AlSb/InAs/InAsP/AlSb Composite-Channel HFETs

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The AlSb/InAs/AlSb quantum well system is attractive for the realization of high-speed low-power HFETs because of its excellent transport properties. However, a drawback of the technology is the low breakdown voltage. The resulting high leakage and kink currents severely degrade the device performance and the application in circuits [1]. One possible solution is the use of composite channels, which has been demonstrated in the InGaAs/InP system [2]. In this study we report the first demonstration of HFETs with InAs/InAsP composite channels alleviating breakdown phenomena and improving the device performance in comparison to single-channel AlSb/InAs/AlSb HFETs.

The materials were grown by solid-source MBE. Significant materials development was performed to optimize the transport properties in both InAs channel and strained InAsP subchannel. As the Hall data in Fig. 1 and 2 show, the mobilities in InAs channels exceeded 20,000 cm^2/V-s for Phosphorous compositions, $x_{p,}$ ranging from 0% to 40%, and a maximum mobility of 7,000 cm^2/V-s was obtained in the $InAs_{0.8}P_{0.2}$ subchannel for the optimal growth temperature of 430 °C. These results promise excellent low-field transport properties in composite channels. The energy band diagram and carrier distribution for the composite-channel layer structure with x_p=20% in subchannel are shown in Fig.3. Another key design feature is the two delta-doping sheets. They are needed to control both the carrier concentration in the channel and the transfer of the carriers between the InAs and the InAsP layers. In the device layer structure the mobility was 14,500 cm^2/V-s and the sheet concentration 1.74x10^{12} cm^{-2} as determined by Hall measurements

Devices were fabricated in a conventional mesa-isolated HFET process using optical lithography. In Figures 4, 5 and 6 the data of an InAs/InAsP composite-channel device are compared to the data of an InAs single-channel device made in our laboratory. From the source-drain characteristics shown in Figure 4, it is evident that breakdown phenomena are suppressed in the composite-channel device: In contrast to the InAs single-channel device, the drain current in the composite-channel device saturates and kink effect is greatly reduced. As shown in Figure 5, the single-channel channel device exhibits a peak in I_g, the gate leakage current, at V_{ds}=0.6 V for $-0.5V<V_{gs}<-0.1V$. This feature, commonly observed in such devices, is attributed to the holes generated by impact ionization in the channel. The composite-channel device shows no such peak in I_g. This is the evidence of reduced impact ionization. The gate bias dependence of the transconductance is shown in Figures 6. For a 0.7 µm gate length device, we observe a peak transconductance of 840 mS/mm, which is similar to the single-channel device. Another composite-channel device with 0.5 µm gate length presents a higher peak transconductance of 950 mS/mm. S-parameter measurements was performed between 5 GHz and 40 GHz on a composite-channel device with a 0.7 µm long gate. From these data we extrapolate maximum current and power gain cut-off frequencies of 46 GHz and 61 GHz respectively. While the product of gate length and cut-off frequency in the composite-channel devices ($f_t \cdot L_g$=32.4 GHz-µm) is below that of the InAs-channel devices ($f_t \cdot L_g$=44 GHz-µm), the device performance is nevertheless encouraging given that the results represent the early phase of device development.

In conclusion, novel AlSb/InAs/InAsP/AlSb composite-channel HFETs were designed and experimentally demonstrated for the first time. Compared to conventional AlSb/InAs/AlSb devices, the composite-channel devices clearly show improved DC performance. In particular the kink effect has been reduced, the breakdown voltage increased and we observe no evidence of impact ionization in the gate leakage current.

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[1] C. R. Bolognesi *et al.*, IEEE Trans. on Electron Devices, Vol. 46, No. 5, 1999.
[2] G. Meneghesso *et al.*, IEEE Trans. on Electron Devices, Vol. 46, No. 1, 1999.

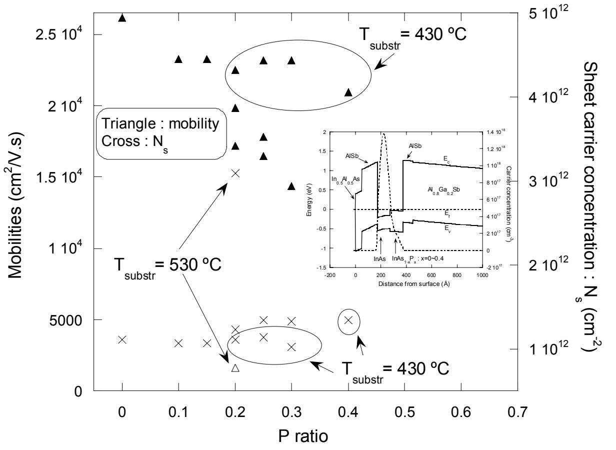

Fig. 1. Measured R-T mobilities and concentrations for different phosphorous ratios in InAsP subchannel. Un-specified data points are for the samples with subchannels grown at 480 °C. The inset shows the relative energy band structure and carrier profile.

