Single- and Dual-Feedback Transimpedance Amplifiers Implemented by SiGe HBT Technology

J.-S. Rieh, O. Qasaimeh, L. H. Lu, K. Yang, L. P. B. Katehi, P. Bhattacharya, and E. T. Croke

***Abstract*— Monolithically integrated SiGe/Si heterojunction bipolar transistor (HBT) transimpedance amplifiers, with single- and dual-feedback configurations, have been designed, fabricated, and characterized. The single-feedback amplifier showed transimpedance gain and bandwidth of 45.2 dBΩ and 3.2 GHz, respectively. The dual-feedback version exhibits improved gain and bandwidth of 47.4 dBΩ and 3.3 GHz, respectively. Their performance characteristics are excellent in terms of their application in communication systems.**

***Index Terms*—Feedback, fiber optical communication, heterojunction bipolar transistor (HBT), SiGe.**

I. Introduction

FIBER optical communication systems have been dominated by III-V-based devices and circuits due to their superior properties over Si, such as high-speed operation, bandgaps corresponding to the long-haul fiber compatible 1.3- or 1.55-μm wavelength, and light-emitting capability [1], [2]. Recent rapid developments in SiGe/Si technology seems to be able to satisfy many requirements of fiber optical communication systems in terms of both performance and cost. Current SiGe/Si heterojunction bipolar transistors (HBT's) demonstrate operating frequencies high enough for next-generation fiber optical communication systems [3], [4]. The bandgap of $Si_{1-x}Ge_x$ alloys can coincide with the wavelength of 1.3 or 1.55 μm by proper choice of Ge mole fraction [5]. SiGe/Si quantum dot light-emitting diodes have been reported, albeit the devices are in an early stage of development [6]. This letter reports experimental results of SiGe/Si HBT-based single- and dual-feedback transimpedance amplifiers, which can be employed as a preamplifier in a front-end photoreceiver of a fiber optical communication receiver module.

II. Fabrication

The schematic of the SiGe/Si n-p-n HBT, grown by molecular beam epitaxy (MBE), is shown in Table I. $Si_{1-x}Ge_x$ alloy was employed as a thin base layer with the Ge mole fraction graded from $x = 0.1$ (emitter side) to $x = 0.4$ (collector side). This grading of Ge composition generates a quasi-electric field which accelerates electrons travelling through the base to collector, resulting in smaller base transit time and eventually higher cutoff frequency compared with a uniform Ge composition profile. The fabrication procedure for mesa-type SiGe HBT's is as follows: emitter metal (Cr/Au = 500/2000 Å) is defined by evaporation on the Si contact layer and used as a mask for the subsequent KOH-based selective wet etching which exposes the base layer for contact formation. Evaporation of the self-aligned base metal (Pt/Au = 200/1300 Å) follows, and then base and collector layers are removed by dry etching to expose the highly doped subcollector layer for collector contact. Collector metal (Ti/Au = 500/2000 Å) is deposited by evaporation on the exposed subcollector layer, and another dry etching is performed for the device isolation. SiO_2 layer is deposited by PECVD and via holes for contacts are formed by selective dry etching of the SiO_2 layer. Evaporation of thick interconnection metal (Ti/Al/Ti/Au = 500/11 000/500/3000 Å) concludes the device fabrication. The process described above leads to high yield and good device characteristics. From the current–voltage characteristics of devices with 2.5 μm $\times$ 10 μm emitter size, a dc current gain β is measured 25. The S-parameters were measured with HP8510 network analyzer in the 0.5–25.5-GHz frequency range. Values of f_T and $f_{\max}$, obtained from the extrapolation of the values of current gain h_{21} and unilateral power gain U at 20 GHz with the assumption of −6 dB/octave roll off, are 23 and 34 GHz, respectively. Two additional processing steps are required to complete amplifier fabrication: formation of thin-film resistors and airbridges. NiCr was

TABLE I
Material Structure of SiGe/Si HBT's

Si	n+	1e19	200 nm
Si	n	2e18	100 nm
$Si_{0.9}Ge_{0.1}$	i		1 nm
$Si_{1-x}Ge_x$ x:0.1→0.4	p+	5e19	30 nm
$Si_{0.6}Ge_{0.4}$	i		10 nm
Si	n-	1e16	250 nm
Si	n+	1e19	1.5 μm
Si Substrate	p-		

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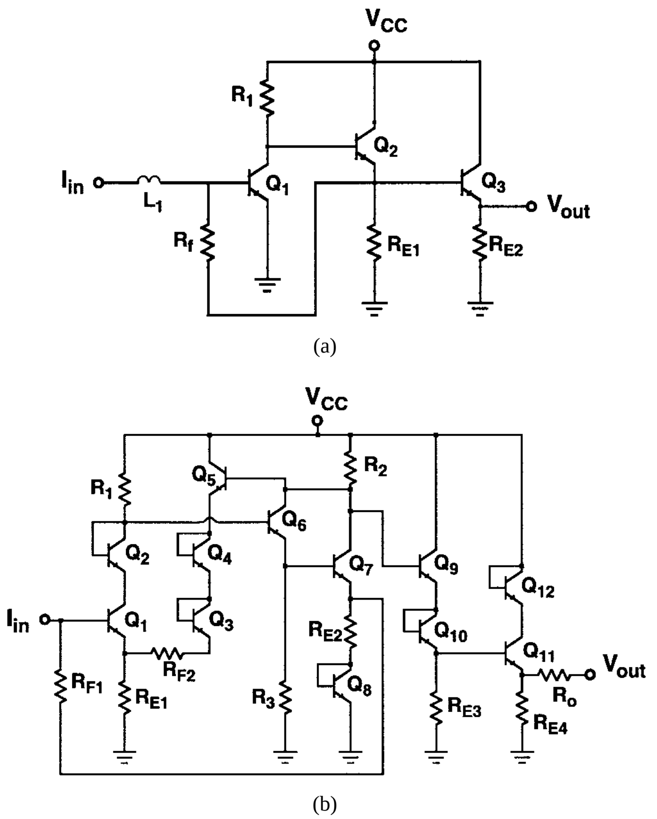

