The First 0.15um MHEMT 6”GaAs Foundry Service: Highly Reliable Process for 3 V Drain Bias Operations

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Lattice matched InAlAs/InGaAs/InP HEMTs have performance advantages over more commonly used GaAs PHEMTs due to the high electron velocity and carrier density[1]. However, manufacturing these devices at high production level is difficult due to the limited size, high cost, and brittle nature of the InP substrate. Growing InAlAs/InGaAs structures metamorphically on GaAs substrates can overcome these substrate issues. However, the ultimate acceptance of MHEMT in commercial application depends upon its providing higher performance compared to other technologies at the same cost. In order to address the needs for both high performance and low manufacturing cost, for the first time, an highly reliable 4 mil 0.15 um MHEMT process has been developed on six inch GaAs substrates with high yield and reproducibility for both power and noise applications.

1-DC and RF Characteristics: The DC and Pulse I-V characteristic of WIN 0.15um MHEMT, as shown in fig.1, is free of any kink and surface trapping phenomena. This proves the maturity of metamorphic buffer growth and the excellent PECVD SiN device passivation. WIN 0.15um MHEMT has $I_{ds,max}$ of 550mA/mm and g_m-peak of 700mS/mm an off-state gate-drain breakdown of 13V. Fig. 2 shows the tight distribution of PCM DC characteristics of 3 lots from two epi-wafer vendors. ft of 140GHz at V_{ds} of 1V and 125GHz at 1.5V drain bias are typically achieved. This process shows very high capability for production with similar manufacturing cost compared to GaAs PHEMT. In fact, the 6-inch MHEMT process is 95% similar to our fully qualified 6-inch 0.15um PHEMT.

2-Noise Performance: The devices showed an excellent noise figure of 0.7dB and associated gain of 10dB at 26GHz and 1.5dB with gain of 8.3dB at 40GHz, as shown in fig.3. The devices width is 2x50 um and biased at Vds=1.5 V and Ids=60 mA/mm. The MHEMT exhibited a 0.3dB noise figure improvement with 2dB more gain compared to WIN 0.15um LN PHEMT. The linearity of our MHEMT is better then our low noise PHEMT related to double side doped structure compared to single side doped for PHEMT.

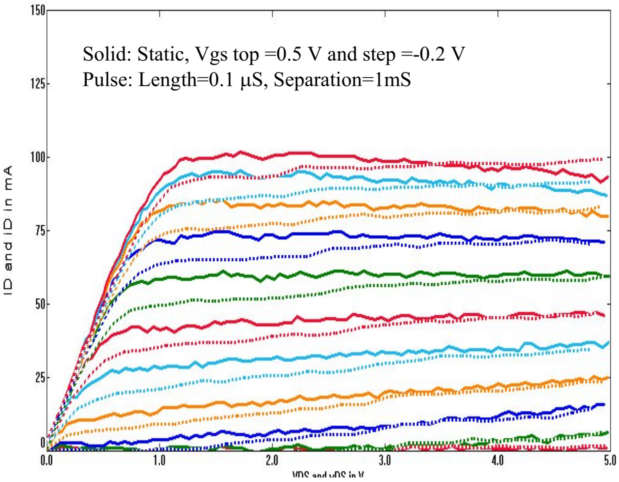


Fig.1: Pulse I-V of 0.15 um MHEMT showing kink and trapping free devices.

The noise performance of WIN 0.15um MHEMT makes it very suitable for low noise amplifiers with high linearity to W-band for radio links and low cost MMICs for automotive radar at 77GHz.

