GaAs pHEMT Technology for Optical Communication System

Tamotsu KIMURA, Tomoyuki OHSHIMA, Masanori TSUNOTANI, Toshihiko ICHIOKA and Shohei SEKI
Optical Components, Oki Electric Industry Co., Ltd.
550-1 Higashi-asakawa, Hachioji, Tokyo 193-8550 JAPAN
Phone: +81-426-62-6621, FAX: +81-426-62-6616, e-mail: kimura100@oki.com

Abstract

GaAs pHEMT is advantageous for high speed analogue ICs, such as laser driver and trans-impedance amplifier used in OC-192(10Gbps) or OC-768(40Gbps), the wide-band fiber communication system. This paper will introduce examples of IC design based on 0.1μm gate GaAs pHEMT with single-recess structure for high cut-off frequency and that with double-recess structure for high breakdown voltage. This approach provides a wide flexibility in the circuit designing. Because of high frequency characteristics, 0.1μm gate GaAs pHEMT can be applicable even for OC-768 (40Gbps).

Introduction

For 10Gbps fiber communication system (OC-192), there are different device technologies available such as SiGe-BJT, Si-CMOS, GaAs-HBT and GaAs-pHEMT. The cut-off frequency (f_T) of SiGe-BJT and Si-CMOS has been recently improved, and those are successfully applied to high-speed digital IC, which requires low power consumption. However, the product of f_T and the breakdown voltage (V_B) is almost constant and inherent in the material of device, and V_B of such high-speed Si-based devices is generally in the range of a few volt [(1)], which is not enough for analogue ICs.

GaAs technology gives a better solution for this. As for GaAs device, HBT and pHEMT are competitive, but in US, HBT seems to be more popular because it is relatively easy to control in the production.

However, we have proved an advantage of HEMT over HBT when the device is scaled-down for targeting much higher speed. Figure 1 shows the propagation delay of a logic inverter of ECL (by InP HBT) and SCFL (by InP HEMT) for 40Gbps application, in this case. By assuming f_T and fmax for ECL and f_T for SCFL, the propagation delay can be calculated depending on the critical size, which is defined as emitter size for HBT and gate length for HEMT. This result shows that the propagation delay is better for HEMT when the gate length becomes smaller than 0.1μm, while no much improvement is expected for HBT even for the size reduced. This is mainly due to the fringing capacitance between base and collector (C_{BC}), which is not negligible in such a small-sized HBT.

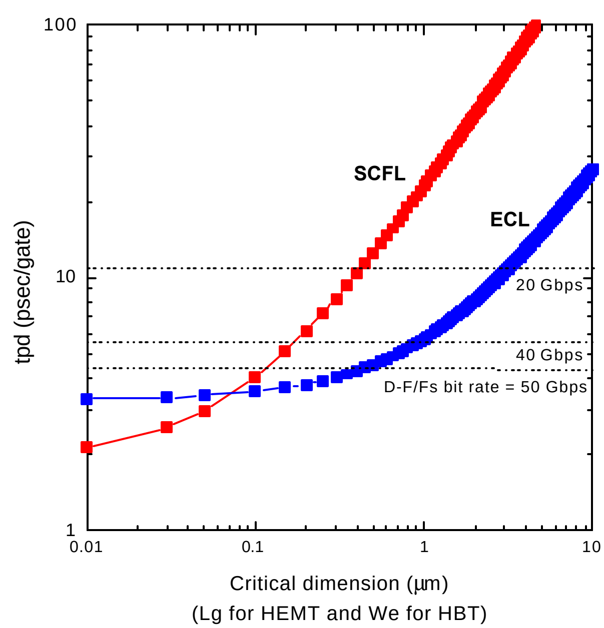


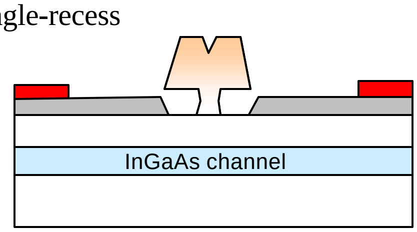
Figure 1: Propagation Delay of ECL and SCFL

Single-Recess and Double-Recess pHEMT

By the reason mentioned above, we take 0.1µm gate GaAs-pHEMT [2] for high-speed analogue application, but we still have to compromise f_T and V_B for optimizing the circuit performance. For this purpose, we have developed two different types of device, a single-recess-gate pHEMT for high speed and a double-recess-gate pHEMT for high breakdown voltage.

