AIP Applied Physics Letters

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Citation: Appl. Phys. Lett. **63**, 1214 (1993); doi: 10.1063/1.109775
View online: http://dx.doi.org/10.1063/1.109775
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v63/i9
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High electron mobility transistor based on a GaN-$Al_xGa_{1-x}N$ heterojunction

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(Received 22 March 1993; accepted for publication 30 June 1993)

In this letter we report the fabrication and dc characterization of a high electron mobility transistor (HEMT) based on a n-GaN-$Al_{0.14}Ga_{0.86}N$ heterojunction. The conduction in our low pressure metalorganic chemical vapor deposited heterostructure is dominated by two-dimensional electron gas at the heterostructure interface. HEMT devices were fabricated on ion-implant isolated mesas using Ti/Au for the source drain ohmic and TiW for the gate Schottky. For a device with a 4 μm gate length (10 μm channel opening, i.e., source-drain separation), a transconductance of 28 mS/mm at 300 K and 46 mS/mm at 77 K was obtained at +0.5 V gate bias. Complete pinchoff was observed for a −6 V gate bias.

$Al_xGa_{1-x}N$ with its tunable (from 3.4 eV at $x=0$ to 6.2 eV at $x=1$) wide band gap is ideally suited for devices in the visible and ultraviolet parts of the spectrum. Its wide band gap, the highly insulating nature of AlN,[1] and the potential of heterojunction fabrication[2] make it a good choice for high temperature high performance electronics circuits.[3] Recently several groups[4,5] including ours[6] have demonstrated metalorganic chemical vapor deposition of high quality single crystal GaN films over sapphire substrates. We have also reported the fabrication and characterization of a metal field-effect-transistor based on such high quality n-GaN films.[7] Interfacial conduction due to high mobility two-dimensional (2D) electron gas has also been demonstrated[8] in GaN-$Al_xGa_{1-x}N$ heterojunctions. We now report the fabrication and dc characterization of high electron mobility transistors (HEMTs) based on these heterojunctions.

The epilayer structure for our HEMT device is shown in Fig. 1. It consists of a 0.6-μm-thick n-GaN channel with a 1000-Å-thick cap layer of n-type $Al_{0.14}Ga_{0.86}N$. The structure was deposited over a basal plane sapphire substrate using low pressure metalorganic chemical vapor deposition with triethylgallium, triethylaluminum, and ammonia as the precursors. The details of the substrate cleaning and the growth procedure are similar to those described in a previous report.[6] After deposition, the heterostructure was characterized for its thickness and the cap layer alloy composition using surface reflectivity and photoluminescence (PL). A pulsed excimer laser was used for the PL measurements. The sheet carrier density and the electron mobilities were then measured at 300 and 77 K using the Hall–Van der Pauw technique. These measured values are listed in Table I. Also included in Table I are the measured electron carrier densities and mobilities for a single 0.6-μm-thick GaN and a 1000-Å-thick $Al_{0.14}Ga_{0.86}N$ layer.

As before,[8] based on quantum Hall and Shubnikov de Hass measurements, we assign the high electron mobility values in GaN-$Al_{0.14}Ga_{0.86}N$ heterostructure to interfacial 2D electron gas conduction.

Figure 2 shows the plan and cross-sectional view of one of our HEMT devices. It was fabricated on 100×200 μm mesa that was electrically isolated using proton implants. We measured the mesa to mesa resistance to be around 1 MΩ and hence well in excess of our channel resistance. For device fabrication we used standard lift-off procedures. Ti/Au (25 Å/1500 Å) was used as the ohmic metallization for source and drain contacts. These were subsequently annealed at 250 °C for 1 min in flowing forming gas. The gate was formed using TiW as the contact metal.

For the device in Fig. 2, Fig. 3 shows the drain-source current (I_{DS}) as a function of the drain-source voltage (V_{DS}) for values of gate-source voltage (V_{GS}) ranging from +0.5 to −2 V at 300 K. For this device the gate length and width were, respectively, 4 and 50 μm. The channel opening (source-drain distance) was 10 μm. As seen from Fig. 3, for a 50-μm-long gate, we measured a saturated drain current of 2 mA for a 0 V gate bias. Using the saturated drain current value at a gate bias of +0.5 V we estimate the transconductance of our device to be 28 mS/mm (gate length 4 μm in a 10 μm channel opening).

