRXRD spectrum as shown in Figure 1. Further reduce in pressure caused too much Al incorporation. The peak for AlInN was further shifted to the right (Figure 1). Based on the calculation, the Al ratio for $Al_xIn_{1-x}N$ layer grown at pressure of 50 torr has the value of x>0.80 which were not well matched to the underneath GaN layer. We adjusted the pressure so that x was near to 0.80 in the growth of $Al_xIn_{1-x}N$ layer so that there was a peak for AlInN at the right of GaN (002) peak as shown in Figure 1. With this value, it has the best lattice matching to GaN layer. This value of pressure (100 torr) was used to fine tune with the growth temperature.

Figure 2(a) shows the effect of the several temperature values to the percentage of indium incorporation. A temperature range of 700-780°C was set for the growth. Temperature higher than 800°C will enhance the evaporation of indium atoms from the surface and reduce the absorption of indium atom into the layer. In this study, the temperature was increased from 700 to 780°C in a step of 20°C. An estimation of 4% indium reduction on each 20°C increment in temperature was observed. A graph (Figure 2(b)) shows the variation of Indium composition to the crystal quality (FWHM). It shows that a best crystal quality (minimum FWHM) occurs at 20% indium composition where the peak for AlInN is best matching to peak for GaN (002). The optimized value for temperature has been set at 740°C. At this temperature, the lattice constant of the grown AlInN layer was closer to GaN which reduced the lattice mismatching strain and provide a lower defects and higher crystal quality.

Based on the optimized value that we have obtained, a device $Al_xIn_{1-x}N$/GaN HEMT has been fabricated. The value of x has been determined by XRD as 0.18. DC measurement has been done. As shown in Figure 3(b) the current cut off at a gate voltage (V_G) of -3V. A saturated current density (I_{dss}) of 280 mA/mm was obtained from the plot in Figure 3(a). A maximum transconductance (g_m) value of about 140 mS/mm was obtained.

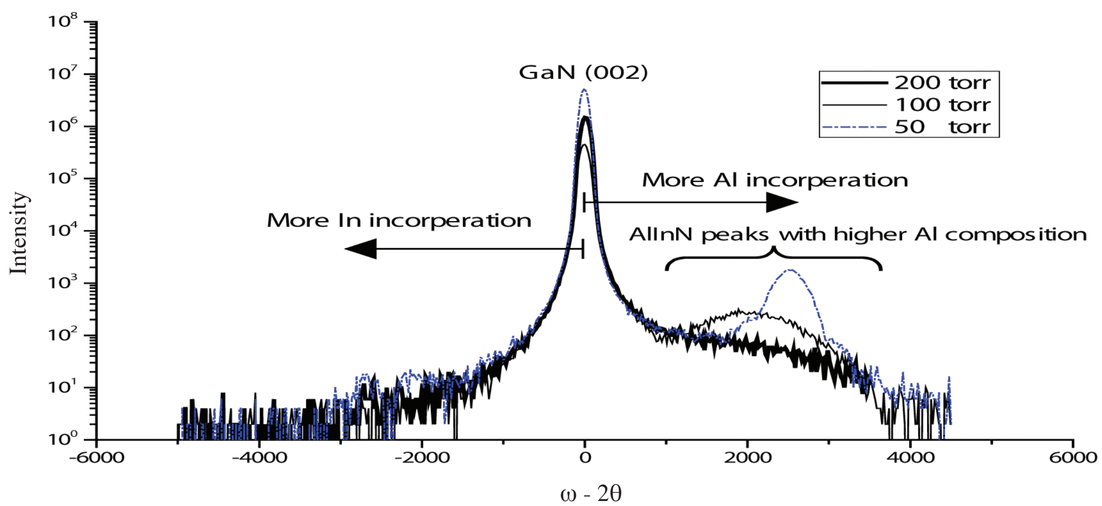

FIGURE 1. XRD spectrum shows the corresponding curves for AlInN layer grown under the pressure of 50, 100 and 200 torr

