High-performance 150nm mHEMT on GaAs grown using MOCVD

Highest f_T value for 150nm device sets stage for potential high-volume production.

Researchers at Hong Kong University of Science and Technology (HKUST) have produced high-performance metamorphic high-electron-mobility transistors (mHEMT) with indium aluminum arsenide (InAlAs) barriers and indium gallium arsenide (InGaAs) channels using GaAs substrates and metal-organic chemical vapor deposition (MOCVD) [Haiou Li et al, IEEE Electron Device Letters, published online 22 July 2011].

InAlAs/InGaAs pseudomorphic HEMT devices on indium phosphide (InP) substrates have achieved cut-off frequencies (f_T) of more than 562GHz. Unfortunately, InP substrates remain expensive, in part due to the downturn in the photonic industry after 2000. Hence, it is attractive to explore other ways to produce such high-performance devices, preferably using MOCVD and GaAs substrates.

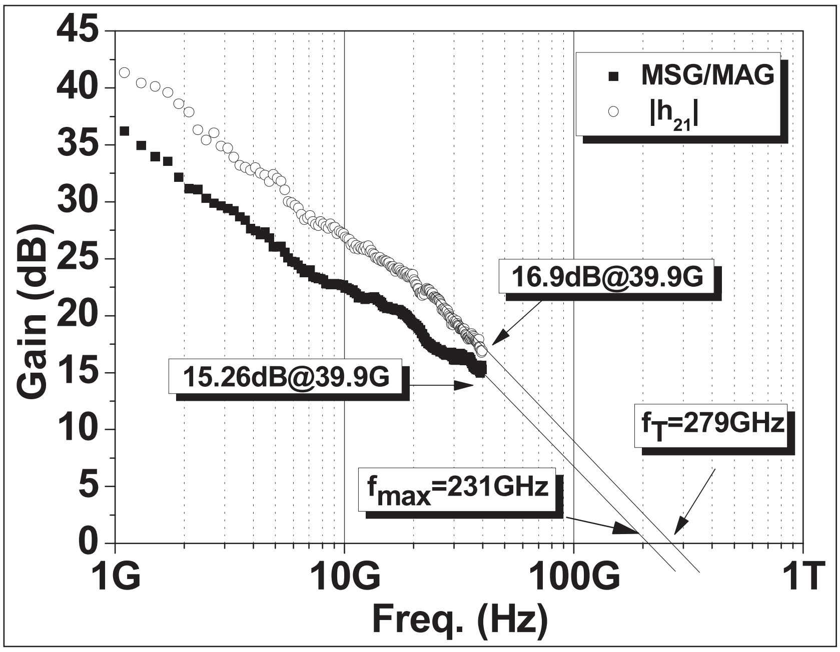

Figure 1. Current gain and MSG/MAG as functions of frequency for HKUST 150nm mHEMT.

The HKUST device has unity current-gain cut-off (f_T) and maximum oscillation (f_{max}) frequencies of 279GHz and 231GHz, respectively (Figure 1). This is comparable to the work of others with InGaAs/InAlAs devices grown with molecular beam epitaxy (MBE) on GaAs or InP (Table 1). The HKUST researchers note that their device has the highest f_T yet reported for 150nm gate-length HEMTs.

The researchers add: "We believe that these results are the best reported for MOCVD-grown mHEMTs and sufficient for high-frequency high-speed applications. With the anticipated demand of commercial high-speed and high-performance transistors, mHEMT technology by MOCVD is very attractive for manufacturing".

Up to now, metamorphic (i.e. low strain) InAlAs/InGaAs devices on GaAs substrates have been mainly grown using MBE, a technique not favored in manufacturing. MOCVD meta-morphic growth has tended to lag behind these developments.

A particular challenge is reducing threading dislocation densities that arise from lattice mismatch (4% between GaAs and InP) and thermal expansion coeffi-

Table 1. Comparison of AlInAs/GaInAs HEMTs performance. The HKUST device is given in the last row.

