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MBE Grown Undoped Superlattice Gate and Modulation-Doped Buffer Structure for Power FET Applications

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A new power FET with a hybrid (MESFET and MD) operation mechanism has been fabricated successfully. The insertion of a modulation-doped (MD) structure between the AlGaAs buffer and GaAs active layer gives high output current and high transconductance. By reducing the gate length to 1 μm, transconductance of up to 340 mS/mm can be expected. Furthermore, the use of an undoped AlGaAs/GaAs superlattice "gate insulator" provides low leakage current and much higher gate breakdown voltage (>30 V). From the experimental results, it is obvious that the proposed structure is suitable for high power applications.

KEYWORDS: superlattice, modulation-doped (MD), gate insulator, hybrid mechanism, MISFET, HEMT

For device appiications to high-power systems, there are several basic requirements, such as high-current handling capability with large transconductance, high-breakdown voltage, good current linearity, and high-cutoff frequency. There are many new gate structures which have been reported to improve the gate breakdown voltage, such as an insulator-gate FET,[1] an IGFET with an oxide layer,[2] and MIS-type GaAs FET with AlGaAs as a "gate insulator".[3,4] The reported devices showed better performance both in high output power and a larger linear saturation current. In our new device, a new MIS structure, an undoped GaAs/$Al_{0.3}Ga_{0.7}As$ superlattice (SL) structure, is first proposed as a "gate insulator". Due to its very low carrier concentration within the "gate insulator", we expect that the low reverse leakage current can be obtained and the advantage of the reported devices can be maintained simultaneously. Furthermore, the modulation-doped (MD) structure is inserted between the active channel and undoped AlGaAs buffer layer. Owing to the additional carrier density and higher electron mobility from the MD structure, a higher transconductance and output power capability can be obtained. The operation mechanism of the studied device is actually composed of MESFET (MISFET) and MD modes.

The studied device was grown by MBE on a (100) oriented Cr-doped GaAs substrate. The details of the substrate preparation have been described elsewhere.[5,6] The substrate temperature was maintained at 610°C to make a uniform doped profile. Figure 1 shows the device structure. First, a 0.5 μm undoped $Al_{0.4}Ga_{0.6}As$ buffer layer was directly grown. Then, an n^+-$Al_{0.4}Ga_{0.6}As$/i-$Al_{0.4}Ga_{0.6}As$/i-GaAs MD structure was incorporated between the AlGaAs buffer layer and the GaAs active channel layer. For the MD structure, the n^+ $Al_{0.4}Ga_{0.6}As$ layer was 150 Å with a carrier concentration of 1×10^{18} cm^{-3}. The thicknesses of the undoped $Al_{0.4}Ga_{0.6}As$ spacer and GaAs layers were 50 Å and 100 Å, respectively. The active channel layer was 0.15 μm with a carrier concentration of 2×10^{17} cm^{-3}. The "gate insulator" layer was formed by 4-period undoped 75 Å-GaAs/175 Å-$Al_{0.3}Ga_{0.7}As$ superlattice layers. Au–Ge was employed as the ohmic contact metal and then sintered for 45 s at 450°C. Al was applied as the Schottky barrier gate on the top of the superlattice "gate insulator". No recessed process was needed.

The studied device presents a very high gate breakdown voltage (>30 V) due to the existence of the undoped superlattice "gate insulator". Figure 2 shows the gate current-voltage characteristics. A conventional AlGaAs buffer MESFET was also employed for comparison. The structure of the AlGaAs buffer MESFET, as shown in the inset of Fig. 2, includes a 0.5 μm undoped $Al_{0.4}Ga_{0.6}As$ buffer layer and a 0.15 μm GaAs ac-

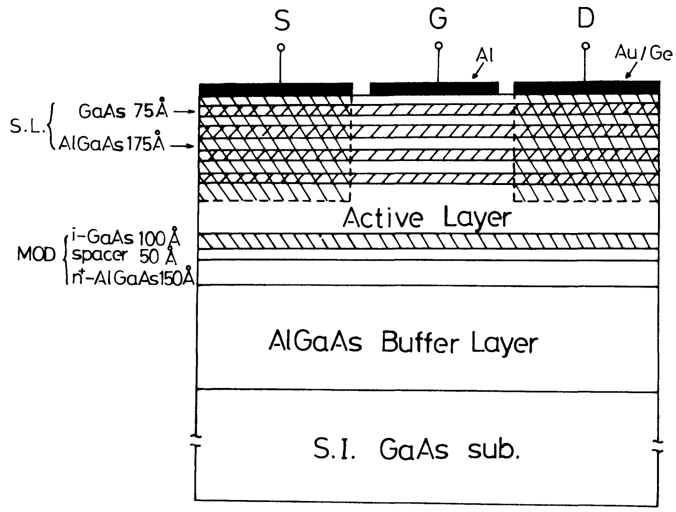

Fig. 1. The structure of the undoped GaAs–$Al_{0.3}Ga_{0.7}As$ superlattice "gate insulator" and modulation-doped buffer FET.