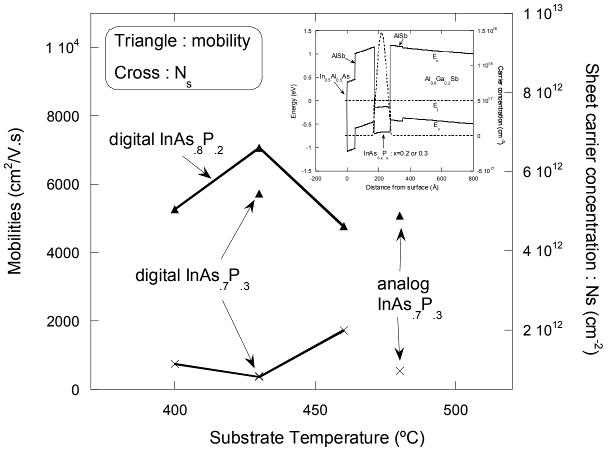

Fig. 2 Measured R-T mobilities and concentrations for InAsP 2-DEG structures grown at different substrate temperatures. The inset shows the relative energy band structure and carrier profile.

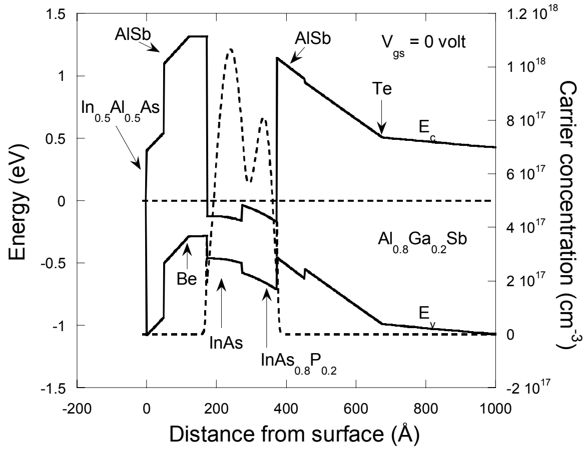

Fig. 3. Energy band diagram and concentration profile of a composite-channel HFET.

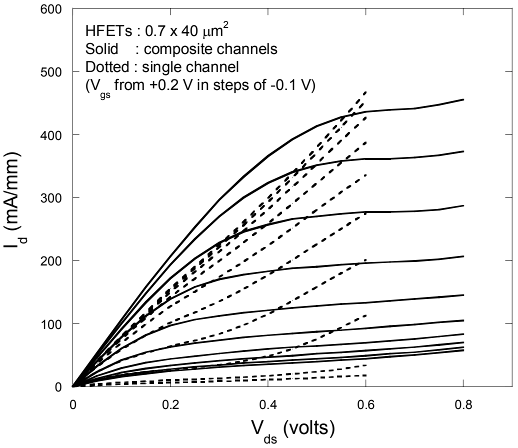

Fig. 4. Current-voltage output characteristics.

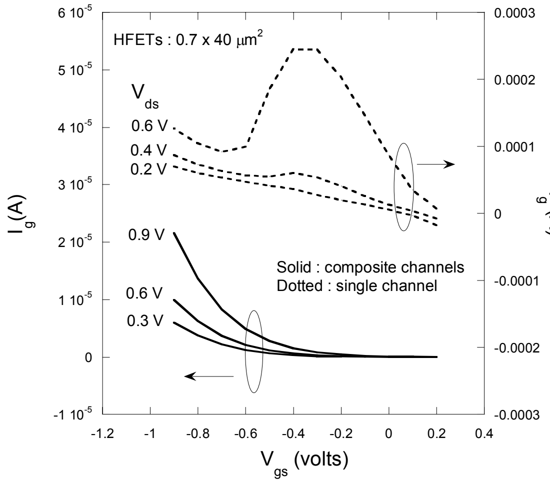

Fig. 5. Gate leakage current as a function of gate . voltage.

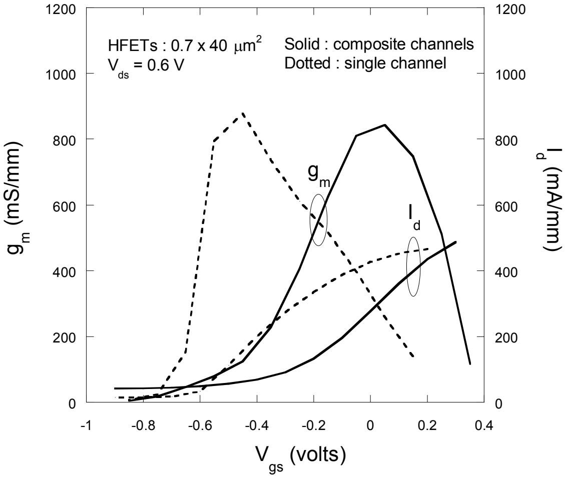

Fig. 6 Drain current and DC transconductance as a function of gate voltage.