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A RAPID JUSTIFICATION OF HEMT DEVICE STRUCTURES BASED ON A THREE-PROBE CONTACT TECHNIQUE

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Abstract Various characteristics of the pHEMT structures have been investigated using a three-probe contact technique. This measurement is considerably new as from the epitaxial layer (sample) prior to the actual device completion; the justification of current-voltage characteristics of transistor device could be done. This justification could lead to reducing time-and cost when poor sample is found. Among the three different samples of pHEMTs of AlGaAs / InGaAs, the current-voltage characterization has shown that the structure with a larger channel thickness (26 nm) shows greater saturation current and breakdown voltage.

Introduction

The characterizations of electronic device performance prior to any device processing could lead to a rapid, simple and less time-consuming process in evaluating the device structure of MOSFET (Gallon *et al.*, 2005). This kind of technique is suitable for an *in situ* characterization of device structure. A pseudo-MOS technique has been used to rapidly determine SOI wafer quality (Cristoloveanue *et al.*, 2000; Liu *et al.*). For HEMT (High Electron Mobility Transistor) device, this characterization could be very useful and has received a great deal of attention due to its potential to be used in various telecommunication areas such for commercial and militaries (Hwang *et al.*, 1999; Bouzaïene *et al.*, 1999; Nguyen and Micovic, 2001). This is due to many superior characteristics exhibited by HEMTs devices such as relatively high speed, low noise, and high gain. Many works have been carried out to study HEMT structure prior to fabrication such as the use of a Surface Photovoltage Spectroscopy technique (Pollak, 2001; Solodky *et al.*, 2003). Use of two probes in the electronic devices measurement have been done on devices such for MOSFETs, as this was done on source and drain contacts by probing mechanically onto the surface of devices structures (Munteanu *et al.*, 1999). In this paper we report a new measurement technique using three probes onto the surface of HEMT structure of $Al_xGa_{1-x}As$ / $In_xGa_{1-x}As$/ GaAs. The results obtained are useful to show the performance of pHEMT device in the early stage and this measurement technique can also be used for other electronic devices.

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Material and Methods

A standard process to test device performance is usually done after completing all processes, such as epitaxy layer preparation until fabrication process involving major of lithography work, mesa-etch, source-drain metallization, and gate formation. These processes are considerably time consuming and costly when the device performance is finally found to be poor due to the poor quality of sample (epitaxy layer). As such, a rapid justification technique for sample justification based on a three-probe method is schematized shown in Fig. 1. Fig. 2 shows a conventional measurement set up of a three-probe method. Three commercialized probes of 2 μm radius have been used. S, G, D denoted for source, gate and drain contacts during measurement. The contact area for tip probe contact onto the surface of sample is oval shaped (Fig. 3). The minor radius of the area in gate contact is to mimic the gate length, meanwhile the shortest distance between source-gate and also gate-drain are identical to the distance for related contacts in HEMT device. Placement the probe on the surface of sample was carried out under a microscope to obtain more accurate scale placement.

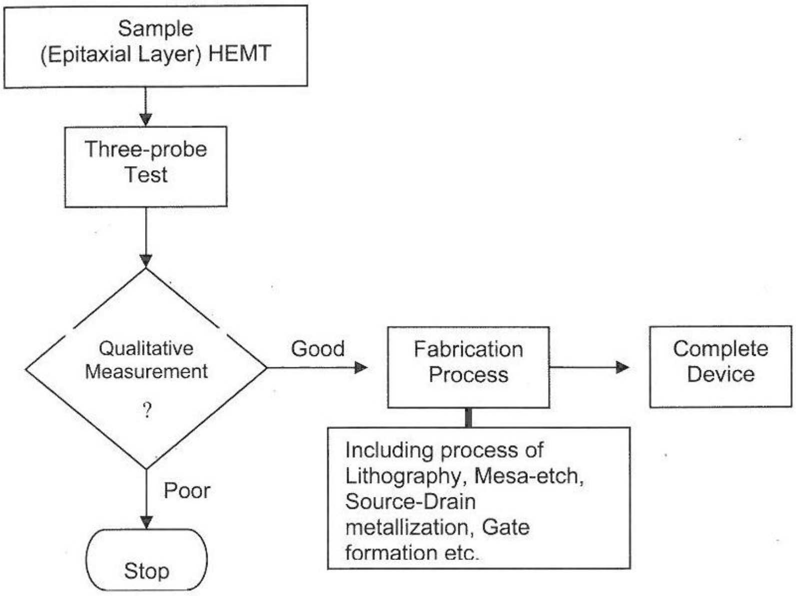

Figure 1. Diagram of major process of a device justification based on a probes technique

For HEMT structures, variations of channel layers of InGaAs have been used. For this, Epitaxial layer of pHEMT structures were grown using an MBE machine for the following order from the top layer. A cap layer was prepared using GaAs material with a heavy doping of silicon of concentration of 3 x 10^{18} cm^{-3} with a layer thickness of 30 nm. Meanwhile, the supply layer was grown of AlGaAs alloy with a concentration of 10^{17} cm^{-3} with a layer thickness of 70 nm. Spacer layer of AlGaAs was prepared for a layer thickness of 6 nm. Channel layer of InGaAs alloy was grown for various thicknesses of 8, 12, and 26 nm attributed as Sample 1, Sample 2, and Sample 3, respectively. Super lattice was prepared for 10 periods of alternate layer of GaAs and AlGaAs for thicknesses of 3.0 nm and 2.5 nm, respectively. Buffer and substrate layers were of semi-insulating GaAs.

