6.2 Å InAsSb High Electron Mobility Transistors for High-Speed and Low Power Consumption

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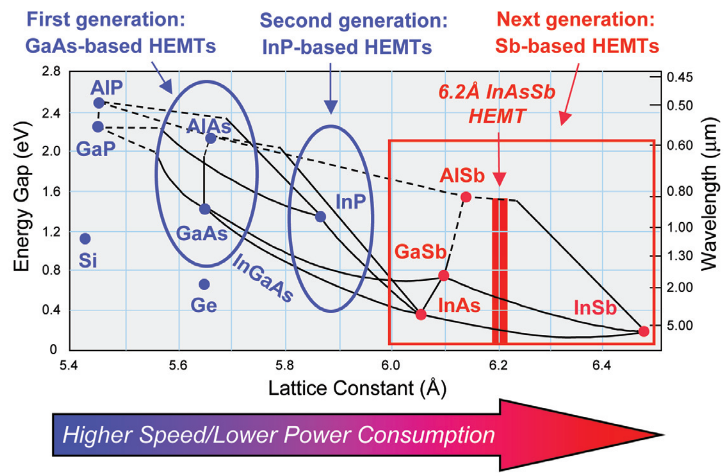
Introduction: An extensive effort has been made within both the military and commercial sectors to reduce the power consumed by millimeter- and microwave solid-state amplifiers. Low power consumption is essential in applications that require lightweight power supplies and long battery lifetimes. With the increased reliance on small platforms such as autonomous sensors, unmanned-air-vehicles, satellites and man-portable systems, the need for reduced operating power is becoming especially important to the DoD. NRL has long been recognized as a world leader in the material growth and fabrication of high electron mobility transistors (HEMTs) in the AlSb/InAs material system.[1] The HEMT, which is an advanced version of the common field-effect transistor, uses band-gap engineered layer designs with feature sizes on the atomic scale to precisely control the material properties within the structure. When compared to InP or GaAs-based HEMTs (Fig. 7), the high performance of the AlSb/InAs HEMTs arises from the superior electronic properties of this material structure grown by molecular beam epitaxy (MBE) with a lattice constant of 6.1 Å. When combined with nanoscale patterning using electron-beam lithography, these HEMTs constitute the state of the art in high-frequency performance at low operating voltage. Recently, the NRL AlSb/InAs HEMT material growth and fabrication technology was transitioned to Northrop-Grumman Space Technology through a Cooperative Research and Development Agreement (CRADA). This resulted in the demonstration of the first X-band and W-band monolithic microwave integrated circuits in this material system.[2,3]

In pursuit of electronic devices that can operate at even higher speed and lower bias voltage, the Electronics Science and Technology Division is developing HEMT technology using MBE-grown InAlSb/InAsSb layers with a lattice constant of 6.2 Å. In addition to a higher electron velocity in the channel, the incorporation of Sb in the channel layer also results in a more desirable band alignment, which acts to confine the holes to the channel. This reduces the gate leakage current, which is a problem with present AlSb/InAs HEMTs. Another positive feature is that InAlSb is stable in air, unlike pure AlSb, which is prone to oxidation. This stability simplifies the fabrication process and makes the devices more amenable to commercial manufacturing. InAsSb-channel HEMTs using novel, high-quality 6.2 Å MBE-grown material have been successfully fabricated for the first time and have exhibited state-of-the-art low voltage performance.

HEMT Design: The HEMTs use a uniform alloy of $InAs_{0.7}Sb_{0.3}$ as the channel layer and adjacent $In_{0.2}Al_{0.8}Sb$ barrier layers, all with a lattice constant of 6.2 Å. This heterostructure results in the formation of a high-mobility two-dimensional electron gas (2DEG) in the undoped InAsSb channel. Figure 8 shows a cross section of the layer design. This device structure is grown on semi-insulating GaAs substrates with an intermediate 1.5-μm thick AlSb buffer layer, which is necessary to relax the strain due to lattice mismatch. The center 50 Å of the top InAlSb barrier was doped n-type with Te to a level of approximately 10^{19} cm^{-3} to provide the donor carriers (electrons) for the 2DEG in the channel. This allows the electrons in the channel to travel faster in the 2DEG since they are not impeded by the ionized impurity scattering that would otherwise occur if the InAsSb channel were doped. The final layers consist of 40 Å $In_{0.4}Al_{0.6}As$ and a 20 Å InAs cap layer to facilitate low ohmic contact resistance. The $In_{0.4}Al_{0.6}As/In_{0.2}Al_{0.8}Sb$ composite design enhances the insulating property of the barrier and enables the use of a gate recess etch into the upper barrier material prior to gate metal definition. The sheet carrier density and mobility of the starting material were 1.8×10^{12} cm^{-2} and 18,000 cm^2/V-s, respectively. For mixed-anion MBE growth, the anion incorporation into the channel layer is not a linear function of group V flux and relies on several different growth variables such as temperature and growth rate. We arrived at 420 °C for the growth temperature of our channel layer by growing a series of samples and comparing mobility as a function of growth temperature.

