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# Design and Fabrication of Packaged Wideband Transimpedance Amplifier by using InGaAs/InP HBT Technology

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## 1. Introduction

In current optical communication systems, high gain and high bandwidth photoreceivers are required for next the generation of optical fiber transmission systems. A preamplifier is typically used as the input stage of the receiver to convert the small current from the photodiode in a voltage signal to be amplified by the subsequent main amplifier [1]. This stage is one of the key circuits in the optical link since it largely sets the sensitivity and maximum bit rate of the receiver. Transimpedance feedback amplifiers are commonly used as preamplifiers with low-input impedance and flat-gain characteristics.

To achieve high quality voltage signals, wideband transimpedance amplifiers have been implemented using InP/InGaAs HBTs technology. Since the InGaAs/InP transimpedance amplifiers allow monolithic integration with a p-i-n photodetector, these amplifiers have been widely investigated and have demonstrated excellent device and circuit performances.These amplifiers have been designed as general purpose gain blocks for using 40 Gb/s system.

## 2. Experiments

The devices used in this work were grown by molecular beam epitaxy (MBE) fabricated using a triple-mesa isolation structure. Si and C were used as the n- and p- type dopants, respectively. Epi-structure was composed of InP-emitter on InGaAs-base layer with abrupt junction. The epitaxial layer mainly consisted of a 500 Å-thick n-InP ($n = 5\times10^{17}$ $cm^{-3}$) emitter layer, a 500 Å-thick p-InGaAs ($p = 4\times10^{19}$ $cm^{-3}$) uniform base layer, a 500 Å-thick n-InGaAs/InAlAs chirp superlattice, a 3000 Å-thick n-InP ($n = 2\times10^{16}$ $cm^{-3}$) collector layer, and a 4000 Å-thick n-InGaAs ($n = 2\times10^{19}$ $cm^{-3}$) sub-collector layer. In this device, the passivated surfaces are side wall of InP emitter mesa and high doped p-type extrinsic InGaAs base layer. A slilicon nitride film was deposited by plasma-enhanced chemical-vapor deposition (PECVD). The NiCr resistor and metal-insulator-metal capacitor were also integrated with InGaAs/InP HBTs.

## 3. Results

The non-self aligned HBT was used for the reliable high-frequency operation in the densely integrated circuits. The device size of HBT used as active device of transimpedance amplifier is $1.2\times8$ $um^2$. DC and RF characteristics for the device were measured. InGaAs/InP HBTs demonstrated the stable DC operation and its offset voltage was 0.137 V, and the current gain more than 54 was routinely obtained. As shown Fig. 1, the developed HBTs showed a cut-off frequency ($f_T$) of 138 GHz and a maximum oscillation frequency ($f_{max}$) of 203 GHz at the collector current of 14.9 mA.

We designed common-base transimpedance amplifier composed of four types of stages: a input stage, gain stage, emitter-follower buffer stages, and a 50-Ω impedance matching stage. Fig. 2 shows the schematic of fabricated transimpedance amplifier. In order to exploit the high responsivity performance of the photodiode-transimpedance amplifier optical receiver, common-base transimpedance amplifier has been fabricated. The common-base transimpedance amplifier buffers the transimpedance amplifier from the high-impedance photodetector, and improves the bandwidth [2]. The input signal current is amplified by the common emitter gain stage. The feedback network which consists of resistor stabilizes the transimpedance gain. The feedback resistance is 700 Ω and single supply voltage is 3.3 V. The overall chip layout was carried out minimizing the signal path from input pad to output pad. Chip size, including electrode pads for on-wafer measurement and packaging wire bond, is $0.675\times0.525$ $mm^2$ for the transimpedance amplifier. RF signal pads for single input and output are configured to ground-signal-ground type with 150 um pitch on the left and right sides, respectively, for RF on-wafer probing.

The transimpedance gain extracted from simulated S-parameters is about 41.0 dB Ω and 3-dB bandwidth of 35 GHz is achieved by using capacitance peaking technique [3]. A peaking capacitor is used to increase the overall bandwidth of transimpedance amplifier. In this work, we carried out the circuit simulation including loss by transmission lines in circuit. When we considered the line effect, the transimpedance gain of the transimpedance amplifier was reduced as frequency was increased.

