Low-voltage, high-speed AlSb/InAsSb HEMTs

J.B. Boos, M.J. Yang, B.R. Bennett, D. Park, W. Kruppa and R. Bass

Antimonide-based HEMTs have heen fabricated with an InAsSb channel. Infra-red photoluminescence measurements at 5K confirm that the addition of Sb changes the band structure from a staggered type II heterojunction lineup to a type I. These HEMTs with 0.1μm gate length exhibit decreased output conductance and improved voltage gain. At V_{DS} = 0.6V, a microwave transconductance of 700mS/mm and an output conductance of 110mS/mm were obtained corresponding to a voltage gain of 6.

Low-voltage, low-power-consumption electronics will be critical in future high-speed analogue and digital applications that require light-weight power supplies, long battery lifetimes, improved efficiency, or high component density. AlSb/InAs-based HEMTs are potential candidates for these applications due to the high mobility, velocity, and sheet charge density that can be obtained in this material system [1]. The combination of high peak electron velocity (4×10^7cm/s) at low electric field and high channel conductivity enable operation at very low drain voltages. The addition of Sb to the InAs channel may improve the low-voltage, high-speed performance due to the higher mobility and velocity which potentially can be achieved. An additional attractive feature is that the addition of Sb changes the band structure from a staggered type-II heterojunction lineup to a type I. The existence of hole barriers on both sides of the quantum well, not present in the type II lineup, enables the confinement of holes which are generated thermally or as a result of impact ionisation in the channel. As a result, the holes can be more effectively drained to the source contact rather than having them move into the AlSb buffer layer where they are likely to cause deleterious trapping effects or be collected at the gate contact and thereby increase the gate leakage current. In this Letter, we report the fabrication and characteristics of antimonide-based HEMTS with an InAsSb channel.

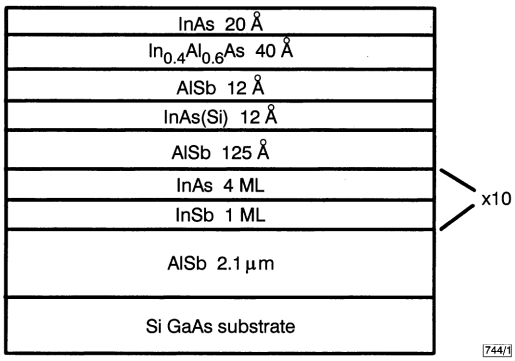

Fig. 1 *HEMT starting material*

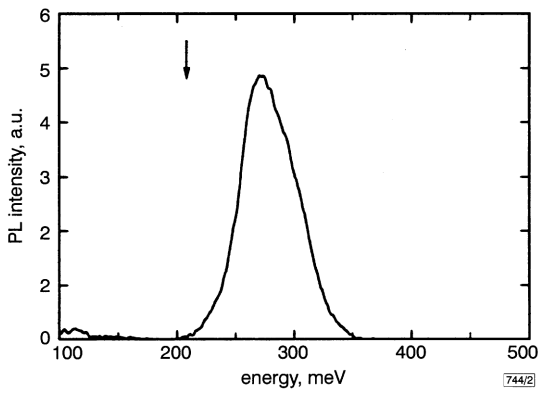

Fig. 2 *Infra-red photoluminescence spectrum from 150Å AlSb/ $InAs_{0.8}Sb_{0.2}$ single quantum well*

Arrow indicates bandgap energy for thick $InAs_{0.8}Sb_{0.2}$; T = 5K, 810nm excitation, 10W/cm²

The AlSb/$InAs_{0.8}Sb_{0.2}$ HEMT material was grown by solid-source MBE on a semi-insulating (100) GaAs substrate. A cross-section of the material layer design is shown in Fig. 1. The $InAs_{0.8}Sb_{0.2}$ channel material was grown at 400°C as a digital alloy superlattice with 10 periods of 4 ML InAs/1 ML InSb [2]. Modulation doping was achieved through the use of a thin Si-doped InAs layer located 125Å above the channel [3]. The sheet carrier density and mobility of the starting material at 300K were 1.4×10^{12}cm^{-2} and 13,400cm²/Vs, respectively. The HEMTs were fabricated using Pd/Pt/Au source and drain ohmic contacts which were formed by heat treatment on a hot plate. A Cr/Au Schottky-gate was then formed using PMMA e-beam lithography and lift-off techniques. Finally, device isolation was achieved by wet chemical etching. With this etch, a gate air bridge was formed which extends from the channel to the gate bonding pad.

