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AlGaAs/GaAs Heterojunction Bipolar Transistor ICs for Optical Transmission Systems

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AlGaAs/GaAs HBT ICs for optical transmission systems, such as preamplifiers, D-F/Fs, differential amplifiers, and laser drivers, have been newly developed using our HBT self-aligning fabrication process. In this process, hetero guard-rings composed of a depleted AlGaAs layer are fabricated on p^+ GaAs extrinsic base regions and emitter mesas are ECR-RIBE dry etched using a thick emitter metal system of WSi and Ti-Pt-Au as etching masks. The preamplifier IC exhibits a DC to 18.5-GHz transimpedance bandwidth with a transimpedance gain of 49 dBΩ. The rise time and fall time for the D-F/F IC are 30 and 23 ps, respectively. The laser driver IC has a 40-mA_{p-p} output current swing. The differential amplifier exhibits a DC to 12.1-GHz bandwidth with a 14.2-dB power gain.

INTRODUCTION

To realize broad-band ISDN, various kinds of monolithic ICs for high-speed optical transmission systems have been developed. Compound semiconductor HBT ICs are expected to be candidates for this kind of system because of their excellent microwave performance and large current driving capabilities.[1]-[6] As key component ICs for this system, a preamplifier, a laser driver, a differential amplifier, and a D-F/F have been newly developed using our HBT fabrication process, which brings about high uniformities.[1] Excellent high-frequency performance over a 10-Gb/s operating range was obtained for all fabricated ICs.

FABRICATION PROCESS

HBT layer structures, prepared by MBE, include an InGaAs emitter cap layer (100 nm, $n^+=2\times10^{19}$ cm^{-3}), an $Al_{0.25}Ga_{0.75}As$ emitter layer (150 nm, $n=3\times10^{17}$ cm^{-3}), a GaAs uniform base layer (80 nm, $p^+=4\times10^{19}$ cm^{-3}), and a GaAs collector layer (500 nm, $n^-=5\times10^{16}$ cm^{-3}). Figure 1 shows the cross sectional view of an HBT fabricated by the developed self-aligning HBT fabrication process. In this process, thick emitter contact metal, consisting of 200-nm-thick WSi and 500-nm-thick Au, is first formed on the InGaAs cap layer. This metal system is used as a mask for the emitter mesa Cl_2 ECR-RIBE dry etching, and the 200-nm-thick SiO_2 sidewall formation is then formed. Below this sidewall, a hetero guard-ring composed of thin-depleted AlGaAs layer is fabricated on the p^+ GaAs extrinsic base region and AuMn base metal is evaporated self-aligning on the emitter mesa.[1][7] This process minimizes dry etching damage and brings about high uniformities in both the HBTs and their IC high-frequency performance.[1] At an operation bias condition for the HBT ICs, when the emitter current density is 4×10^4 A/cm^2, current gain β is 25, and cut-off frequency f_T and maximum oscillation frequency f_{max} are 34 and 32 GHz, respectively.

CIRCUIT DESIGN

Figure 2 shows the HBT IC circuit configurations. For the preamplifier IC (Fig. 2(a)) a transimpedance-type configuration was adopted to obtain both a large transimpedance gain and a broad bandwidth.[1] The feedback resistor value was

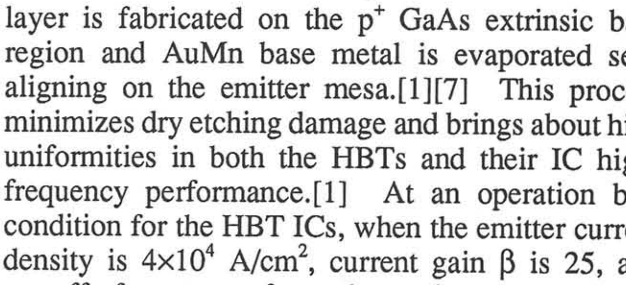

Fig. 1 Cross sectional view of an HBT.

determined to be 300 Ω using circuit simulation so that a 50-dBΩ transimpednace can be realized over a 10-GHz bandwidth.

The D-F/F IC (Fig. 2(b)) was constructed with a master-slave flip-flop stage, input emitter-follower buffer stages, and an output buffer stage. To suppress input and output impedance mismatch between the IC and external circuits, on-chip resistors of 50 Ω and 100 Ω were fabricated for input and output buffers, respectively.

The differential amplifier IC (Fig. 2(c)) consists of two differential amplifier stages with parallel feedback resistors. The feedback resistor values for both amplifier stages are 100 Ω. In this circuit, all HBTs are designed to be biased at a collector-emitter voltage of about 2.0 V to achieve their high-speed operation.

The laser driver IC (Fig. 2(d)) is constructed of input emitter-follower buffer stages and an open-collector-type differential amplifier output stage. HBTs with dual fingers of 2×30-μm^2 emitter stripe were employed to reduce emitter current density at large output current operation.