DC and Microwave Characterization: The HEMTs were fabricated using alloyed Pd/Pt/Au source-drain ohmic contacts and a TiW/Au gate metalization that was defined using advanced electron-beam lithography. Figure 9 shows a typical set of drain characteristics for HEMTs with a 0.2 μm gate length and a 1 μm source-drain spacing. The drain current I_{DS} is plotted vs the drain voltage V_{DS} with the gate voltage V_{GS} as an additional parameter that controls the drain current. The gate pinchoff voltage is –0.5 V.



Sb-based materials have highest electron mobilities and velocities, lowest bandgaps, and reach electron peak velocity at lowest electric fields.

FIGURE 7
Energy gap vs lattice constant chart showing high-speed, low-power semiconductor trend in HEMT technologies.

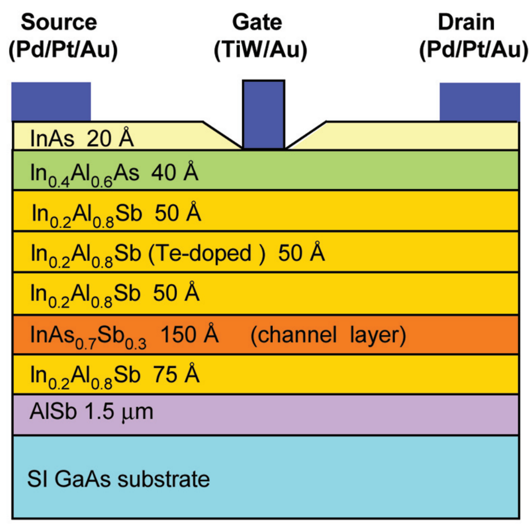


FIGURE 8
Cross section of the 6.2 Å InAlSb/InAsSb HEMT layer design.

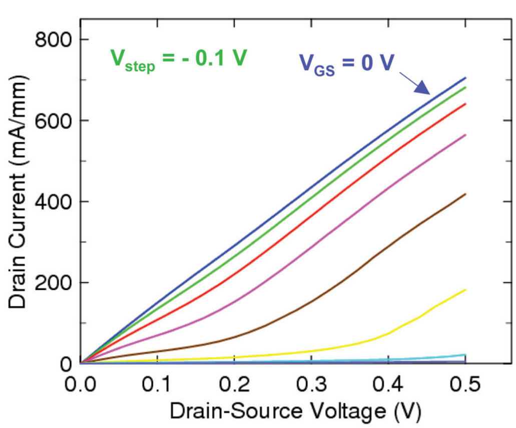


FIGURE 9
Drain characteristics for a HEMT device with L_G = 0.2 µm, L_{DS} = 1.0 µm, W_G = 27 µm, V_{GS} = 0.1 V/step.

At a drain voltage of only 300 mV, a transconductance ($g_m = \Delta I_{DS}/\Delta V_{GS}$) above 800 mS/mm is observed from V_{GS} = –0.25 to –0.5 V, with a maximum value of 1.3 S/mm occurring at V_{GS} = –0.35 V. The transconductance at this drain voltage is the highest observed for any HEMT reported in the literature. The microwave S-parameters of the HEMTs were measured on-wafer from 1 to 40 GHz and yielded a unity power gain cutoff frequency of 80 GHz at a drain voltage of 0.6 V. The extremely high frequency capability and low consumed power of these devices makes them a leading candidate technology for the next generation of high-speed, low-power electronics.

[Sponsored by ONR and DARPA]

References

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