An AlGaAs/InGaAs Pseudomorphic HEMT Modulator Driver IC with Low Power Dissipation for 10 Gb/s Optical Transmission Systems

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ABSTRACT

An optical modulator driver IC has been developed for 10 Gb/s optical communication systems. In order to realize both high frequency operation and low power dissipation, 0.2-μm T-shaped gate AlGaAs/InGaAs pseudomorphic HEMTs, which give large transconductance, g_m, of 610 mS/mm and high cut-off frequency, f_T, of 67.5 GHz, have been employed. In addition, by using a current mirror circuit with cascode configuration as high impedance current source, power dissipation of 1.1 W is achieved at a 10 Gb/s NRZ signal output with 3 $V_{p\text{-}p}$. This dissipation is the lowest value ever reported. As an additional function, the output voltage swing can be controlled from 2 to 3.3 $V_{p\text{-}p}$ by the current mirror circuit in order to adjust the duty factor of optical output signal through an optical modulator.

INTRODUCTION

For 10 Gb/s long-haul optical communication systems, optical transmission systems with external optical modulation are preferable to direct optical modulation in order to suppress the broadening of the spectral linewidth at high bit-rate modulation. An electroabsorption(EA)-modulator driver IC requires both high speed operation and large voltage drive because an EA-modulator usually needs large voltage swing over 2 $V_{p\text{-}p}$ to obtain sufficient extinction ratio at 10 Gb/s [1]. Additionally, there is strong demand for a driver IC with low power dissipation to realize an air-cooled system [2]. There are several reports on large-output driver ICs using HEMT, HBT and Si-bipolar transistor [3-5]. Compared with an HBT IC or Si-bipolar IC, a HEMT IC, which can operate at a low supply voltage of -5.2 V, has the advantage of low power dissipation. In our approach, we have adopted 0.2-μm-gate AlGaAs/InGaAs pseudomorphic HEMTs for the driver IC. Since the HEMTs have higher transconductance and cut-off frequency than pseudomorphic 2DEG FETs [3], the driver IC can operate with lower power dissipation. In designing the IC, a current mirror circuit with cascode configuration is used as a current source with high impedance for a pre-driver in the IC. The current mirror circuit improves the high frequency performance of the pre-driver, which leads to lower power dissipation. This paper describes device structure, circuit design and characteristics of the IC.

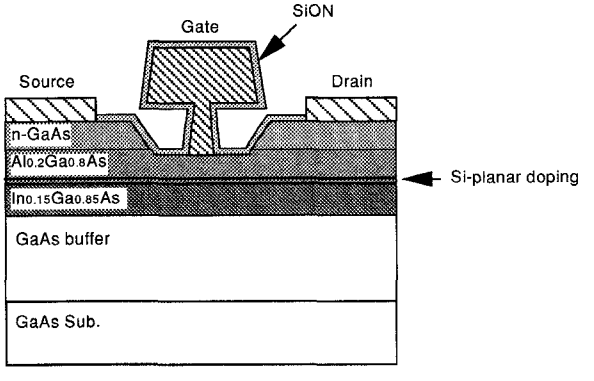

Fig.1. Schematic cross-section of the AlGaAs/InGaAs pseudomorphic HEMT.

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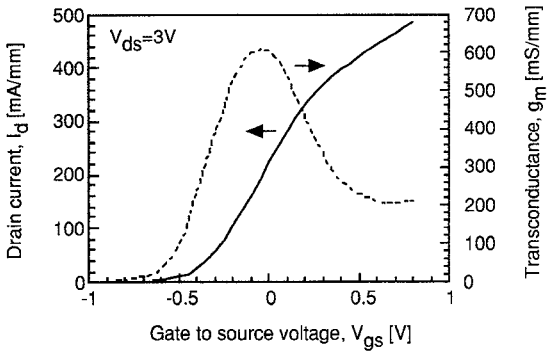

Fig. 2. Drain current and transconductance dependence on gate-to-source voltage of pseudomorphic HEMT.

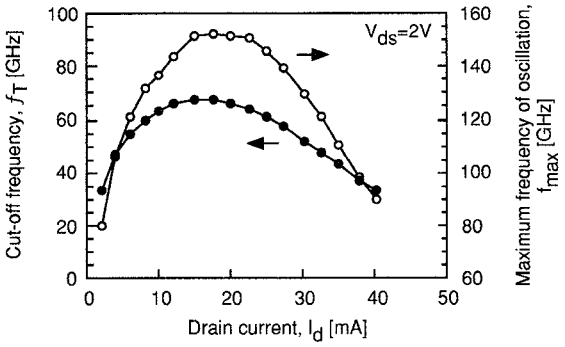

Fig. 3. f_T and f_{max} of pseudomorphic HEMT.

