InP-HEMTs for Ultrahigh-Frequency Power Devices

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InP High Electron Mobility Transistors (HEMTs) exhibit the highest speed characteristics of any kind of transistor. Indeed, a cutoff frequency of over 400 GHz and a maximum frequency of oscillation of over 600 GHz have been reported so far. These high-frequency characteristics arise from the outstanding electronic properties of this material system such as the high electron mobility of InGaAs and the large sheet carrier concentration produced by the InAlAs/InGaAs quantum well system. The small bandgap of InGaAs, however, leads to a large impact ionization rate at relatively low drain voltages that is regarded as a cause of low breakdown voltage of InP HEMTs. Generally speaking, there is a trade off between breakdown voltage and speed performance because the former decreases while the latter improves as the gate length is shrunk. Mitigating this trade off is a key issue in the design of ultrahigh-speed InP-HEMT circuits particularly for high-power applications.

Although the physical mechanism behind breakdown are still under investigation, simulations tell us that the accumulation of impact-ionized holes in the body of the device plays an important role. Since the device is surrounded by the n-type ohmic contacts and the semi-insulating buffer, holes cannot be easily extracted from the body of the device. This results in an accumulation of holes under the gate that shifts the threshold voltage of the device. Similar effects are observed in Silicon-On-Insulator (SOI) MOSFETs, in which inserting a body contact is found to be an effective way to enhance the breakdown voltage.

The InP material system usually involves arsenides (InAs, GaAs, and AlAs) but occasionally contains phosphides (InP, GaP, and AlP) for some specialized purposes. Another group of materials, antimonides (InSb, GaSb, and AlSb), on the other hand, has unique properties from the viewpoint of band engineering. Alloys of antimonides, such as GaAsSb and AlAsSb lattice matched to InP, have relatively high valence band energy so that they make type II heterojunctions with InGaAs. The type II heterojunction enables us to produce a quantum well for holes separately from that of electrons and in this way provide a path to extract the holes similar to the body contact of SOI MOSFETs.

An approach that we are considering is shown in Figure 19. The GaAsSb layer underneath the InGaAs channel acts as a hole path as shown in the band profile in Figure 20. The additional contact to the GaAsSb layer, which is an extension of the source electrode in Figure 19, prevents the impact-ionized holes from accumulating in the body of the intrinsic device. This should result in a markedly improved breakdown voltage with minimum cost to the high frequency performance of the device.

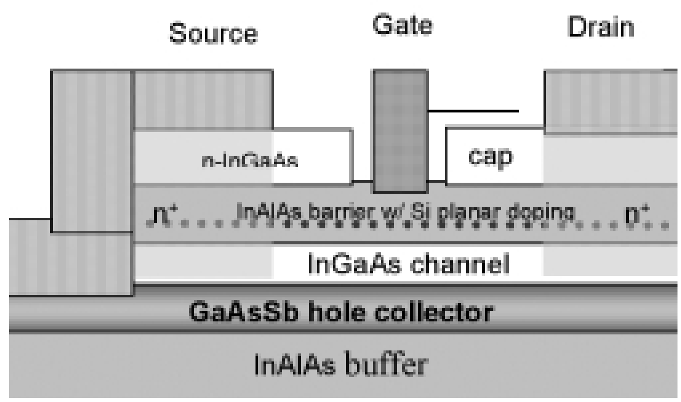

Fig. 19: Cross sectional view of InP-HEMT with hole collector.

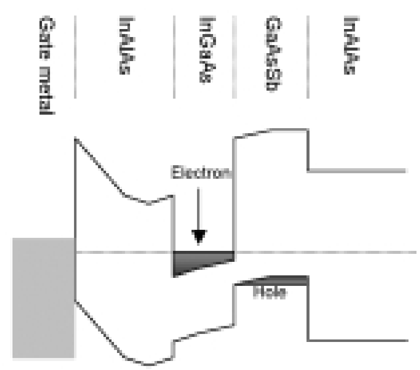

Fig. 20: Band profile of heterostructure under gate