All the epitaxial layers were grown by MBE on GaAs substrates. Then by wet chemical etching, the structure of the single-recess (figure 2(a)) or the double-recess (figure 2(b)) was formed, and T-shaped gate of Al with 0.1 µm footprint (gate length) was defined by using EB lithography within this recessed region.

(a) Single-recess



(b) Double-recess

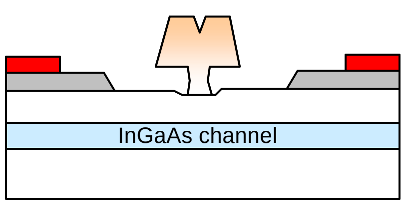
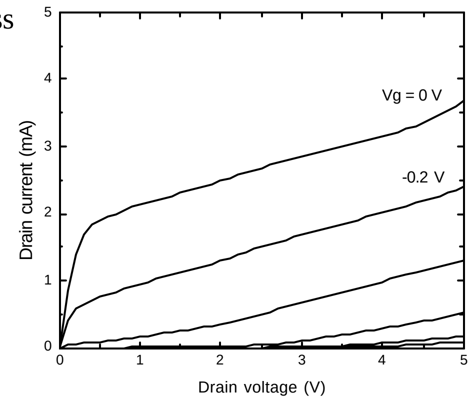


Figure 2: Recess-gate of pHEMT

Typical I-V characteristics are shown in the figure 3(a) and (b). V_B of the single-recess pHEMT measured was about 8V, while that of the double-recess was >10V with a better saturation of drain current. f_T is shown in the figure 4(a) and (b), where the maximum value observed was about 100GHz for the single-recess, and 70GHz for the double-recess.

(a) Single-recess



(b) Double-recess

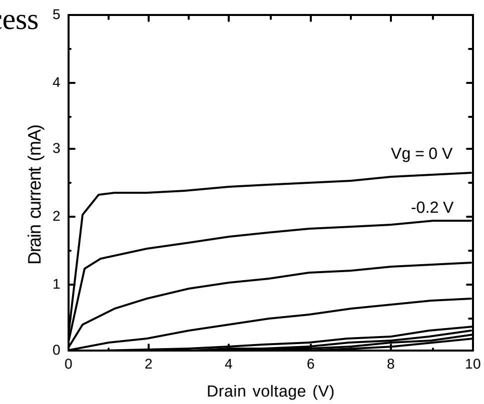
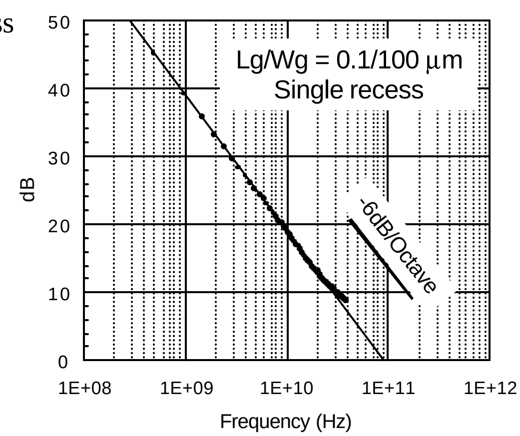


Figure 3: I-V characteristics

(a) Single-recess



(b) Double-recess

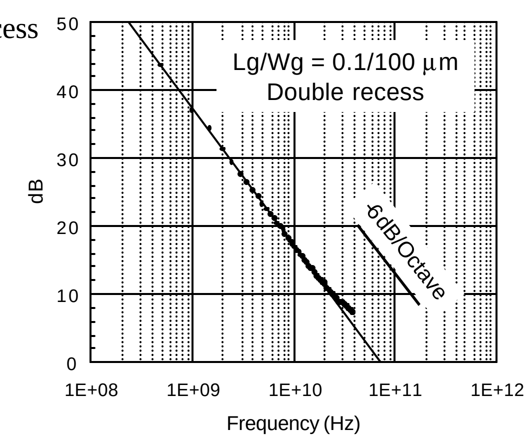


Figure 4: Cut-off frequency

Application of Single-Recess pHEMT to OC-192

Figure 5 shows an example of a block diagram of OC-192 transmission module. Here, 0.1μm GaAs pHEMT is used for laser driver (or electric absorption (EA) modulator driver) and transimpedance amplifier (TIA).