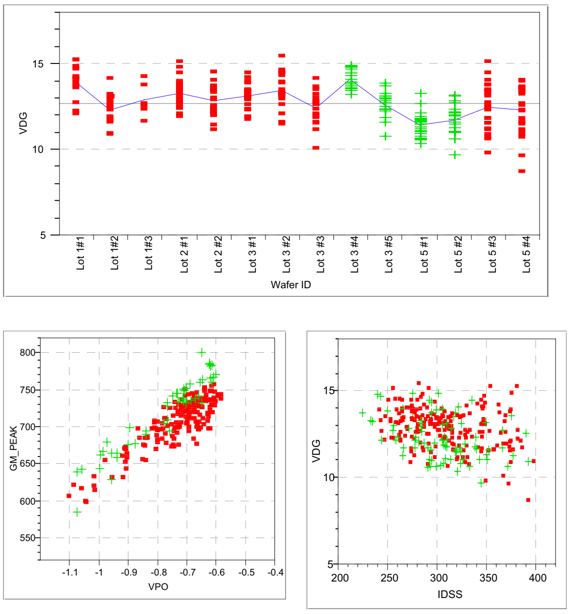


Fig.2: Distribution of gm, Vp, V_{DG} and I_{dss} from wafer to wafer and batch to batch with Epi wafers from two vendors.

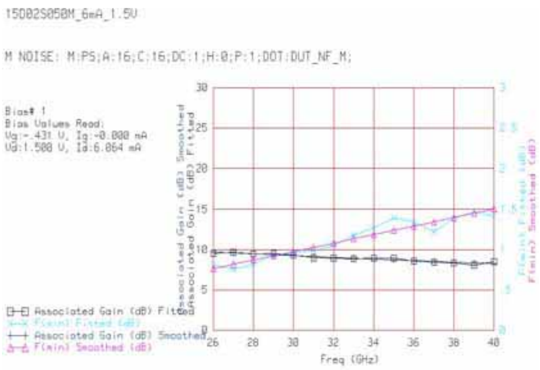


Fig.3: Plot of noise figure and associated gain versus drain current at 26 GHz of 0.15 um MHEMT at Vds=1.5 V and Ids=60 mA/mm for device gate width 2x50um.

California Institute of Technology, CA, evaluated the MHEMT or 4-8 GHz cooled MIC LNA. The LNA consists of a low noise 0.15um MHEMT as the first stage and 0.1 um InP HEMT for second gain stage. Fig. 4 shows a noise temperature (K) of a MIC LNA at RT and 11K. The LNA has demonstrated an extremely low noise figure at RT of 0.46dB. When cooled to 11K, the noise temperature is extremely low - 4.4K - at 4-8GHz. This is the first demonstration of a cooled LNA using MHEMT devices. The MHEMT did not show any trap symptoms at 11K.

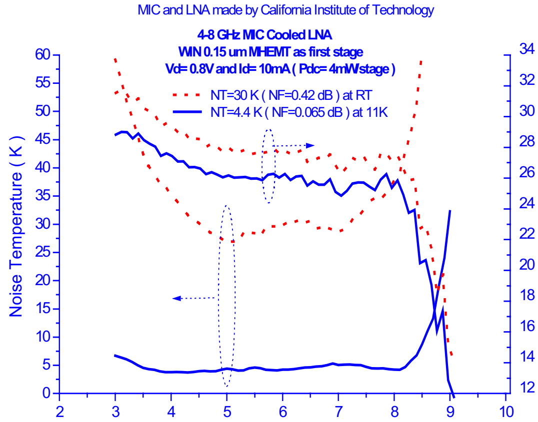
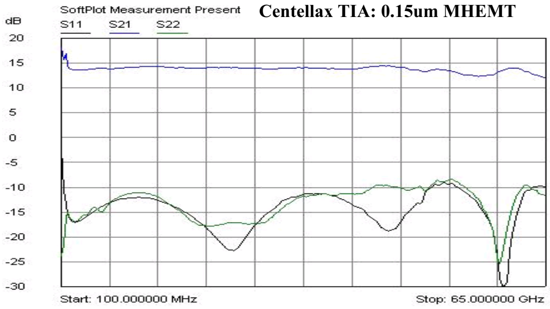


Fig.4: 4-8 GHz LNA, using WIN's 0.15um MHEMT as first stage, giving average noise temperature of 4.4K at 11K. LNA made and measured by California Institute of Technology.

