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A p-Channel Double Heterojunction GaAs/AlGaAs Modulation Doped Field Effect Transistor

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Abstract A p-channel modulation doped field effect transistor(MODFET) with double heterojunctions grown by molecular beam epitaxy has been successfully fabricated. With this structure, the two dimensional hole gas (2DHG) density is enhanced by a factor of 2-3. ($1.9\text{-}2.7\times10^{12}/cm^2$ at 77°K) compared to a single heterojunction p-MODFET. This leads to a sheet resistance as low as $\approx 1k\Omega/\square$ at 77°K. This result is approximately a half that of single heterojunction p-MODFETs. The transistor showed good pinch-off characteristics at room temperature as well as at 77°K. The gate leakage current has also been improved.

P-channel modulation doped field effect transistors (p-MODFETs) have received considerable attention recently because of their potential application in complementary MODFET circuits.[1-3] The major drawback of complementary MODFET circuits is their relatively slow switching speed due to the low current capability of the p-channel MODFET,which is attributed to the low hole mobility even at cryogenic temperatures. In order to improve the sheet resistance,there are two approaches: one is to improve the hole mobility with new materials such as InGaAs, the other way is to increase the carrier concentration without degrading the mobility. The former approach has thus far not achieved a high enough 2D hole gas concentration due to the lower density of states in InGaAs.[4]

We report the fabrication of p-channel MODFETs with enhanced carrier concentration using double heterojunction GaAs/AlGaAs. The p-type modulation doped double heterostructures were grown by MBE on undoped, (100)-oriented LEC semi-insulating GaAs substrates. The double heterojunction structure consists of the following layers: 5000Å of undoped GaAs, 2000Å of undoped $Al_{.4}Ga_{.6}As$, 250Å of 1.7×10^{18} cm^{-3}Be doped p-$Al_{.4}Ga_{.6}As$, 75Å of undoped $Al_{.4}Ga_{.6}As$, 100Å-400Å of undoped GaAs,75Å of undoped $Al_{.4}Ga_{.6}As$, 500Å of 1.7×10^{18} cm^{-3} Be doped p-AlGaAs and 50Å of 2×10^{18} Be doped p-GaAs. The quantum well thickness have been chosen to range between 100Å and 400Å because wider well thickness leads to the formation of two separate layers ,which may result in a FET with an undesirable non-linear I-V characteristics.

The mobility of the structure measured by van der Pauw method was 3200 cm^2/Vsec at 77°K with a carrier concentration of $\approx 2\times10^{12}$ cm^{-2}. The single heterostructure with the same doping and thickness in the top (AlGa)As layer had a mobility of 3650 cm^2/Vsec with a carrier concentration of $\approx 1\times10^{12}$ cm^{-2}. Those values were almost constant over the well thickness range of 200Å-400Å and the mobility decreases as the quantum well thickness shrinks down to 100Å. The mobility drop in narrow quantum wells may be a result of enhanced Coulomb scattering from the confinement layers since the tails of the wave functions increase in the higher band-gap material (AlGa)As layers under these conditions. The incresed carrier concentrations are far more than enough to cancel the mobility degradation to yield about half of the sheet resistance compared with single heterojunction case. The sheet resistance values are fairly constant over the quantum well range of our experiment. The well thickness of 300Å was chosen for the p-MODFET device fabrication discussed in the next paragragh. This thickness was chosen to be a compromise for (a) minimizing the distance between gate and channel to keep high g_m and (b) for maximizing the thickness to maximize the hole mobility.

P-channel double heterostructure MODFETs have been fabricated with a conventional GaAsFET process: mesa etch for device isolation, SiO_2 deposition (used as a spacer layer when ohmic and gate metal lift-off are done), ohmic metal (Au 300Å/AuZn 200Å) evaporation and lift-off, ohmic contact alloy at 450°C for 30 seconds, 300Å gate recess with H_3PO_4 : H_2O_2: H_2O, gate metal (Ti/Au) evaporation and lift-off. The devices had good pinch-off characteristics even at room temperature. The I_g-V_g characteristics show that higher gate voltages can be applied to the double heterostructure MODFETs without causing severe gate leakage current. This result implies that the double heterostructure approach reduces the gate leakage problem which is inherent to all kind of AlGaAs/GaAs heterojunction FETs. Both of the I_d-V_d and I_d-V_g curves show that the maximum current has been doubled using the double heterostructure. Although transconductances appear not so impressive (7.8mS/mm at 300°K,19mS/mm at 77°K measured at drain voltage of 1.0 volt) because of the long gate length (gate length=2μm, source-drain distance = 6μm) and the measurement condition(V_{ds}=1v), it is clear that the current capability and the transconductance g_m have been doubled by employing the double heterojunction in making p-MODFET. An optimized short channel double heterostructure p-MODFET will lead to complementary circuit with switching speed increased by a factor of two. It will also be useful to achieve source and drain of a FET with lower resistivity sheet resistance compared to ion implanted self aligned structure. This work was supported by Semiconductor Research Corporation under contract No.SRC-84-02-047.