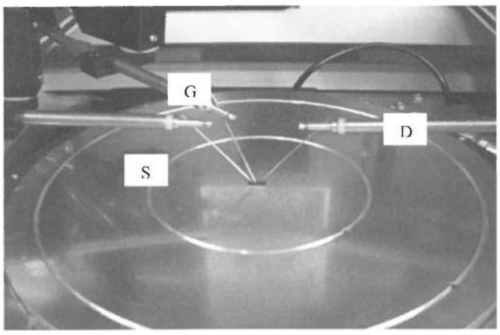

Figure 2. A conventional set up of a three-probe method

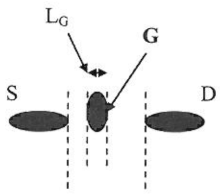

Figure 3. A schematized diagram of contact areas performed by tip of probes onto the surface of HEMT structure

Results and Discussion

From the measurement carried out using a four-point probe technique for HEMT structure, it was found that increasing Al content in AlGaAs layer of supply and spacer lead to decrease of sheet resistance (Fig. 4). Measurement was also done on the cap layer only (no HEMT structure) for a comparison. Sheet resistance of cap sample was found to be greater than the HEMT structure. From this result, it could be deduced that the current will flow to penetrate into the structure when voltage biased through the probes on the cap layer of heavy doping. This phenomenon was supported by a simulation result done using Taurus Medici software (Fig. 5). As indicated in the figure, current is observed to flow from source to drain through the cap layer and also through the channel (Hariyadi *et al.*, 2005). The possibility of current flow through probes and then penetrating into the deeper layers in the HEMT structure is considered to occur as the probes were mechanically contacted onto the surface of cap layer. Annealing process was not done to the structure, so Schottky contact was considered for current flow instead of the standard ohmic contact when annealing treatment was done after metallization for a real contact device. This phenomenon also indicates that electron mobility in the structure is also contributed by the supply and spacer layer except by the channel layer (Soetedjo *et al.*, 2005).

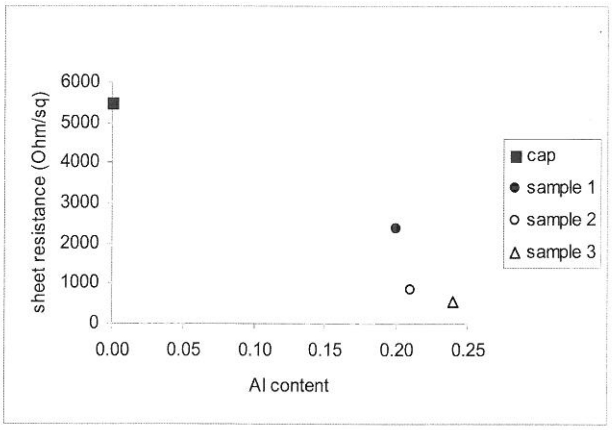

Figure 4. Sheet resistance respects to variation of Al contents

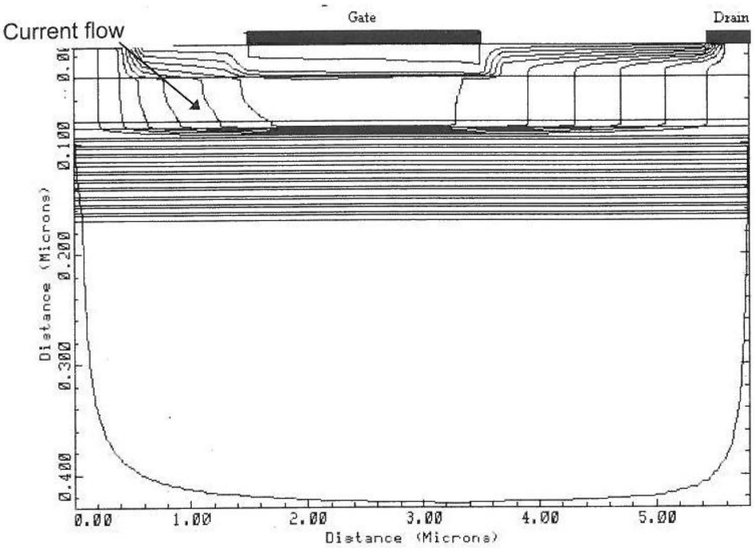

Figure 5. Current flow through the contacts prepared on the cap layer of pHEMT structure as obtained from the simulation

From the current-voltage characterization done to the HEMT structure using a three-probe technique, a characteristic was obtained (Fig. 6). As shown in Fig. 6, increasing gate voltage (V_{GS}) results in a larger offset current when drain-source voltage, V_{DS} = 0 Volt. This phenomenon is associated with the semiconductor properties of cap layer which introduced leakage current and allow the current to flow from source to drain when no bias of gate voltage. By normalizing the curves, namely by considering no current flow when V_{DS} = 0 Volt (as this occurred for an ideal transistor), curves were adjusted by suppressing the current until I_{DS} is zero when no gate voltage biased. This will yield the normalized curves as shown in Fig. 7.

