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Changes of electrical properties by Al content of $Al_xGa_{1-x}As$ in pHEMT structures as observed using HRXRD

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Abstract

Characterizations on the pseudomorphic High Electron Mobility Transistor structure under High-Resolution X-ray Diffraction (HRXRD) have been carried out at room temperature. Variation of Al contents in $Al_xGa_{1-x}As$ alloys has been found to show a shift of diffraction peaks. This variation is also found to show the change of lattice constant of crystal and also sheet carrier concentration as obtained from a Hall effect measurement. The latter phenomenon is considerably interesting to study in the early stage of the electrical properties of device based on the crystal structure.

Keywords: HRXRD; pHEMT; Lattice constant; Epitaxial layer

1. Introduction

High-resolution X-ray diffractometry (HRXRD) has been used widely as a powerful technique for structural studies of epitaxial layers of semiconductor devices. The concept of this technique is non-destructive and does not require any sample preparation. Basically HRXRD technique provides some information concerning crystalline quality, thickness, and strain layers in a relatively simple manner. Many research works have been carried out to study the epitaxial layer of pseudomorphic High Electron Mobility Transistor (pHEMT) structure using HRXRD for crystallography point of view. This kind of electronic devices is well known for their potential to perform high-speed transistor, low noise, and high gain. These characteristics are potential to be used to investigate the device for best preparation, which are suitable for various applications such as telecommunications in commercials and also militaries [1–3]. Work has been conducted to find a relationship between Al composition of a coherent $Al_xGa_{1-x}As$/GaAs heteroepitaxial layer and lattice parameter difference [4,5]. Meanwhile, a relationship between crystalline structure and electrical properties of HEMT structure has not yet been reported. Therefore, in this paper we report our work to find any relationship between material structure of pHEMT and its electrical property of sheet carrier concentration, which potentially leads to further analysis of device's performance.

2. Material preparation and measurement techniques

HRXRD machine used was of PANalytical with incident angle resolution of 0.003°. For a measurement, the power was set at 40 kV and 30 mA, meanwhile measurements were carried out at room temperature. X-ray source of Cu K_α radiation was used with the combination of a gradient parabolic X-ray mirror and a 4-crystal Ge monochromator in (2 2 0) setting. The open detector with a 1 mm receiving slit in format has been used for the rocking curve measurement. The alloy compositions and growth rates were controlled or monitored by RHEED intensity oscillations and beam equivalent pressure (BEP) measurements. For an electrical characterization of the pHEMT structure, the samples were measured using a Hall effect measurement at room temperature. During measurement, magnetic intensity applied was for 0.3 T perpendicular with respect to the sample by using Van der Pauw method. From this measurement, sheet carrier concentrations for

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variation of Al contents in the pHEMT structure will be studied. Three different samples of pHEMT have been characterized using HRXRD and Hall effect measurements. The structure of samples used is tabulated in Tables 1 and 2. All the samples were covered by cap layers of heavily doped GaAs.

3. Results and discussion

From the measurement results, rocking curves were measured by $\omega/2\theta$ scan for three different samples as shown in Fig. 1. The narrow high-intensity peaks obtained are due to the GaAs (0 0 4) substrate diffractions. Meanwhile, the next left peaks are for $Al_xGa_{1-x}As$ layers in the structure. This peak observation was also conducted by Kim et al. [6]. The layer thickness interference fringes appeared at the relative angular from −2000 to −300 s. These peaks were assumed due to the superlattice. Superlattice was grown to minimize the propagation of defects and to obtain a smooth surface. Meanwhile, big broad peaks obtained at the most left region are considered to be due to the $In_xGa_{1-x}As$ layer for three different samples. Broadening of the diffraction peaks, as we can see from the results, was assumed as due to non-uniform spacing of the lattice planes. This was because of the alloy composition or strain in the layer. Broad peaks of $In_xGa_{1-x}As$ for three samples occurred are assumed to be not much different from each other as those three sample structures have In content with a bit variation for 0.19 (samples A and B) and 0.20 (sample C). Different intensities, particularly among the samples, are considerably due to different qualities of epitaxial layer during preparation and also variation of channel thicknesses. For $In_xGa_{1-x}As$ peaks, sample B is found to be highest among the others as the channel thickness prepared was greater (26 nm) among the other samples. Nevertheless, peak angle position is another important parameter for crystal structure analysis.