References

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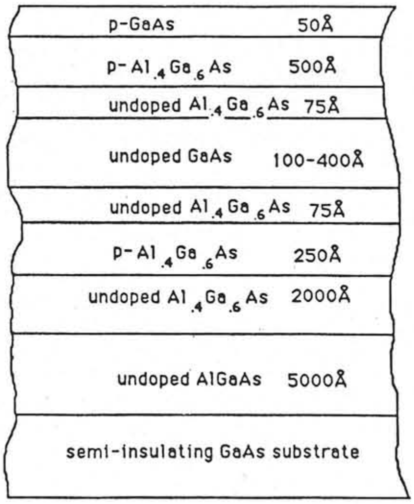

Figure 1 Double-Heterostructure p-MODFET

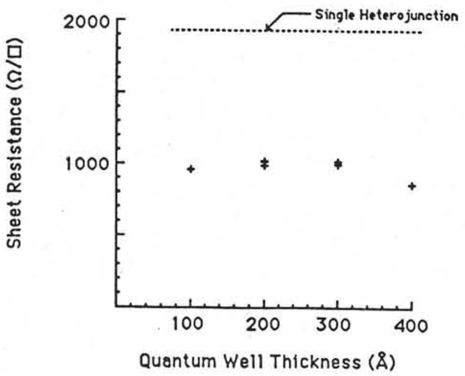

Figure 2. Sheet resistance of double heterojunction p-type modulation doped structure (77°K)

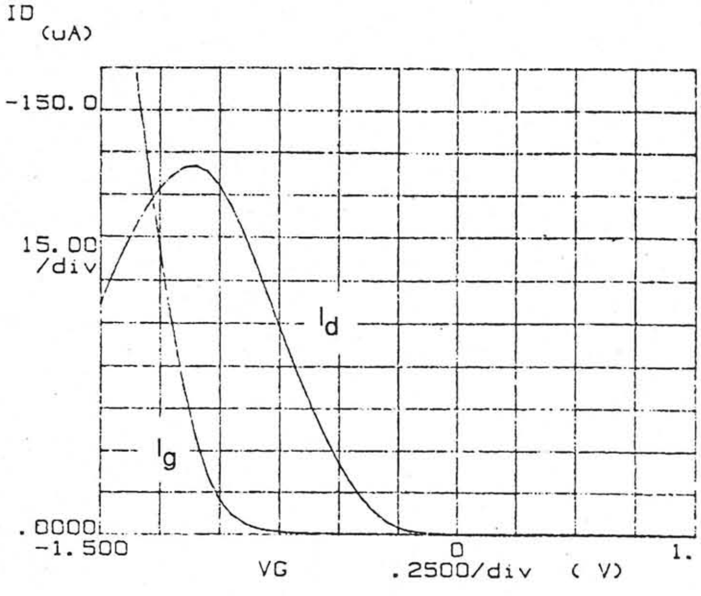

Fig.3 I_d-V_g and I_g-V_g characteristics of a single heterostructure MODFET (300°K)

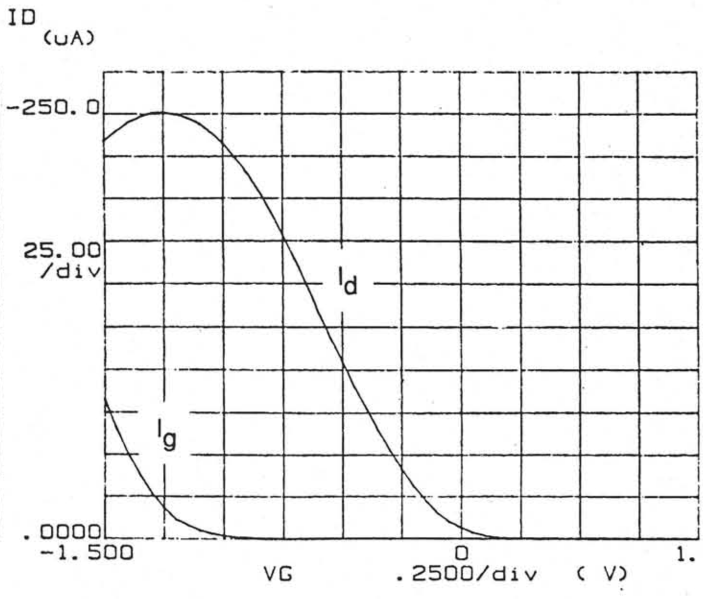

Fig.4 I_d-V_g and I_g-V_g characteristics of a double heterostructure MODFET (300°K)