Substrate	Growth	Mobility cm^2/V-s	L_g nm	G_m mS/mm	f_T GHz	f_{max} GHz	Date
GaAs	MBE	N/A	100	750	154	300	2004
GaAs	MBE	N/A	100	890	189	334	2004
GaAs	MBE	9100	150	740	150	240	2003
InP	MBE	8800	150	800	151	172	2008
GaAs	MBE	7850	100	700	210	N/A	2005
GaAs	**MOCVD**	**8740**	**150**	**1074**	**279**	**231**	**2010**

cient differences. This is usually handled using a series of buffer layers to bridge the differences in lattice parameters. However, these layers can be less resistive than desired due to unintended impurities, leading to leakage currents in the buffer. These leakage currents hinder the achievement of 'pinch-off'.

The HKUST reports: "We have developed a growth technique of a comparatively thin multi-stage buffer to obtain high resistivity in the buffer layer, leading to good device performance. This sets the stage for potential high-volume production of mHEMTs by MOCVD."

The researchers plan to further reduce buffer leakage by optimizing the buffer layer growth in future.

The f_T value was derived from short-circuit current gain (|h21|) extrapolation, and de-embedding structures were used to subtract the effect of parasitic capacitance of the probe pads. The f_{max} value came from extrapolation of maximum stable gain and maximum available gain (MSG/MAG) measurements.

The optimum bias position was determined to be at gate (V_{GS}) and drain (V_{DS}) potentials of −0.6V and 1.0V, respectively (Figure 2).

The epitaxial material for the HEMTs (Figure 3) was grown using MOCVD on semi-insulating (SI) 4-inch (001) GaAs substrates. The resulting structure (with cap layer removed for Hall measurements) showed a room-temperature electron concentration in the two-dimensional electron gas (2DEG), which creates the channel, of $4.6 \times 10^{12}/cm^2$ and mobility of $8740 cm^2/V\text{-}s$. These values result in a sheet resistance of 156Ω/sq. Some 60° threading dislocations were observed in the buffer layers.

The devices were made with mesa isolation. The ohmic source/drain contacts consisted of a non-alloyed 6-metal system of nickel-germanium-gold-germanium-nickel-gold with transmission-line method measurements giving contact resistances down to 0.02Ω-mm. The low resistance value is attributed to "higher doping concentration of cap layer and optimization of ohmic contact metal systems".

The 150nm T-gate was created using two-stage electron-beam lithography and etch processes on layers of silicon dioxide and silicon nitride deposited using plasma-enhanced chemical vapor deposition. The Schottky gate metal structure on the AlInAs barrier consisted of titanium-platinum-gold.

The device works in depletion-mode (normally-on) with a threshold voltage V_{th} of about −0.8V. There was some variation in threshold between mHEMT devices in the range from −1.0V to −0.8V. The researchers attribute this to surface roughness, which has a root-mean-square value of more than 2.9nm across a scan area of 20μm x 20μm. It is hoped in future to optimize the growth of the HEMT material to reduce this.

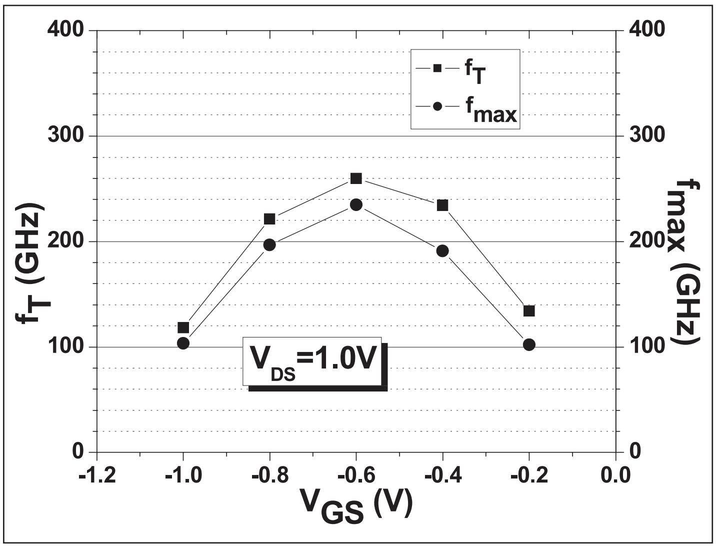

Figure 2. Dependencies of fT and fmax on gate bias for 150nm mHEMTs, where VDS is fixed at 1.0V.

