High Uniformity of $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As/In}_{0.15}\text{Ga}_{0.85}\text{As}$ Doped-Channel Structures Grown by Molecular Beam Epitaxy on 3" GaAs Substrates

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Al$_{0.3}$Ga$_{0.7}$As/In$_{0.15}$Ga$_{0.85}$As doped-channel structures were grown by molecular beam epitaxy on 3" GaAs substrates. The uniformities of electrical and optical properties across a 3" wafer were evaluated. A maximum 10% variation of sheet charge density and Hall mobility was achieved for this doped-channel structure. A 1 μm long gate field-effect transistor (FET) built on this layer demonstrated a peak transconductance of 350 mS/mm with a current density of 470 mA/mm. Compared to the high electron mobility transistors, this doped-channel FET provides a higher current density and higher breakdown voltage, which is very suitable for high-power microwave device applications.

Key words: AlGaAs/InGaAs, heterostructure field-effect transistor, molecular beam epitaxy

INTRODUCTION

High-speed and high-frequency electronic devices, based on heterostructure designs, have been developed more than a decade, and have demonstrated great performance in integrated circuit applications. High electron mobility transistors (HEMTs) are the most successful example of the realization of high speed and high frequency electronic devices. Due to the immunity from impurity scattering in the HEMT structure, carrier transport in the conducting channel can be dramatically enhanced. However, to further increase the device and circuit density, high uniformity of electrical properties across a large area on GaAs substrates is an essential issue. The variation of material and device parameters should be minimized in this case to meet the strict requirements regarding fabrication cost and production yield.

In this study, we investigated the uniformities of material parameters across a 3" GaAs epitaxial wafer grown by molecular beam epitaxy (MBE), and used a heterostructure described below to fabricate 1 μm long gate field-effect transistors (FETs). Instead of using HEMT designs, we adopted a doped-channel structure to carry out this uniformity study. Although carriers suffer from the impurity scattering in doped-channel FETs (DCFETs), carrier densities are much higher as compared to the HEMT. As a consequence, high-speed performance can still be expected from the doped-channel FETs.

MATERIAL GROWTH AND DEVICE FABRICATION

Undoped semi-insulating 3" GaAs substrates were grown by the liquid-encapsulated Czochralski (LEC) method. The average etch pit density (EPD) was $1 \times 10^4$ cm$^{-2}$; the typical resistivity was $1 \times 10^8$ Ω-cm, corresponding to a mobility of 5000 cm$^2$/V-s across a 3" wafer. The variations of these parameters along a 3" substrate were all within ±10%, which demonstrates that these substrates are qualified for further device applications. The detailed information regard-
Fig. 1. Device cross section of Al_{0.3}Ga_{0.7}As/In_{0.15}Ga_{0.85}As doped-channel FETs.

The Al_{0.3}Ga_{0.7}As/In_{0.15}Ga_{0.85}As doped-channel structures shown in Fig. 1 were grown by MBE on a Riber-32P system. The entire structure was grown at 620°C, excepting the In_{0.15}Ga_{0.85}As (n = 5 \times 10^{18} \text{cm}^{-3}) doped-channel which was grown at 550°C. This pseudomorphic channel was followed by a 200Å undoped Al_{0.3}Ga_{0.7}As layer and a 200Å n+GaAs capped layer.

Device fabrication was realized by conventional optical lithographic techniques. The active mesa regions were defined by using NH_{4}OH:H_{2}O_{2}:H_{2}O chemical etching solutions. Ohmic contacts were carried out by thermal evaporation of Ge/Ni/Au alloy and followed by a 400°C, 1 min furnace anneal. The separation between source and drain contacts was 3.5 μm. After gate recess to remove the top n+GaAs layer, 1 μm long Al gates were thermally evaporated and defined by a lift-off process. Finally, the devices were completed by the interconnection Au metal.

CHARACTERIZATION OF Al_{0.3}Ga_{0.7}As/In_{0.15}Ga_{0.85}As DOPED-CHANNEL STRUCTURES

Al_{0.3}Ga_{0.7}As/In_{0.15}Ga_{0.85}As doped-channel structures were first characterized by double crystal x-ray spectroscopy, and results are shown in Fig. 2. Since the pseudomorphic In_{0.15}Ga_{0.85}As doped channel is relatively thin (150Å), this strained layer signal is below the detector sensitivity. The average full width at half maximum (FWHM) is 19.6 arc-sec for these x-ray rocking curves, corresponding to ±10% variation, across a 3” GaAs epitaxial wafer. As to the electrical properties, we conducted Hall-effect measurements across this 3” epitaxial wafer at 300 and 77K. Ten samples along the [110] direction were tested, and the results at 300K are shown in Fig. 3. The average sheet charge density is 6.03 \times 10^{12} \text{cm}^{-2}, corresponding to an average mobility of 1570 cm²/V-s for this pseudomorphic doped-channel design. Although the carrier mobility in this doped-channel structure is low due to the impurity scattering, the carrier density is much higher than that of similarly designed HEMTs (approximately 2-3 \times 10^{12} \text{cm}^{-2}). Again, the variations for sheet charge density and Hall mobility are within only ±5 and ±10%, respectively. Figure 4 shows the Hall results for the same samples tested at 77K. The average sheet charge density remained the same, while the average mobility increased to 1805 cm²/V-s. The variations of sheet charge density and mobility in this case are only ±3 and ±7%, respectively. This high uniformity of Al_{0.3}Ga_{0.7}As/In_{0.15}Ga_{0.85}As doped-channel epitaxial layer achieved in a 3” GaAs wafer demonstrates that the layer is qualified for device and integrated circuit applications.

Finally, these ten samples were evaluated by low temperature photoluminescence (PL). Figure 5 illus-