The High-Electron Mobility Transistor at 30: impressive accomplishments and exciting prospects

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2010 marked the 30th anniversary of the High-Electron Mobility Transistor (HEMT). The HEMT was originally demonstrated by Mimura and colleagues from Fujitsu in 1980 in the AlGaAs/GaAs system. It represented a triumph of applied physics and material science. At the heart of the HEMT is the concept of modulation doping and its ability of producing ultra-high mobility two-dimensional electron systems. This was discovered by Dingle and collaborators at Bell Labs in 1978. Modulation doping and the HEMT were demonstrated thanks to, at the time, newly available revolutionary atomic layer precision growth capabilities of molecular-beam epitaxy. The two-dimensional nature of the electron gas in a modulation-doped structure can be exploited to make field-effect transistors in which electrons travel very fast and maintain excellent short-channel effects. This is the HEMT. Today, HEMTs based on the AlGaAs/InGaAs system (Pseudomorphic HEMTs), the InAlAs/InGaAs system and more recently, the AlGaN/GaN system have found wide spread use in a broad range of applications in communications, high speed signal processing, radar, consumer and defense systems. HEMTs today hold the world record for the lowest noise figure, the highest frequency response and the highest power handling ability at high frequencies of any solid state device.

High-mobility two-dimensional electron systems not only gave us the HEMT but have also became a playground for new physics. The greatest success was the discovery of the fractional quantum-Hall effect in an AlGaAs/GaAs 2DEG system which earned the Nobel Prize in Physics in 1989. Long-range coherence of electrons in the AlGaAs/GaAs 2DEG system at very low temperatures have also yielded spectacular manifestations of ballistic transport and electron interference. Electrostatic “carving” of the 2DEG by shaped gates allowed the formation of quantum wires and quantum dots and the demonstration of single-electron transistors.

As we look ahead, the future of the HEMT and modulation doped structures looks brighter than ever. The extraordinary power handling abilities of the GaN-HEMT system will lead to high-frequency power amplifiers that will start displacing vacuum devices in several terrestrial and space applications. In addition, new GaN HEMT switching power devices will enable the demonstration of power management systems with efficiencies superior to those achievable by Silicon technology. Si could well also be the victim of a future III-V CMOS technology based on InGaAs or InAs quantum-well FETs. If not HEMTs, these devices will exploit the extraordinary transport properties and outstanding short-channel effects that are achievable in highly-quantized 2DEG systems in III-Vs. HEMTs operating in the THz regime are just around the corner. A whole new range of devices are in the horizon: III-V HEMT-based Hall sensors for scanning Hall probe microscopy, THz detectors, and AlGaN/GaN MEMS structures for chemical and biological sensor applications, among others.

This talk will review the origin of the HEMT, its accomplishments in the last 30 years and its future prospects.