The maximum drain current of the device was 1130mA/mm at a gate potential (V_{GS}) of 0.4V and a drain bias (V_{DS}) of 1.5V. The maximum extrinsic transconductance was found to be 1074mS/mm at V_{GS} of −0.25V and V_{DS} of 1.0V. ■

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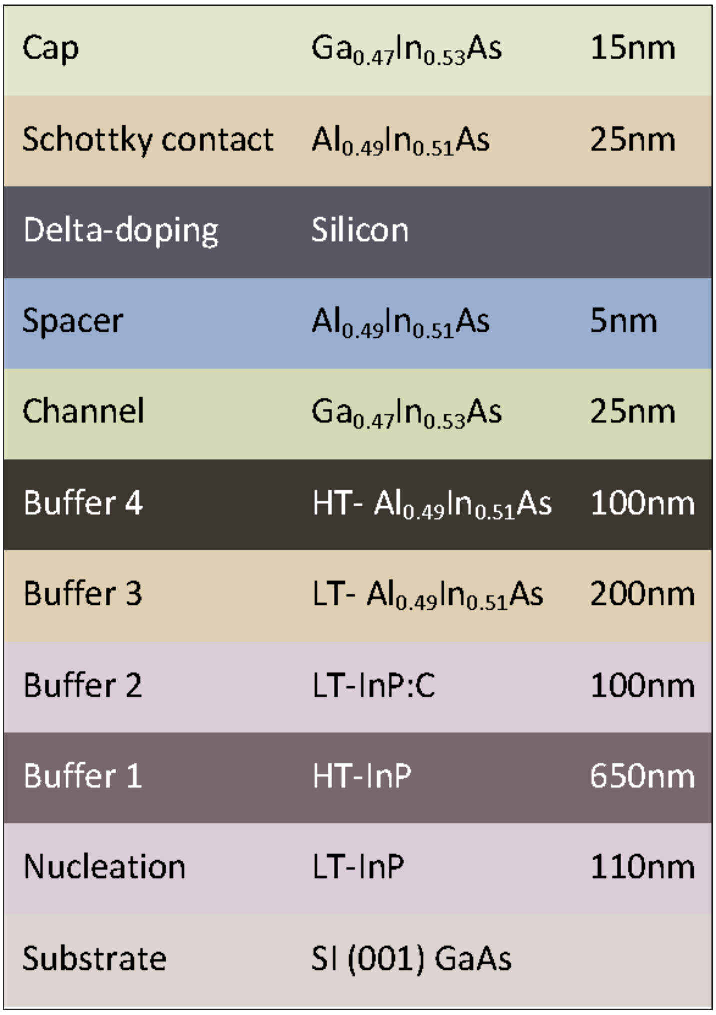

Cap	$Ga_{0.47}In_{0.53}As$	15nm
Schottky contact	$Al_{0.49}In_{0.51}As$	25nm
Delta-doping	Silicon	
Spacer	$Al_{0.49}In_{0.51}As$	5nm
Channel	$Ga_{0.47}In_{0.53}As$	25nm
Buffer 4	HT- $Al_{0.49}In_{0.51}As$	100nm
Buffer 3	LT- $Al_{0.49}In_{0.51}As$	200nm
Buffer 2	LT-InP:C	100nm
Buffer 1	HT-InP	650nm
Nucleation	LT-InP	110nm
Substrate	SI (001) GaAs	

Figure 3. Epitaxial metamorphic HEMT structure.