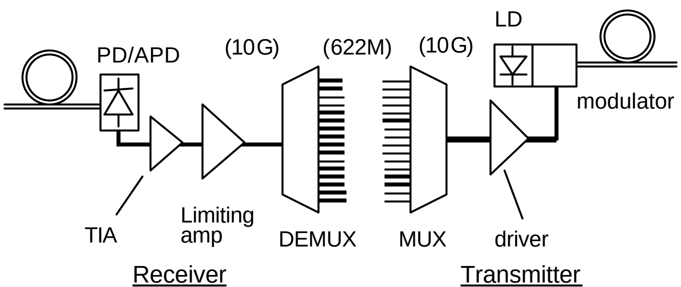


Figure 5: Block diagram of OC-192

Figure 6 shows a micro-photograph of a driver IC [3] implemented by the single-recess pHEMT. The chip size was 2.3mm×1.6mm. The voltage supply obtained was -5V and the power dissipation was less than 1W. Because the bandwidth of this circuit was as wide as 13GHz owing to high f_T of pHEMT, the driver can operate even at 12.5Gbps with a good eye-pattern in the output waveform, as shown in the figure 7. The total gain of this IC is higher than 20dB, so the output voltage swing can be controlled at up to 3Vpp (single-ended with 50Ω termination), for the input level of 0.5Vpp. The rise time (tr) and the fall time (tf) observed was as small as 30ps.

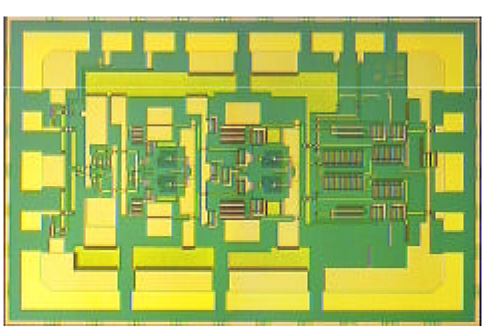


Figure 6: Photograph of driver IC

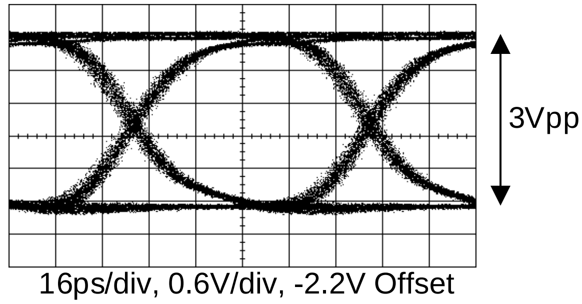


Figure 7: Output waveform of driver at 12.5Gbps

As another example of the single-recess pHEMT, the figure 8 shows a typical performance of trans-impedance amplifier (TIA) [4], a dependence of bit error rate (BER) at 10Gbps on the optical input power for a PIN photodiode assembled with TIA. Because the input noise of GaAs pHEMT is small, the input noise current density of this IC is small, and the minimum optical input power (input sensitivity) as small as –21.2dBm (at BER of 10^{-9}) was resulted.