tive channel with a carrier concentration of 2×10^{17} cm^{-3}. Apparently, the undoped superlattice "gate insulator" exhibits a much lower reverse leakage current. Typical DC *I-V* characteristics are depicted in Fig. 3. As expected, the output-saturated curves are very flat owing to the existence of a larger band gap of undoped AlGaAs buffer which confines carriers in the active layer. Furthermore, the studied device presents a higher output current drivability than the AlGaAs buffer MESFET. This is contributed by the additional high mobility electrons supplied from the MD buffer. The electron mobility and sheet carrier density, obtained by Hall measurement, of the studied device are 5500 cm^2/v·s and 3.9×10^{12} cm^{-2}, respectively, which are higher than those of the AlGaAs buffer MESFET (3700 cm^2/v·s, 2.9×10^{12} cm^{-2}). Consequently, the output performance of the studied device is thought to be combined by MESFET and MD operation modes which results in a higher carrier density and output current drivability. From the DC *I-V* characteristics, as shown in Fig. 3(b), the output current can be divided into two distinct regions. The output current based on each carrier density probably corresponds to the current flow (MESFET) from $V_{GS}=0$ V to $V_{GS}=-1$ V, and the other one (MD) from $V_{GS}<-1.0$ V. Even though the substrate temperature is not so high (610°C), it presents good pinch-off characteristics.[7] Since there is no recessed gate treatment, all devices fabricated on the same wafer have uniform current drivability as well as the same threshold voltage.

Figure 4 depicts transconductance as a function of the gate bias. The triangular symbols represent the conven-

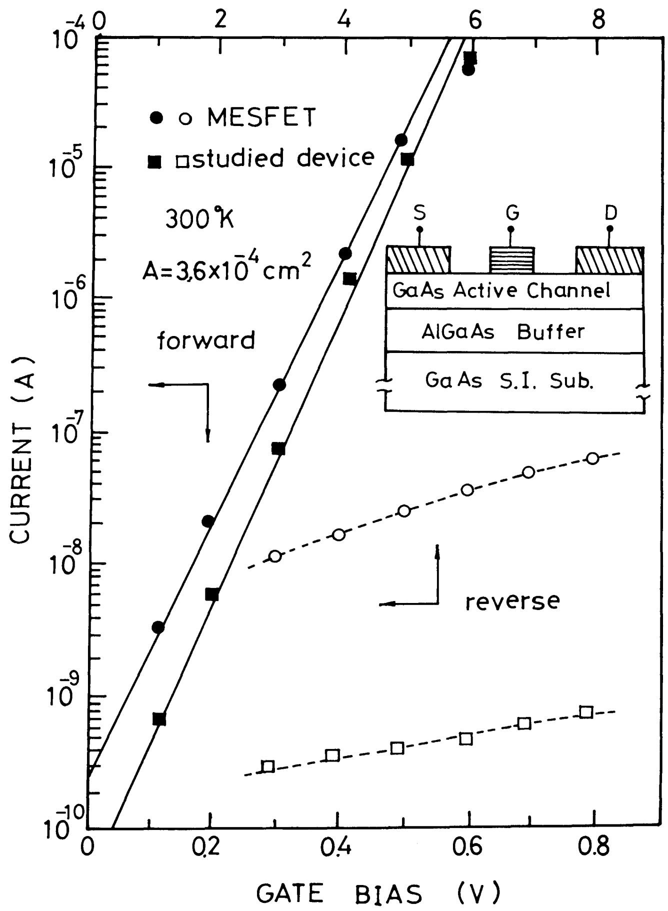

Fig. 2. The gate current-voltage characteristics of the studied device and AlGaAs buffer MESFET. The structure of an AlGaAs buffer MESFET, as a comparison, is also shown in the inset.