Centellax Corp. (USA) designed TIAs which were biased as Electro-Absorption Modulator driver (EAM) at V_{dd}=4.5 V and I_{ds}=120 mA for OC-768 also using the 0.15um PHEMT, as shown in fig.5-b. The same design is used with WIN's 0.15um MHEMT and the results show a gain improvement of 2dB across the entire frequency band and a 10-12GHz improvement in the amplifier bandwidth with the MHEMT (see fig. 5-a). These results demonstrate that the MHEMT technology is superior for an amplifier requiring gain, bandwidth, linearity, low noise and high dynamic range, when compared to both 0.15um GaAs Low Noise and Power PHEMTs. This makes the 0.15um MHEMT an excellent choice for 40G/s Fiber-Optic Communications, Broadband amplifier and 77GHz automotive radar applications.

3- Power Performance: WIN MHEMT showed a better noise performance and higher gain them our low noise PHEMT.

WIN MHEMT can be used for power application s up to 3-4 V.



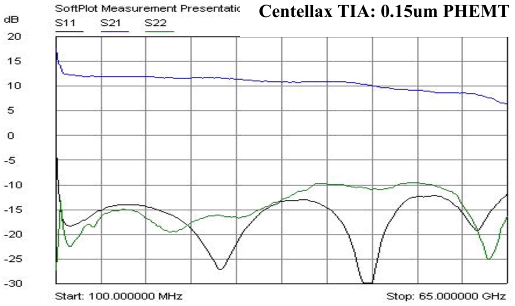


Fig.4: TIAs biased as EMA driver at V_{dd}=4.5V and I_{ds}=120mA for MHEMT (a) and PHEMT (b). Centellax performed TIA design and measurement.

As shown in fig. 6, load pull power measurement at 29GHz of a 0.15um unit cell MHEMT (2x75um) has demonstrated P_{1dB} of 330 mW/mm with linear gain of 14.2dB and PAE of 53% at V_{ds}=3V. In constrast, at Vds=3V, WIN's 0.15um power PHEMT shows P_{1dB} of 260mW/mm with 13dB gain and of 43% PAE. Compared to the power PHEMT, the MHEMT provides ~10% more efficiency and ~1.5dB more gain, demonstrating an excellent potential of power MHEMT for very high efficiency and high gain applications.

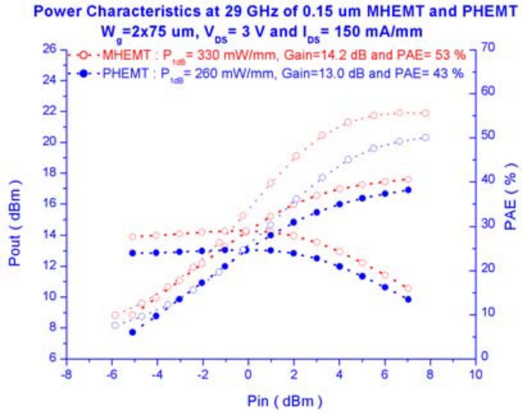
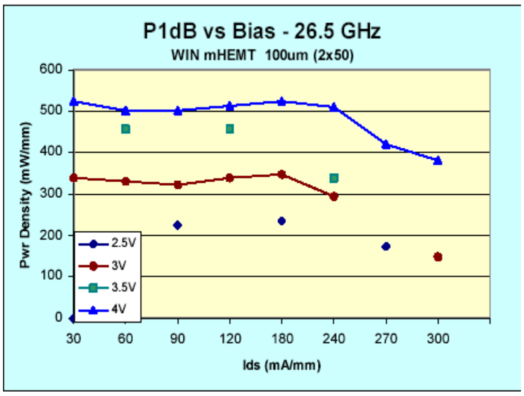
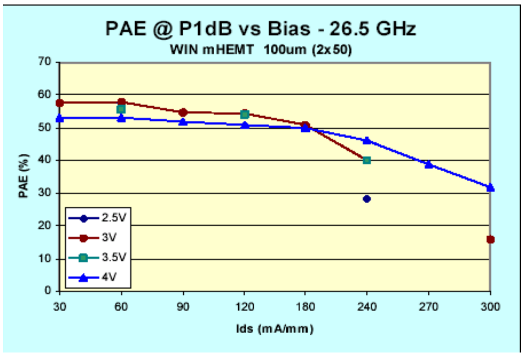


Fig.6: Load Pull Power measurement at 29 GHz showing the advantage of MHEMT to the PHEMT Power process at 3V and MMW frequencies.





