Semiconductor Technology from A to Z

Compound Semiconductors

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HEMT and HBT for RF Applications

The HEMT Principle for High-Frequency Applications

The High Electron Mobility Transistor (HEMT) uses a heterostructure of two semiconductors with different band gaps, typically AlGaAs on GaAs or AlGaN on GaN, to create a two-dimensional electron gas (2DEG) at the interface. Because the electrons are spatially separated from the doped donor region and flow in an undoped channel, scattering at ionized impurities is largely avoided, and the electron mobility in the 2DEG at room temperature typically reaches 6000 to 9000 cm^2/Vs – far above the 400 to 600 cm^2/Vs of a comparable silicon MOSFET channel.

For high-frequency applications, GaAs is typically used in the form of a pseudomorphic HEMT (pHEMT) or a metamorphic HEMT (mHEMT) with an InGaAs channel, since InGaAs, with mobilities of 10,000 to 12,000 cm^2/Vs, offers even higher electron mobility than pure GaAs. Parameters such as the transit frequency f_T and the maximum oscillation frequency f_{max} of modern GaAs pHEMTs reach 100 to 150 GHz, while highly scaled InP HEMTs with gate lengths below 50 nm have demonstrated f_T values above 600 GHz in the laboratory, making these devices suitable for applications approaching the terahertz-adjacent millimeter-wave range.

The Heterojunction Bipolar Transistor (HBT)

The heterojunction bipolar transistor (HBT) applies the heterostructure principle to the bipolar transistor by using an emitter material with a wider band gap than the base, such as InGaP or AlGaAs on a GaAs base. The wider band gap of the emitter suppresses the back-injection of holes from the base into the emitter, which allows the base to be doped much more heavily than in a conventional bipolar transistor (typically 10^{19} to 10^{20} cm^{-3}) without sacrificing current gain, which for GaAs HBTs typically reaches values of 50 to 150.

The heavier base doping reduces base resistance and allows thinner base layers, often only 50 to 100 nm, which substantially improves carrier transit time and therefore cutoff frequency – commercial GaAs HBTs reach f_T and f_{max} values in the range of 150 to 300 GHz. HBTs are also known for a very linear transfer characteristic and low phase noise, which makes them particularly well suited to power amplifiers.

Applications in High-Frequency Electronics

GaAs-based HEMTs and HBTs have formed the backbone of power amplifiers (PAs) in mobile handsets for decades, delivering typical output powers of 0.5 to 2 W at supply voltages around 3.4 to 5 V with high efficiency and good linearity. Low-noise amplifiers (LNAs) in the receive path of satellite communication and radar systems, on the other hand, mostly rely on HEMTs, whose noise figures range from a few tenths of a dB to a few dB in the relevant frequency range and whose low parasitic capacitance and low intrinsic noise are the deciding factors.

Unlike GaN power HEMTs, which are optimized for high breakdown voltage and switching power, GaAs- and InP-based RF HEMTs target minimum noise and maximum cutoff frequency. However, GaN HEMT technology is also gaining ground in high-power base station and radar applications: GaN RF devices achieve output power densities of several W/mm of gate width there, enabling transmit powers from several tens to over a hundred watts in compact form factors, where GaAs devices would run into their thermal and breakdown-voltage limits.