DEVICE

Figure 1 shows the schematic cross-section of the AlGaAs/InGaAs pseudomorphic HEMT. For gate recessing, a pH-adjusted citric acid:NH_4OH:H_2O_2 solution [6] is used to realize the small deviation of threshold voltage which is essential to integrated circuits. Figure 2 shows the dependence of measured drain current, I_d, and transconductance, g_m, on gate voltage, V_{gs}, of the HEMT. At V_{gs} = 0 V, the maximum g_m of 610 mS/mm is obtained. The typical threshold voltage is -0.8 V and the gate-to-drain breakdown voltage, V_{gdo}, is as high as 10 V. Figure 3 shows the characteristics of measured f_T and f_{max} in terms of I_d of the HEMT with 100-μm-gate width. A maximum f_T of 67.5 GHz and f_{max} of 152.6 GHz are obtained. These characteristics are effective in realizing lower power dissipation of the 10 Gb/s driver IC.

CIRCUIT DESIGN

Figure 4 shows the circuit diagram of the driver IC. The IC consists of an input buffer which has an SCFL (0, -1V) interface, a pre-driver which is a two-stage differential amplifier, and an output driver. In designing the IC, our target of output voltage swing was 3 $V_{p\text{-}p}$,

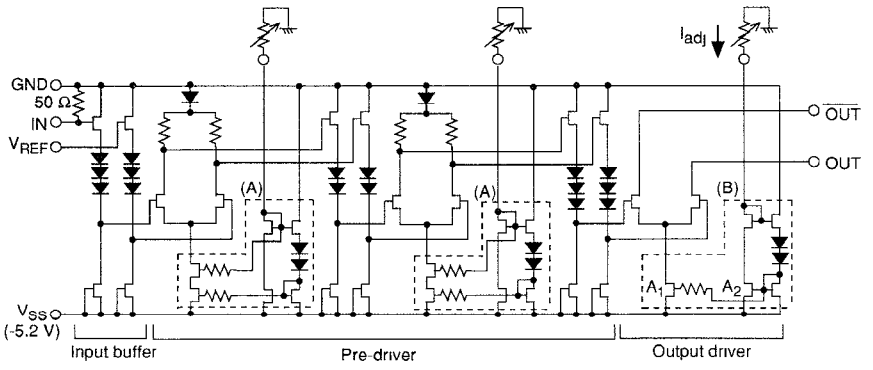

Fig.4. Circuit diagram of the driver IC.

which corresponds to a modulation current of 60 mA_{p-p} in the output driver. The pre-driver provides high gain of 14 dB to keep the output voltage swing constant for a change in the single input signal from 0.4 V_{p-p} to 1 V_{p-p}. The output driver has been designed to convert differential input signals of about 0.8 V_{p-p} into an output voltage swing of 3 V_{p-p}. For each differential stage of the pre-driver, a current mirror circuit with cascode configuration (A) is adopted as a current source in order to reduce the change in output voltage due to variation in the supply voltage. In addition, the high frequency performance of the pre-driver is improved by using this current mirror circuit with high impedance, which leads to lower power dissipation. The output driver also includes a current mirror circuit (B). The output voltage swing is controlled by the current mirror circuit in order to adjust the duty factor of the optical output signal through an optical modulator which has non-linear characteristics of optical power versus input voltage. The ratio of gate width of A_1 to A_2 is set to 16:1 to make the control current, I_{adj}, small. As another merit of the current mirror circuit, variation of the output voltage dependent on the supply voltage or the ambient temperature can be compensated by an external bias control circuit [7]. Figure 5 shows the simulated output diagram for differential control current, I_{adj}, at 10 Gb/s. The input signal of 1 V_{p-p} is a pseudo-random bit sequence (PRBS) of 2^7-1. In this simulation, we considered that the parasitic capacitance connected in parallel with a 50-Ω load resistor, which includes on-chip metalization-line capacitance and the pad capacitance, was 0.3 pF. Figure 6 shows the microphotograph of the driver IC. A coplanar structure with impedance of 50 Ω is employed for the input and output lines. The resistor of 50 Ω for the input matching and metal-insulator-metal capacitors are integrated as bypass capacitors for stabilizing the power supplies of -5.2 V. The chip size is 3.0 mm x 2.5 mm.

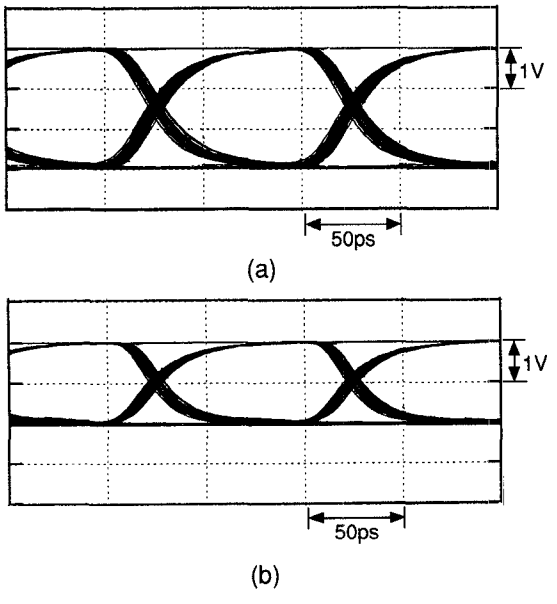

Fig. 5. Simulated output diagram at 10 Gb/s, 2^7-1 PRBS for different control currents, I_{adj}: (a) I_{adj} = 3.5 mA and (b) I_{adj}=2.0 mA.