Fig. 1. (a) Circuit diagram of single-feedback transimpedance amplifier. (b) Circuit diagram of dual-feedback transimpedance amplifier.

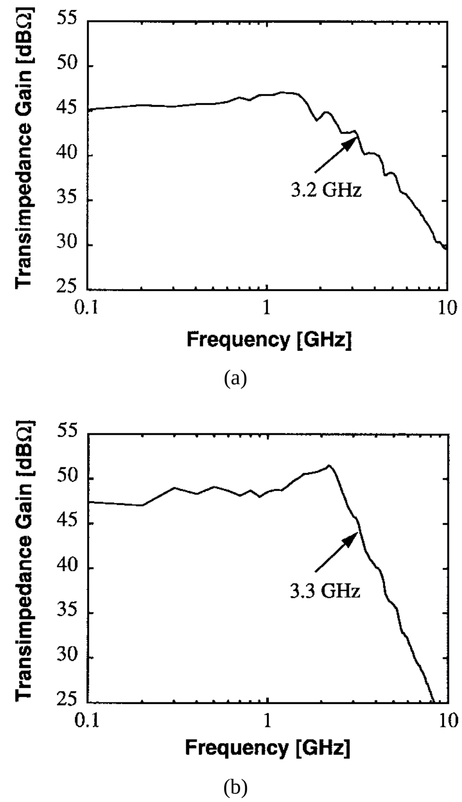

Fig. 2. (a) Frequency response of single-feedback transimpedance amplifier. (b) Frequency response of dual-feedback transimpedance amplifier.

evaporated (700 Å) and used as resistors, with measured sheet resistance of 25 Ω/□. Evaporated metal (Ti/Al/Ti/Au = 500/14 000/500/3000 Å) was used to form airbridges.

III. Results and Discussion

Fig. 1(a) shows the circuit diagram of the single-feedback transimpedance amplifier. It consists of a common emitter gain stage, two emitter follower buffers, a resistive feedback loop, and a front-end inductor. The feedback resistor R_F is the most important component in this configuration since it determines the bandwidth, gain, and noise characteristics of the whole circuit. The value of this resistor should be selected based on tradeoff between these parameters. It is generally known that the increase of R_F increases the gain and improves the noise characteristics, while degrading the bandwidth of the circuit. In this study, the value of R_F was chosen to be 550 Ω, with slightly more emphasis on the bandwidth. The inclusion of front-end inductor L_1 has been shown to improve the signal-to-noise ratio and enhance the bandwidth of the amplifier [1]. The circuit diagram of the dual-feedback amplifier is shown in Fig. 1(b). It includes a second gain stage following the first one, and an extra feedback loop including a resistor R_{F2}, allowing R_{E1} to behave as a voltage feedback. This second feedback, along with the reduced value of R_{F1} (200 Ω), increases the bandwidth of the amplifier. The gain would be reduced due to the additional feedback configuration, but the additional gain from the second gain stage compensates for the reduction and provides an increase of overall gain-bandwidth product of the amplifier compared with the single-feedback amplifier.

The S-parameters of the fabricated amplifiers were measured with a HP8510 network analyzer in the 0.1–10.0-GHz frequency range. Fig. 2(a) shows the transimpedance gain versus frequency characteristics of a single-feedback amplifier circuit. It shows a transimpedance gain of 45.2-dBΩ and −3-dB bandwidth of 3.2 GHz at the bias point $V_{CC} = 3$ V. The gain shows uncharacteristic ripples in the high frequency range, which arise from the external bias probing in on-wafer measurement. The measured bandwidth is slightly enhanced by this ripple and the real value is conservatively estimated to be around 3 GHz. A moderate gain overshoot can be seen in the gain plot. This is ascribed to the parasitic inductance arising from the narrow coplanar ground line surrounding the whole circuit. The frequency response of a dual-feedback amplifier is shown in Fig. 2(b). The transimpedance gain is 47.4 dBΩ and the −3 dB bandwidth is measured to be 3.3 GHz at the bias point of $V_{CC} = 7$ V. This circuit shows improvement in both gain and bandwidth compared with the single-feedback version. These performance characteristics are comparable to III-V-based circuit of the same complexity [7] and indicate the possibility of applying SiGe technology to fiber optical communication systems with the advantages of low cost and simpler fabrication. Increase of V_{CC} affected both gain and bandwidth, leading to an increase of gain and decrease of bandwidth. A similar trend was observed for the single-feedback amplifier. This effect gives rise to another degree of freedom for achieving a tradeoff between gain and bandwidth and allows a postfabrication tuning of gain and bandwidth, which may compensate for the possible deviation of these parameters from designed values due to process variation.

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