InGaAs-based devices for future terahertz and post-CMOS applications

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Integrated circuits based on InGaAs transistors are widely used in many RF devices for electronics, defense and space communication systems. Currently, InGaAs ICs are also being studied for new millimeter wave devices for collision avoidance and terahertz (THz) applications. Due to scaling limitations faced by Si CMOS, InGaAs-channel MOSFETs have emerged as a potential alternative. These new domains of research are generating new prospects for InGaAs FETs to be used for future THz and post- CMOS applications.

$In_xGa_{1-x}As$ is a ternary III-V semiconductor that can be regarded as an alloy of GaAs and InAs systems. As the In composition varies from 0% to 100%, the optical and electronic properties vary strongly. The electron mobility of InGaAs varies from 6000 to 30000 $cm^2/V\cdot s$ depending on the composition. The high In content InGaAs layers allow the device to operate at very high frequencies. Furthermore, InGaAs-based quantum well FET and MOSFET have demonstrated excellent characteristics for low-power, high-speed logic applications.

Due to higher mobility than Si, InGaAs-based devices can operate in the THz regime with unparalleled performance. For example, an InAs HEMT with $In_{0.65}Ga_{0.35}As$ sub-channels has delivered record-high f_T (current-gain cut-off frequency) beyond 700 GHz and devices capable of f_T = 1 THz are currently being examined. Additional progress in device technology is necessary to further improve the device operating frequency. In HEMT devices, the barrier separating the channel from the gate also separates the contacts from gate, contributing to contact resistance. By using dielectric materials and slightly modifying the design, Ohmic contacts can be realized. The hurdle to date is mainly due to difficulty in scaling the barrier thickness while maintaining the carrier mobility.

In the past few years, the prospect of InGaAs MOSFETs has attracted the attention of researchers for logic circuit applications. This also coincides with Si scaling path based on Moore's law. With a correct combination of channel composition design and proper oxide deposition, InGaAs MOSFETs can deliver outstanding logic performance. The InGaAs MOSFETs fabricated using ALD-deposited aluminum and hafnium oxides can achieve a very low interface state density in the Al_2O_3/InGaAs MOS structure. This reveals that low interface state density in the conduction band can be achieved for an *n*-channel device. Excellent results have been demonstrated with high-permittivity dielectrics deposited by ALD on InAs-rich InGaAs.

High-performance deep-submicron inversion-mode InGaAs MOSFETs with record g_M exceeding 1.1 mS/μm have been reported. HBr pre-cleaning, retrograde structure and halo implantation processes have been used for III-V MOSFETs to steadily improve high-κ/InGaAs interface quality and on/off current ratio. Much more work on high-κ/InGaAs interface and InGaAs ultra-shallow junctions is being carried out to make III-V a viable alternative technology at the 15 nm CMOS technology node.

Overall, from the present experimental results, InGaAs based devices looks very promising for THz and post-CMOS applications.