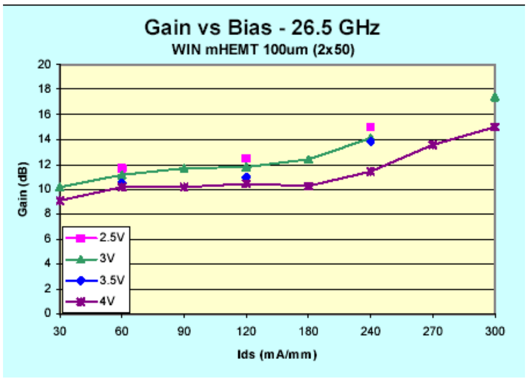


Fig.7: Load Pull Power measurement at 26.5 GHz at different drain bias and drain current showing high gain and pae of WIN MHEMT.

Further, for Ka-band power performance, 2x50 um devices were load pulled at 26.5 GHz. Different drain voltage with quiescent drain current densities between 30 mA/mm to 300 mA/mm were used for load pull, as shown in fig.7. For Gain stage, the MHEMT can be biased at 2 V drain bias with15 dB gain at Ids=250 mA/mm. For the Output power stage, the MHEMT can be biased at 3.5 V with power density at P1dB of 450 mW/mm and Pae of 55 %. These performances make the MHEMT the best technology for mmW power amplifier, which require a high pae and gain with medium power compared to PHEMT. Sanders[2], TriQuint[3] and Raytheon[4] showed the MHEMT has ~ 10 % more pae compared to their phemt.

4-Device Reliability: Accelerated DC life tests were carried out on metamorphic HEMT at three different temperatures and under 3 V drain bias. With 20% drop on maximum drain current as criterion, an activation energy of 1.72eV and MTTF of extrapolate to 3e7 hours at Tch of 125 C was obtained, as shown on fig.8. These results meet even strength lifetime requirements for commercial, military and space applications. The main degradation mechanisms observed on our MHEMTs are gate sinking and drain resistance degradation related to high gate-drain electrical field. Our MHEMT showed the same MTTF and activation energy for three lots processed separately. These results showed the robustness of our MHEMT technology for 3V operations. Further, we did not see any device failure during accelerated lifetime. To the best of our knowledge, this is the first report on highly reliable MHEMT at 3V drain-source bias.

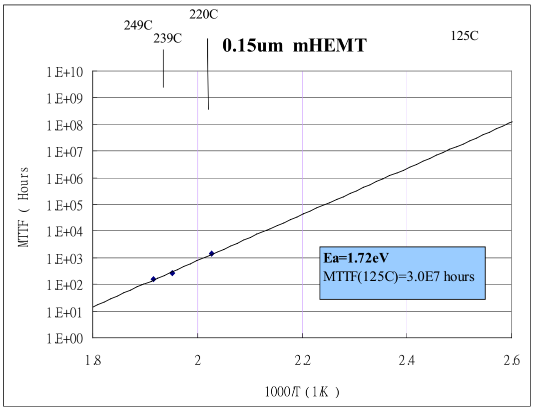


Fig.8: Arrhenius plot for 0.15 um MHEMT at drain bias 3V giving MTTF of 2e7 hours with Ea of 1.72 eV.

In conclusion, we have demonstrated first 6” GaAs wafer with high performance 0.15um Metamorphic HEMT technology. High yield and reproducibility have been achieved across 6-inch GaAs wafers. WIN MHEMT showed superior performance for noise and power at mmW compared to PHEMT. Good reliability at 3V drain bias has also been demonstrated. This is the first successful demonstration of 0.15um MHEMT technology on 6”GaAs substrates for foundry service. The baseline release of MHEMT technology to production is on going and the customers already started eng lots.

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