0.1μm AlSb/InAs HEMTs with InAs subchannel

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

AlSb/InAs HEMTs with a 0.1μm gate length have been fabricated with a thin InAs subchannel separated from the InAs channel by 30Å of AlSb. As a result, these HEMTs exhibit improved charge control and a higher current-gain cutoff frequency. The devices have a microwave transconductance of 850mS/mm and an f_T of 180GHz at V_{DS} = 0.6V. After subtracting the gate bonding pad capacitance, an f_T of 250GHz was obtained.

AlSb/InAs HEMTs are candidates for high-speed and low-bias voltage applications due to the attractive features of this material system, which include high electron mobility and velocity, high sheet charge density and good carrier confinement. These features should enable improved scaling of the current-gain cutoff frequency as the gate length is reduced to the nanometre range [1]. The HEMTs, however, are susceptible to charge control problems associated with impact ionisation in the InAs channel. These effects become increasingly pronounced as the gate length is reduced due to the higher fields present, thus hindering the performance of short-gate length HEMTs. The large 1.35eV conduction band offset of the AlSb/InAs heterojunction offers unique opportunities to reduce impact ionisation effects by using channel layer designs that exploit quantum confinement in this region. In this Letter, we report the DC and microwave characteristics of 0.1μm AlSb/InAs HEMTs which exhibit improved charge control due to the addition of a thin InAs subchannel.

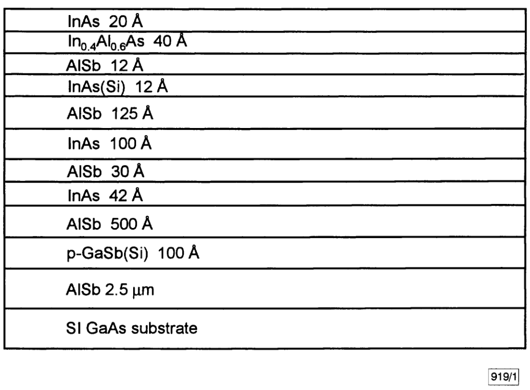

Fig. 1 *HEMT starting material*

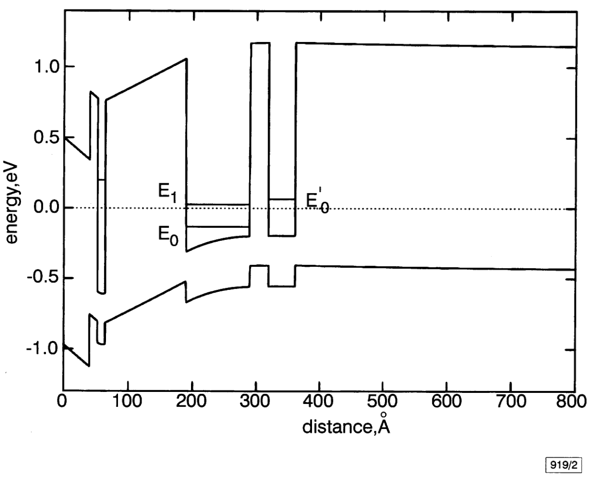

Fig. 2 *Calculated band structure*

The AlSb/InAs HEMT material was grown by molecular beam epitaxy on a semi-insulating (100) GaAs substrate. A 2.5μm undoped AlSb buffer layer was used to accommodate the 7% lattice mismatch. A cross-section of the device, showing the material layer design, is shown in Fig. 1. The energy band diagram for V_{GS} = 0 obtained from a self-consistent calculation is shown in Fig. 2, where the Poisson equation, the 2D density of states, and the non-parabolicity in the InAs quantum wells have been taken into account [2]. Modulation doping was achieved through the use of a thin Si-doped InAs layer located 125Å above the 100Å undoped InAs channel [3]. The large confinement energy of the 12Å InAs quantum well allows the electrons to transfer into the InAs main channel. Modulation doping using a thin Si-doped InAs layer located below the channel has previously been used to fabricate AlSb/InAs inverted HEMTs [4]. The $In_{0.4}Al_{0.6}As$/AlSb composite barrier enables the use of a gate recess etched into the upper barrier material prior to gate metal definition, which otherwise would be prohibited by the high reactivity of the AlSb in air. A 100Å Si-doped GaSb layer ($p \simeq 3\times10^{17}cm^{-3}$) located 500Å below the InAs subchannel is intended to drain a portion of the impact-ionisation-generated holes back to the source contact rather then allowing them to remain in the AlSb buffer layer and cause deleterious trapping effects [5]. The room temperature Hall mobility and sheet carrier concentration of the starting material for the HEMTs reported here were 20000cm^2/Vs and $1.9\times10^{12}cm^{-2}$, respectively.