Photographs of the chips for these ICs are shown in Fig. 3. The emitter size of the HBTs employed in ICs, except for the laser driver IC, is $2\times10\ \mu m^2$ or $2\times20\ \mu m^2$. Built-in voltage over base-emitter heterojunction was utilized for level-shift diodes, and WSiN thin-film resistors were employed for load resistors.

CIRCUIT PERFORMANCE

Circuit performance for fabricated ICs was evaluated using on-wafer probing systems.

Figure 4 shows the transimpedance characteristics for the fabricated preamplifier. A transimpedance gain of 49.0 dBΩ with a DC to 18.5-GHz bandwidth was obtained. On the other hand, power gain and bandwidth were 17.2 dB and DC to 12.9 GHz, respectively.

Figure 5 shows the D-F/F output waveform for 10-Gb/s NRZ signal input. The rise time t_r and the fall time t_f are reduced to 30 and 23 ps, respectively. Since t_r and t_f are degraded by the bandwidth of on-wafer measurement systems, actual values for t_r and t_f can be considered to be faster than the measured values. These values therefore suggest that the maximum operating speed for the D-F/F will be up to 20 Gb/s. Data input sensitivity and clock phase margin were 99.8 mV and 245 degrees, under the error rate of less than 10^{-9} for 10-Gb/s 2^{15}-1 pseudorandom NRZ signals. No waveform degradation was observed for various mark ratios from 1/8 to 7/8.

The differential amplifier exhibited a power gain of 14.2 dB with a bandwidth of DC to 12.1 GHz, as shown in Fig. 6. Input and output return losses were less than -6.0 and -14.6 dB, respectively.

Figure 7 shows the measured output waveform for the laser driver, driving a 50-Ω load for 10-Gb/s NRZ signal input. An output voltage swing of 2.0 V_{p-p} was attained, corresponding to an output current swing of 40 mA_{p-p}. A t_r of 34 ps and a t_f of 29 ps were obtained from 20 to 80% of the output amplitude.

CONCLUSION

We have developed four types of analog and digital ICs for optical transmission systems using AlGaAs/GaAs HBTs. For fabrication of these ICs, the developed AlGaAs/GaAs HBT fabrication process are adopted. Excellent circuit performance for the ICs at high-frequency ranges was obtained: a DC to 18.5-GHz transimpedance bandwidth with a 49.0-dBΩ transimpedance gain for the preamplifier; a t_r of 30 ps and a t_f of 23 ps for the D-F/F; a DC to 12.1-GHz bandwidth with a 14.2-dB power gain for the differential amplifier; and a 40-mA_{p-p} output current swing for the laser driver. These results confirm that this process is suitable for fabrication of high-speed circuits, and that these HBT ICs are adaptable to over 10-Gb/s optical transmission systems.

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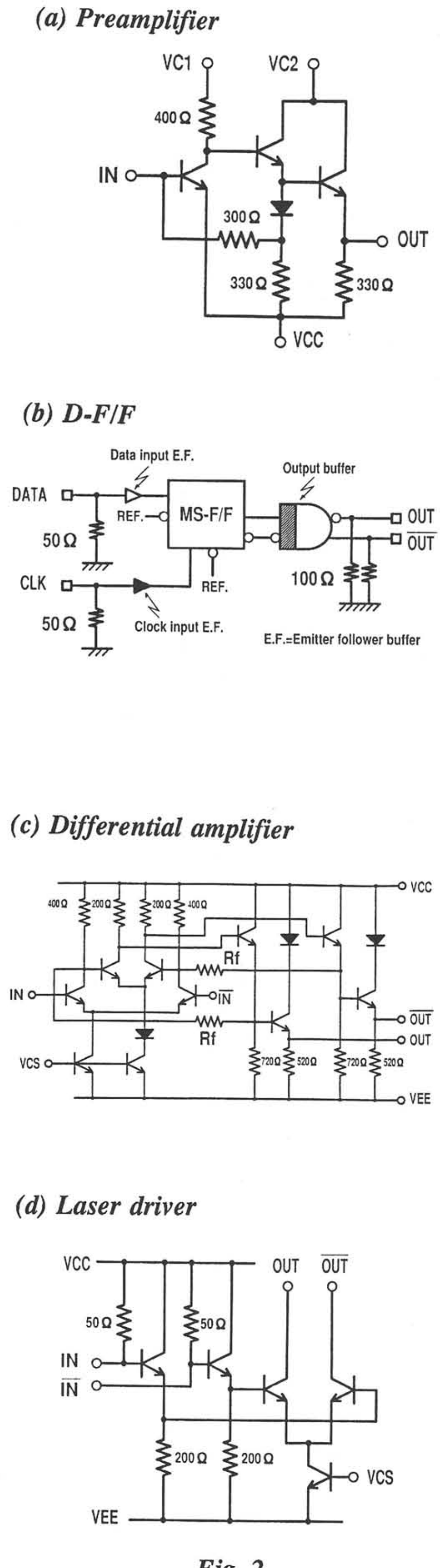

Fig. 2
HBT ICs circuit configurations.