Figure 4 shows the source-drain characteristic curves (for varying gate voltages) at 77 K for the same device

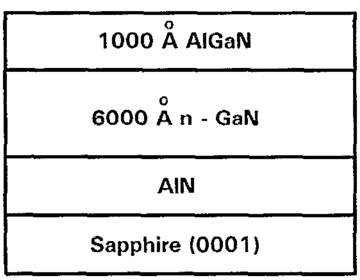

FIG. 1. Epilayer structure for the $Al_xGa_{1-x}N$/GaN based HEMT.

TABLE I. Sheet carrier densities and mobilities for a HEMT structure, a 0.6 μm GaN layer and a 0.1 μm $Al_{0.14}Ga_{0.86}N$ layer at 300 and 77 K.

Structure	Sheet carrier density (cm^{-2}) 300 K	Sheet carrier density (cm^{-2}) 77 K	Carrier mobility ($cm^2 V^{-1} s^{-1}$) 300 K	Carrier mobility ($cm^2 V^{-1} s^{-1}$) 77 K
GaN/$Al_{0.14}Ga_{0.86}N$	1.15×10^{13}	7.6×10^{12}	563	1517
GaN (0.6 μm)	1.5×10^{13}	4.3×10^{12}	75	56
$Al_{0.14}Ga_{0.86}N$ (0.1 μm)	1.2×10^{14}	1.05×10^{14}	59	56

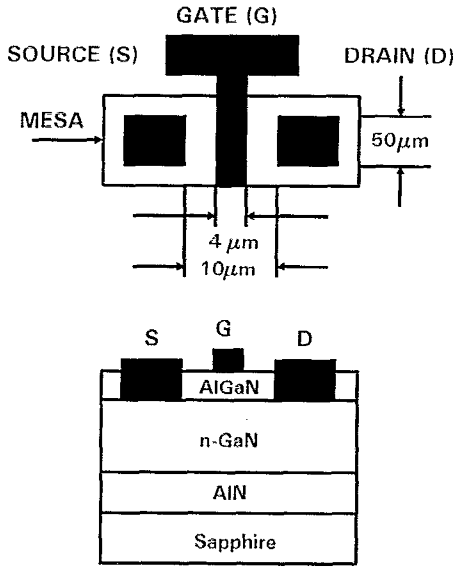

FIG. 2. Plan and cross-sectional view of fabricated HEMT.

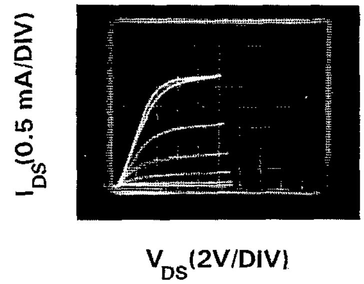

FIG. 4. Characteristic *I-V* curves for HEMT device showing I_{DS} as a function of V_{DS} for V_{GS} ranging from 0.5 to -2 V at 77 K. Drain current, 0.5 mA/div; drain voltage, 2 V/div; gate voltage, 0.5 V/step.

shown in Fig. 2. As before the 77 K transductance is estimated to be 46 mS/mm. From Table I we estimate a value of 1.78 for the ratio of the sheet carrier density of mobility product (conductance) at 77 and 300 K. This is in good agreement with the measured transconductance ratios (1.64) for our HEMT device.

In summary we describe the fabrication and dc characterization of a high electron mobility transistor based on a GaN-$Al_{0.14}Ga_{0.86}N$ heterojunction. Room-temperature transconductance of 28 mS/mm was measured for a device with a 10 μm channel opening and a gate length and width of 4 and 50 μm, respectively (gate voltage +0.5 V). This increases to a value of 46 mS/mm at 77 K. We found a good agreement with the 77 and 300 K transconductance ratio with the values estimated from Hall sheet carrier density and mobility values. To the best of our knowledge this is the first report of a HEMT device based on the wide band-gap $Al_xGa_{1-x}N$ material system.

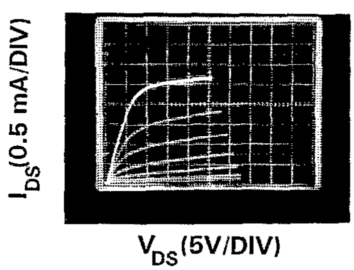

FIG. 3. Characteristic *I-V* curves for HEMT device showing I_{DS} as a function of V_{DS} for V_{GS} ranging from 0.5 to -2 V at 300 K. Drain current, 0.5 mA/div; drain voltage, 5 V/div; gate voltage, 0.5 V/step.

We would like to thank Roger Gifford and Robert Torreano for their material deposition and characterization efforts. This work was partially supported by Navy Contract N00014-92-C-0090 and was monitored by Max Yoder of the Office of Naval Research.

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