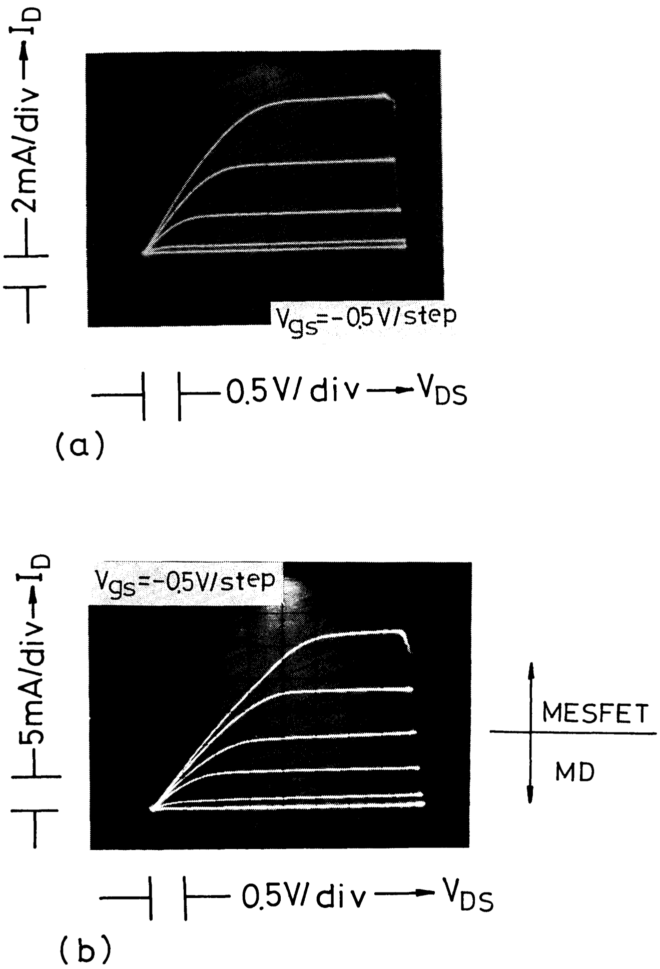

Fig. 3. The typical output DC current-voltage characteristics of (a) AlGaAs buffer MESFET, (b) studied device.

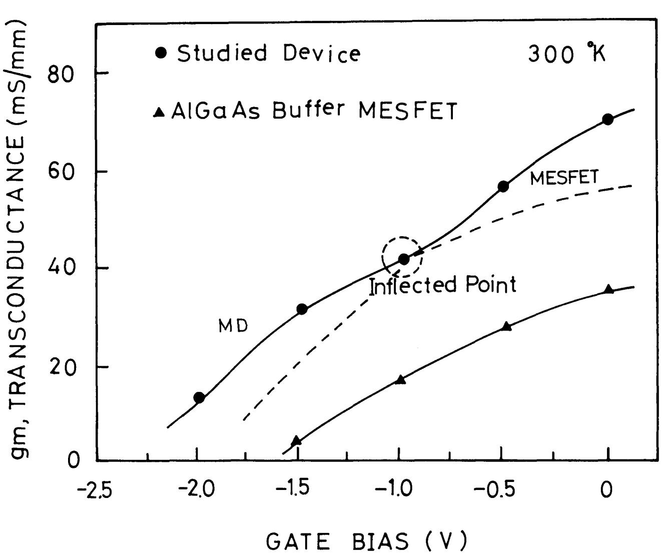

Fig. 4. Transconductance as a function of gate bias for the studied device and AlGaAs buffer MESFET. An inflected point about $V_{GS}=-1.0$ V is also indicated.

tional AlGaAs buffer MESFET. Both devices possess the same gate dimension ($5\times 250\,\mu m^2$). Obviously, the improved device exhibits higher transconductance. Furthermore, the variation trend of the studied device is different, as shown by the dashed line and solid line, within the whole range. From $V_{GS}=0$ V to -1.0 V, the MESFET operation mode is dominant, whereas another mechanism (MD) plays a more effective role for $V_{GS}<-1.0$ V. An inflected point, at about -1.0 V, used to distinguish the hybrid operation mode is also indicated in Fig. 4. Due to the limitation of the gate dimension, the maximum transconductance is about 68 mS/mm. If the gate length is reduced to 1 μm, a higher transconductance of about 340 mS/mm can be expected.

In the past year, the modulation-doped structure has been widely used to fabricate high mobility, high speed transistors (HEMT). In our studied device, the MD structure was adopted to improve the output current drivability. The use of the undoped GaAs/$Al_{0.3}Ga_{0.7}As$ superlattice "gate insulator" provides lower leakage current and much higher gate breakdown voltage. Therefore, a new power FET with MESFET and MD hybrid operation mechanisms has been fabricated successfully using the GaAs/AlGaAs superlattice "gate insulator" and MD buffer structure.

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