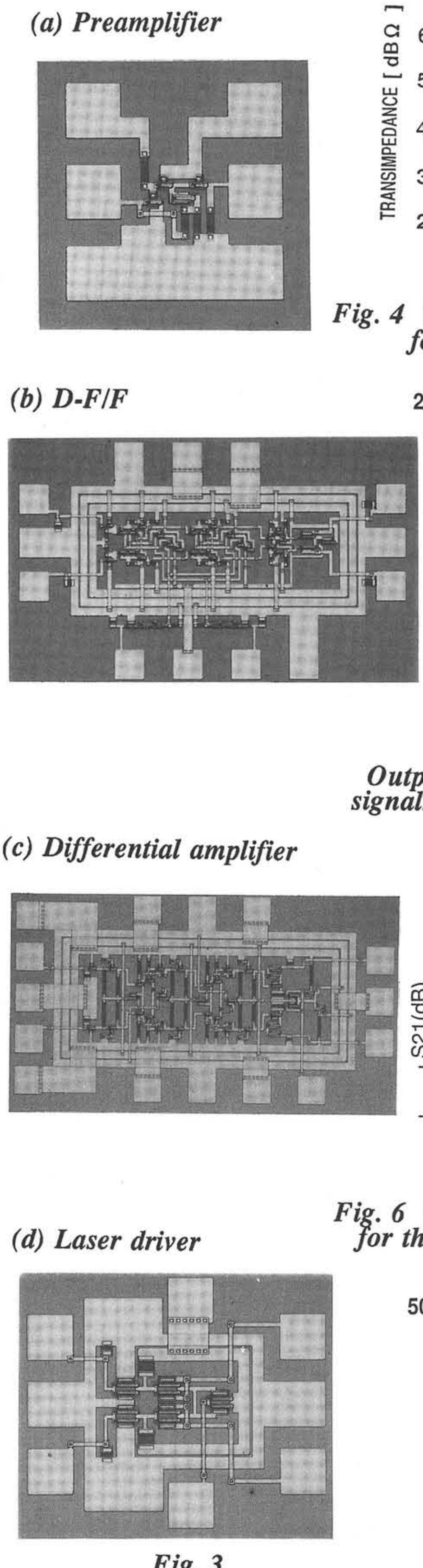

Fig. 3
HBT ICs chip photographs.

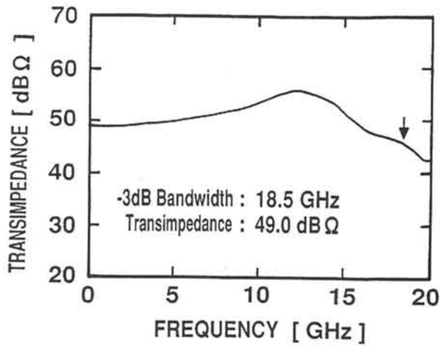

Fig. 4 Transimpedance characteristics for the HBT preamplifier.

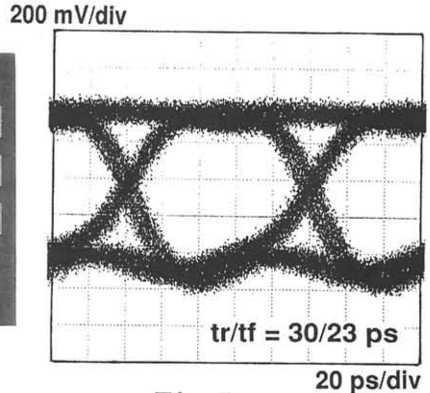

Fig. 5
Output waveform for 10-Gb/s NRZ signals, obtained for the HBT D-F/F.

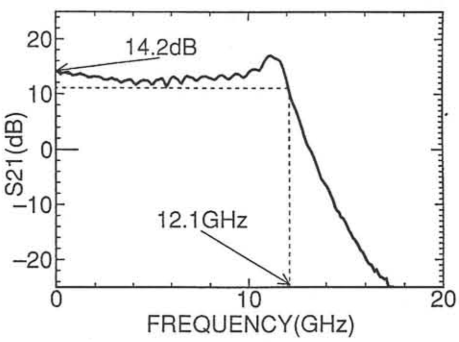

Fig. 6 Gain bandwidth characteristics for the HBT differential amplifier.

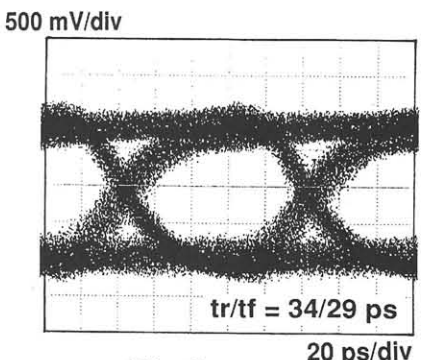

Fig. 7
Pulse response for 10-Gb/s NRZ signals, obtained for the HBT laser driver.