To reduce impact ionisation effects in the device, we introduced a thin InAs undoped subchannel layer which, due to quantisation, has a larger effective bandgap. The 42Å subchannel layer is separated from the 100Å InAs channel by 30Å of AlSb. This approach is conceptually similar to the InGaAs/InP composite-channel design used in InP-based HEMTs [6], where electrons are transferred to a larger-bandgap subchannel before gaining enough kinetic energy for impact ionisation. The thickness of the subchannel was chosen so that not only its lowest subband (E'_0) lies slightly above the second subband (E_1) of the main InAs channel at V_{GS} = 0V, but also $E'_0 - E_0$ is smaller than the effective bandgap of the main channel. When the device is under an increasing negative gate bias, the separation between E_1 and E'_0 is reduced. As E_1 and E'_0 are aligned, the possibility for electrons resonantly tunnelling into the subchannel through E_1 is strongly enhanced. Electrons can also undergo real space transfer to the subchannel by incoherent tunnelling. As a result, the extent of impact ionisation in the channel is reduced.

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-based 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.

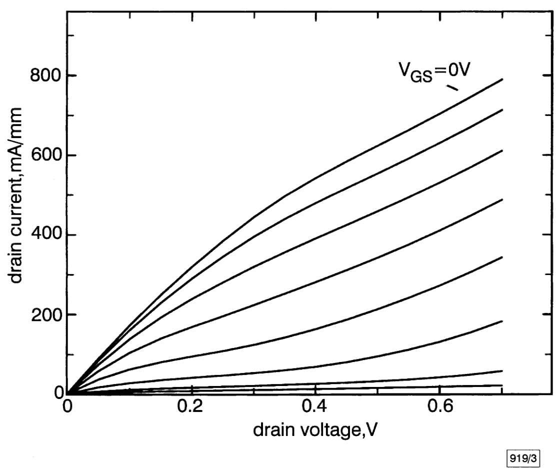

Fig. 3 *HEMT drain characteristics*

L_G = 0.1μm, L_{SD} = 1.0μm, W_G = 26μm, V_{GS} = 0.1V/step

A typical set of drain characteristics for HEMTs with a 0.1μm gate length is shown in Fig. 3. The low-field source-drain resistance at V_{GS} = 0V is 0.55 Ωmm. At V_{DS} = 0.5V, a transconductance above 800mS/mm is observed from V_{GS} = –0.1 to –0.5V, with a maximum value of 1.3S/mm occurring at V_{GS} = –0.35V. When compared to similar devices without the subchannel, these devices exhibited lower output conductance, particularly at more negative gate biases.

The S-parameters of the HEMTs were measured on-wafer from 1 to 40GHz. Based on the usual 6dB/octave extrapolation, an f_T and f_{MAX} of 180 and 80GHz, respectively, at V_{DS} = 0.6 and V_{GS} = –0.4V were obtained. Using a simplified equivalent circuit, the microwave transconductance and output conductance for a 100μm gate width device were 850 and 200mS/mm, respectively, corresponding to a microwave voltage gain of 4.2 at this bias condition. Compared to previous 0.1μm devices of similar design [7], the devices exhibit a higher transconductance and a lower gate-source capacitance which is believed to be primarily due to the improved charge control as a result of the addition of the InAs subchannel. After removal of the gate bonding pad capacitance from the equivalent circuit, an f_T of 250GHz was obtained, which is the highest reported for this material system. Optimisation of the subchannel layer design is needed to fully exploit the reduction of impact ionisation in the channel using this approach.

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