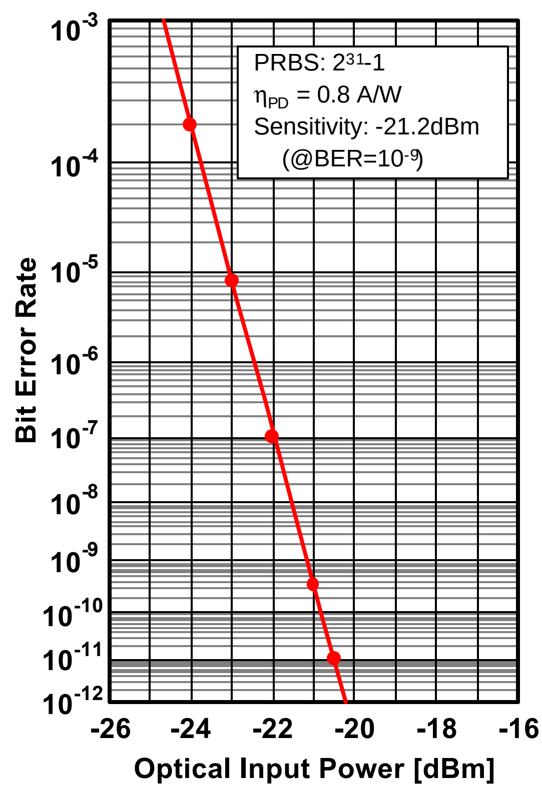


Figure 8: Bit Error Rate of TIA at 10Gbps

Application of Double-Recess pHEMT

The double-recess pHEMT with high breakdown voltage has been applied for an output stage in the $LiNbO_3$ Mach-Zehnder (MZ) modulator driver, which requires large output swing. The single-recess pHEMT is also applied in this device for a pre-amplifier stage. Figure 9 shows an example of the output waveform, where the output voltage swing was as large as 6Vpp (single-ended with 50Ω termination) and tr/tf was as small as 30ps/38ps.

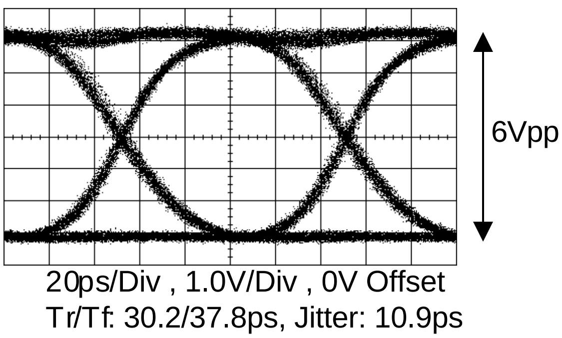


Figure 9: Output waveform of MZ driver at 10Gbps

Application to OC-768

0.1μm pHEMT can be applied even for much higher frequency range. Figure 10 shows the small signal characteristics of a distributed amplifier developed. The bandwidth was observed as wide as 69 GHz with a gain of 11.5dB.

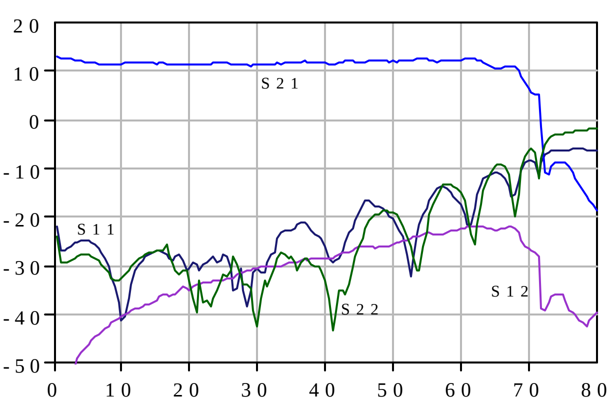


Figure 10: Small Signal Characteristics

Figure 11 shows an example of the output waveform for the application of OC-768 (40Gbps). The output voltage swing observed was 2.8Vpp under the condition of the input voltage of 1.0Vpp, which is large enough to drive an EA modulator.

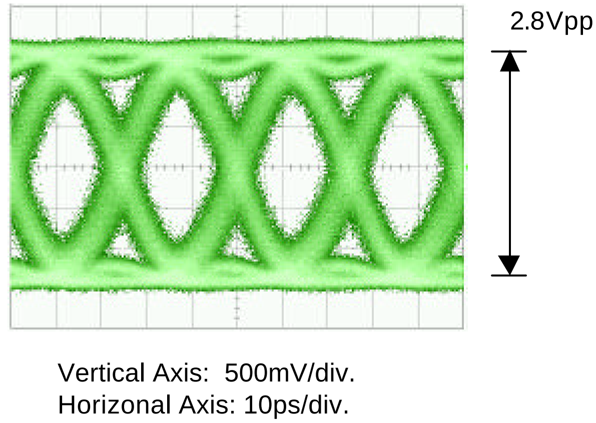


Figure 11: Output Waveform at 40Gbps

Conclusion

GaAs pHEMT is now competing with GaAs HBT, SiGe BJT and even Si CMOS for high-speed application. However, because of its high f_T, high breakdown voltage and also low noise features, it is definitely a key device especially for analog ICs used in the wide-band optical communication system of OC-192 and even OC-768.

References

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