CHARACTERISTICS

The IC was assembled on a ceramic carrier and measured in 50-Ω test systems. Figure 7 shows the output diagram and section of the output pulse sequence for SCFL input with PRBS of 2^{23}-1 when 50-Ω load is driven by the IC. The maximum voltage swing of 3.3 V_{p-p} and rise/fall time (20%-80%) of 32.4/30.2 ps are obtained at 10 Gb/s. Good eye opening is observed. The sensitivity for the input voltage swing at single input operation is as low as 0.4 V_{p-p}. Figure 8 shows the measured and simulated output voltage swing dependence on the control current, I_{adj}, as shown in Fig. 4, and the output diagram at I_{adj} = 2.0 mA. The output voltage swing is changed from 2 to 3 V_{p-p} in proportion to I_{adj}, indicating good agreement with simulation. The power dissipation at the output voltage swing of 3 V_{p-p} is 1.1 W. This is the lowest value ever reported [2-4].

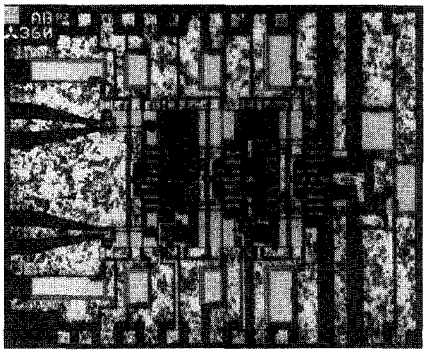

Fig. 6. Microphotograph of driver IC. (Chip size : 3.0 mm x 2.5 mm)

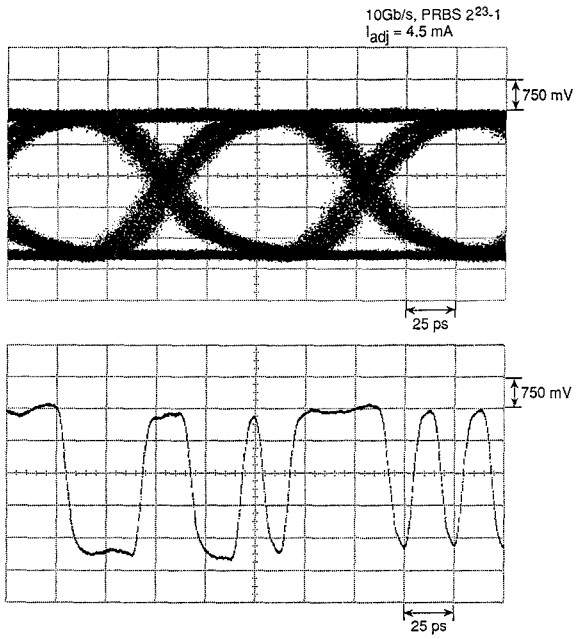

Fig. 7. Measured output diagram (top) and section of the output pulse seqence (bottom) for output volt age swing of 3.3 V_{p-p} at 10 Gb/s.

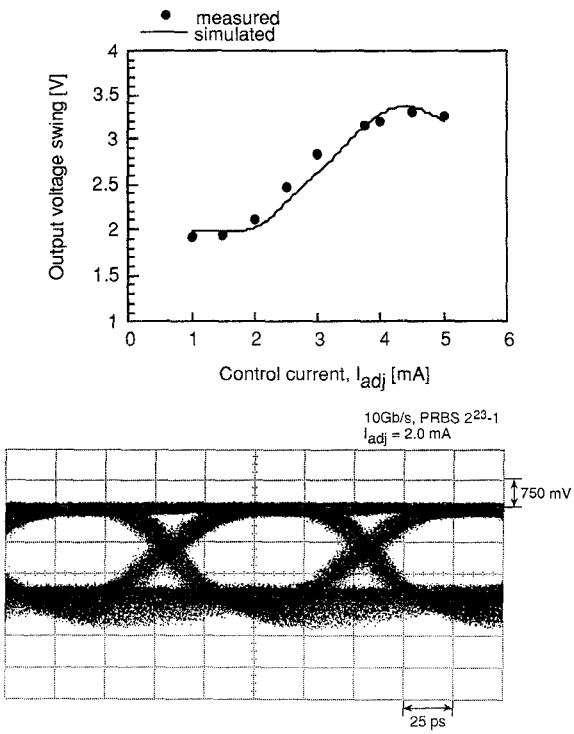

Fig. 8. Measured and simulated output voltage swing dependence on the control current, I_{adj},(top) and output diagram at I_{adj} = 2.0 mA (bottom).

CONCLUSION

A modulator driver IC using 0.2-μm-gate AlGaAs/InGaAs HEMTs has been developed for 10 Gb/s optical transmission systems. The IC achieves a large output voltage swing of 3.3 V_{p-p} with power dissipation of 1.1 W. The IC is expected to contribute to the realization of 10 Gb/s long-haul optical communication systems.

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