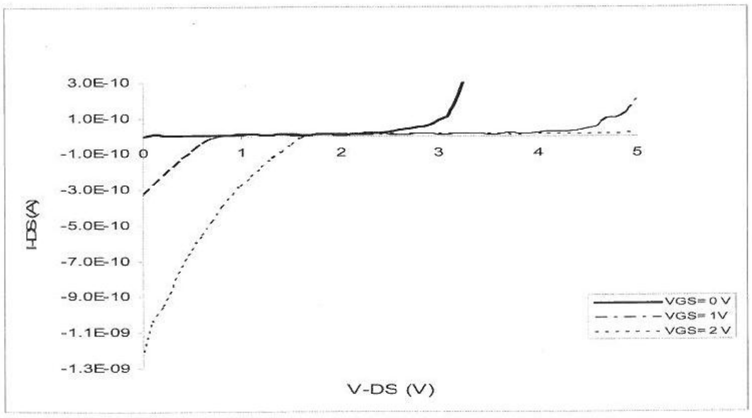

Figure 6. Current-voltage characteristic obtained from the measurement

For a variation of pHEMT structure (Sample 1, 2, and 3), the current-voltage characteristics obtained from the measurement for V_{GS} = 1 V are shown in Fig. 8. Here, the saturation current for sample 2 is found to be higher (500 pA) than the others. The breakdown voltage was also found to be larger by about 4.2 Volts. This low current flow is considered due to the effect of semiconductor properties of cap layer instead of ohmic current from source to drain contacts for the actual device. This variation in current-voltage characteristics is an interesting point as a small variation in the Al content in the structure will cause changes in the device performance. For further work as a qualitative measurement to justify the quality of sample, it is important to compare the characteristic of transistor when real contacts (source, gate and drain) are prepared and the characteristic are obtained from a three-probe technique. The magnitude order of parameter such as current I_{DS} could then be extracted for the magnificent factor. This qualitative measurement is important as it indicates the device performance before proceeding onto further work on completion of device fabrication.

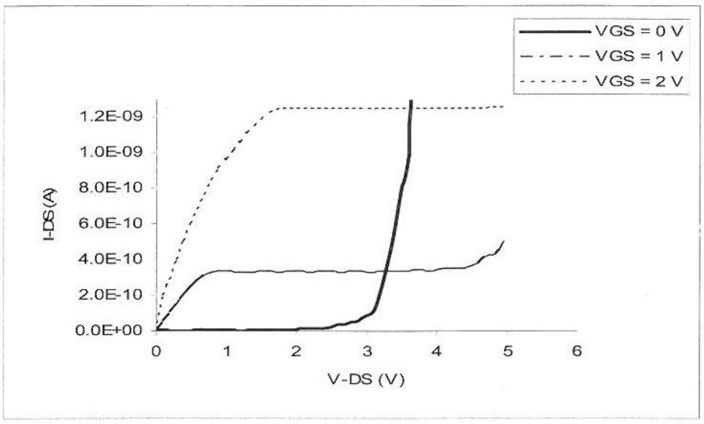

Figure 7. A HEMT samples characteristic obtained from the measurement for variation of V_G

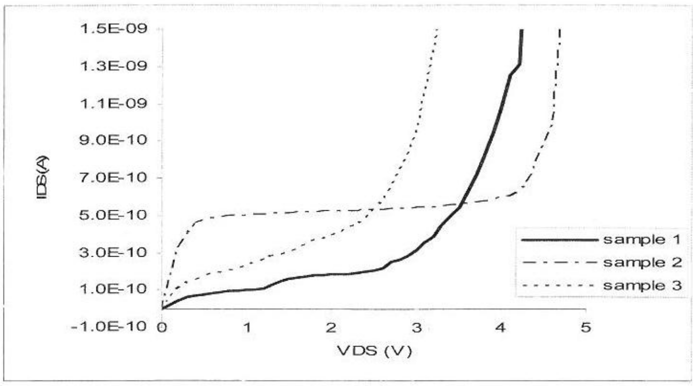

Figure 8. Current-voltage characteristic of different structures of pHEMT for V_{GS} = 1 V

Conclusion

By referring to the experimental results mentioned above, the measurement technique of three-probe contact has shown encouraging results as an early measurement for sample justification prior to the complete device fabrication. The current offset during the measurement is believed to be due to the property of high doping cap layer material. Nevertheless, various structures of pHEMT were observed to vary with their device performances. The technique is considerably rapid, simple and economical for a qualitative justification of HEMT structures prior to the complete preparation of device.

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