The effective transimpedance gain without photodetector was measured on-wafer with coplanar probes. The transimpedance amplifier exhibited an $S_{21}$ gain of 7.3 dB, and $S_{22}$ was less than –5 dB over a frequency range of less than 40 GHz. The developed transimpedance amplifier provides a bandwidth of 33.5 GHz and a transimpedance gain of 40 dBΩ as shown in Fig. 3. The transimpedance gain ripple about 3.7 dB was also showed. Power dissipation was 82.5 mW with single voltage supply of 3.3 V. These characteristics make the transimpedance amplifier suitable for use in a high-speed optical receiver.

For packaging processes, the whole wafer was sliced to separate chips. Each chip was mounted on a patterned ceramic board and wire bonded and assembled in an

Au-plated metal case with SMA connectors for input and output ports. Fig. 4 shows the assembled transimpedance amplifier module. The eye patterns for the finally packaged transimpedance amplifier were measured using 40 Gb/s multiplexing system. The 40 Gb/s output eyes show a clear pattern of 47 mVpp for input of 15 mVpp with the rise and fall times less than 10 psec, as shown in Fig. 7. When the input signal was 51 mVpp, the measured output voltage swing amplitude was 146 mVpp.

## 4. Conclusion

In conclusion, we have successfully developed wide-band transimpedance amplifiers by using InGaAs/InP HBT technology. InGaAs/InP technology is preferred for design and fabrication of 40 Gb/s transimpedance amplifier. Experimental results demonstrate a transimpedance of 40 dBΩ and 33.5 GHz 3dB-bandwidth with S-parameters measured on wafer. Power consumption for the amplifier is 82.5 mW and the chip size is 0.354 $mm^2$. Transimpedance amplifier modules were fabricated by ceramic substrates and wire bonding. Eye diagram measurements for transimpedance amplifier modules were carried out at a data rate of 40 Gb/s. The electrical 40 Gb/s voltage signal was generated by multiplexing pseudo-random 10 Gb/s signals. A clear opened eye diagrams at 40 Gb/s data rates were achieved.

## References

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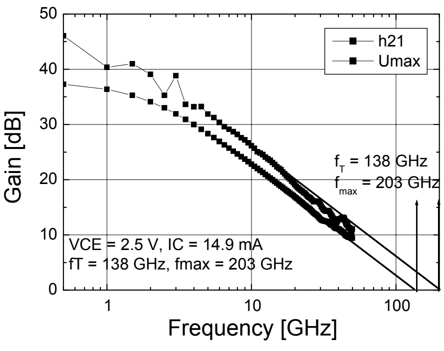


Fig. 1 Microwave performance of 1.2×8 $um^2$ single emitter InGaAs/InP HBT at $V_{CE}$ = 2.5 V, $I_C$ = 14.9 mA.

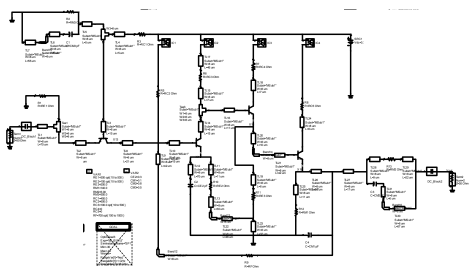

Fig. 2 Schematic of the transimpedance amplifier.

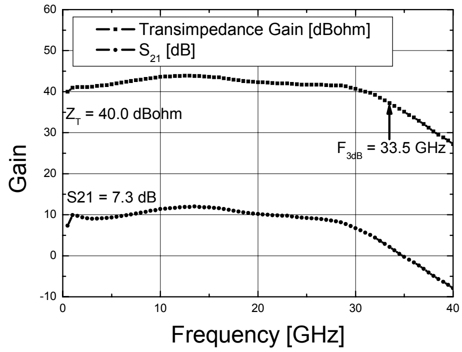


Fig. 3 Measured transmission coefficient $S_{21}$ and transimpedance gain of the transimpedance amplifer.

Fig. 4 Photographs of the fabricated transimpedance amplifier module.

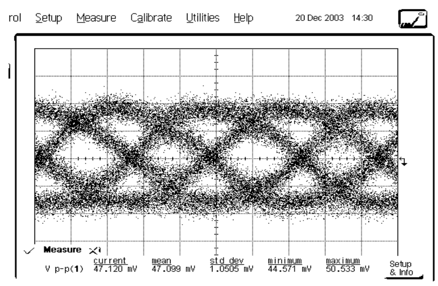


Fig. 5 Measured output eye diagram for 40 Gb/s input signal of the transimpedance amplifier module.