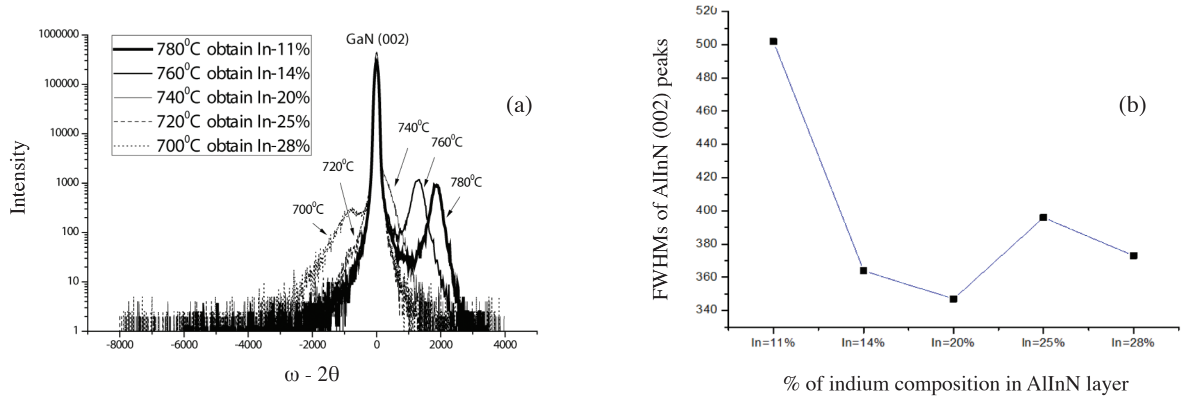

FIGURE 2. (a) The different substrate temperatures will result in different In contents in contents in the AlInN layer, (b) the variation of FWHM of AlInN (002) XRD peak to the composition of indium on the InAIN layer the AlInN layer

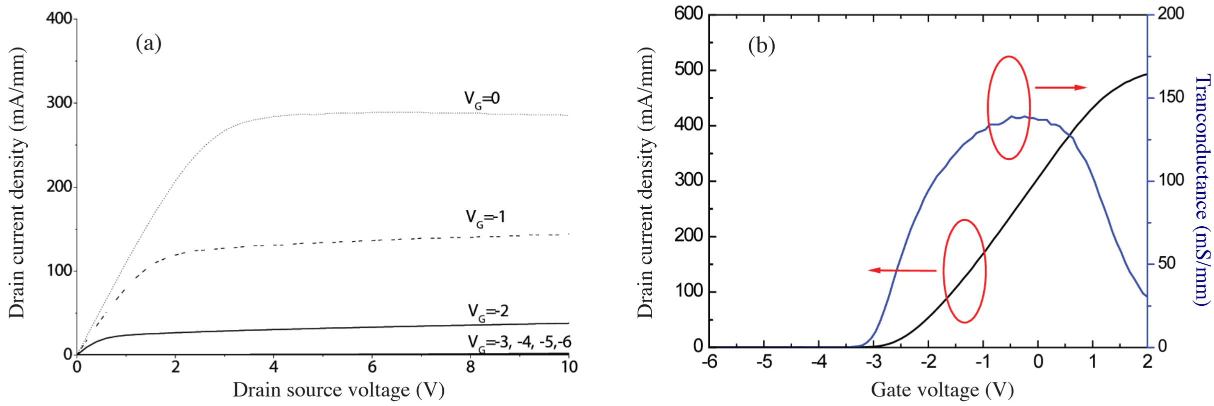

FIGURE 3. (a) I_{ds}-V_{ds} of an $Al_{0.82}In_{0.18}N$ /GaN HEMT structure (b) Density of drain current and transconductance characteristics for an $Al_{0.82}In_{0.18}N$ /GaN HEMT

CONCLUSION

AlInN HEMT structure has been fabricated where the AlInN layer was lattice matching with the underneath GaN layer. The optimization value for both the temperature and pressure of the growth process has been obtained as 740°C and 100 torr. HRXRD has determined the x to be about 0.82 in the $Al_xIn_{1-x}N$ layer for the AlInN HEMT device and DC characteristic has been done.

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