To elaborate the $Al_xGa_{1-x}As$ structure, the curves in Fig. 1 have been zoomed out for angles from −200 to 30 s as shown in Fig. 2. From the curves (of samples A, B, and C), we can see that variation of Al contents; x leads to a change of Bragg peak angles and also their peak intensities. The arrows are used to show the peak position of each curve. The peaks of substrate of GaAs are being used as references and were set for an angular of 0 s. For curve A, a peak for a GaAs substrate is found a bit broader than for the others. This is assumed to be due to the effect of wafer curvature. Meanwhile, peak intensities of $Al_xGa_{1-x}As$ layer were observed to occur in order by means of the

Table 1
A schematized cross-section of pHEMT structure

Layer	Concentration (cm^{-3})
30 nm cap (doped GaAs)	10^{19}
40 nm supply (doped-$Al_xGa_{1-x}As$)	10^{17}
6 nm spacer (undoped-$Al_xGa_{1-x}As$)	
Channel ($In_xGa_{1-x}As$)	
7.5 nm superlattice : GaAs (10 times)	
$Al_xGa_{1-x}As$ (10 times)	
1000 nm buffer (GaAs)	
Substrate (semi-insulating GaAs)	

Table 2
Al and In contents and channel thickness of alloys in the pHEMT structure

Sample	Al content	In content	Channel thickness (nm)
A	0.20	0.19	8
B	0.21	0.19	26
C	0.24	0.20	12

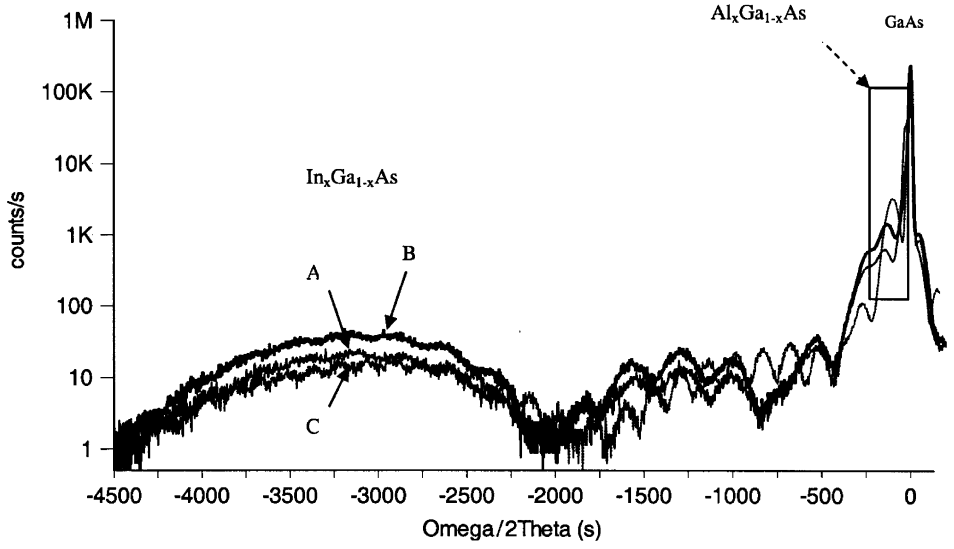

Fig. 1. HRXRD experimental results for $Al_xGa_{1-x}As$ alloy for different Al contents of three different samples. Peaks in the box are for $Al_xGa_{1-x}As$ layer.