To confirm the type I alignment between AlSb and $InAs_{0.8}Sb_{0.2}$, we carried out photoluminescence (PL) measurements at 5K with a Fourier transform infra-red spectrometer. Samples were mounted on a cryogenic dewar and excited with an 810nm laser diode. The room-temperature blackbody radiation was eliminated by a double-modulation technique [4]. Fig. 2 shows the PL spectrum from the $InAs_{0.8}Sb_{0.2}$ single quantum well. In contrast to the nonluminous AlSb/InAs single quantum wells, this sample exhibits bright luminescence at 272meV. The arrow in Fig. 2 indicates the measured bandgap energy for a thick $InAs_{0.8}Sb_{0.2}$ digital superlattice. Our results imply that the lowest sub-band energy for a 150Å $InAs_{0.8}Sb_{0.2}$ quantum well is 62meV, consistent with $k{\cdot}p$ calculations.

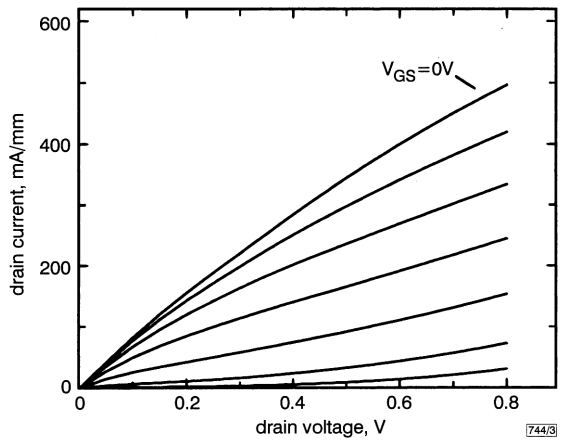

Fig. 3 *HEMT drain characteristics*

L_G = 0.1μm, L_{DS} = 1.2μm, W_G = 100μm, V_{GS} = 0.1V/step

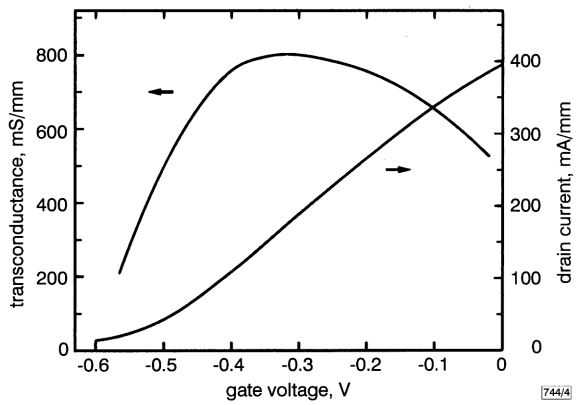

Fig. 4 *HEMT transconductance and drain current against gate voltage*

V_{DS} = 0.6V

The drain characteristics obtained for an HEMT with a 0.1μm gate length are shown in Fig. 3. The low-field source-drain resistance at V_{GS} = 0V is 1.2Ω mm. The dependence of the transconductance and drain current on the gate voltage at V_{DS} = 0.6V is shown in Fig. 4. A maximum transconductance of 800mS/mm is observed at V_{GS} = –0.3V. The S-parameters of the HEMTs were measured on-wafer from 1 to 40GHz. Based on the usual 6dB/octave extrapolation, an

f_T of 130GHz and an f_{MAX} of 80GHz were obtained at V_{DS} = 0.6V and V_{GS} = –0.4V. Using a simplified equivalent circuit, the microwave transconductance and output conductance for a 100μm gate width device are 700 and 110mS/mm, respectively, corresponding to a voltage gain of 6 at this bias condition. After subtraction of the gate bonding pad capacitance, an f_T of 180GHz is obtained. The highest f_{MAX} observed was 120GHz which was measured on a device with a 50μm gate width that had an output conductance of 50mS/mm and a voltage gain of 9. The output conductance and voltage gain are the best values reported for a 0.1μm antimonide-based HEMT. The improvement is believed to be caused by the confinement of holes in the channel as a result of the type I band lineup and the lower Δ-L valley energy separation which results in more saturation of the drain current. Improved high-speed performance should be possible with the addition of subchannel designs [3] which enable improved charge control and reduced impact ionisation.

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