Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 368–369

F-3-1 (Invited) InP HBT Device technologies for Ultra High-Speed Optical Communication Ics

T. Tanoue, K.Ouchi, K. Watanabe, and R. Takeyari
Central Research Laboratory, Hitachi, Ltd.
1-280 Higashi-Koigakubo, Kokubunji, 185-8601 Tokyo, Japan

Introduction

The data volume in optical-fiber transmission has been increasing rapidly. For the backbone transmission systems, 10-Gb/s optical transmission system has already been widely used. In order to further increase the bit rate of the optical transmission system up to 40-Gb/s, transistors with four-times higher performances than those used for 10-Gb/s systems are required. We have developed InP HBTs to be used in the 40-Gb/s optical transmission ICs. A 40-Gb/s optical transmitter with full monolithic ICs were realized using developed InP HBTs. In this paper, device technologies developed for the InP HBTs are presented.

In optical transmission ICs, as a rule of thumb, the cut-off frequency f_T (in GHz) required for the transistors is about four times the bit-rate (in Gb/s). The maximum oscillation frequency f_{max} is around twice as high as fT. This means that fT of transistors for 40-Gb/s systems should exceed 160GHz and f_{max} 320GHz. We have aimed at achieving this level of performance, along with realizing simple fabrication process for high yield and low thermal resistance for high thermal stability.

Device structure

In order to realize very high performance, we chose InP/InGaAs HBT which have shown about 1.5 times higher fT than AlGaAs/GaAs HBT with the same layer thicknesses. Consequently, the base-collector capacitance (C_{BC}) of an InP/InGaAs HBT can be reduced to 2/3 of that of an AlGaAs/GaAs HBT with the same fT and lateral geometry. It should be noted that, in realizing high f_{max} for optical communication ICs, the reduction of C_{BC} is much more important than the reduction of the base resistance Rbb'.The epitaxial layers were grown by gas-source molecular beam epitaxy (MBE), using elemental In and Ga for group III source, thermally cracked AsH_3 and PH_3 for group V source, and elemental Si and CBr_4 gas for n-type and p-type dopants, respectively. By optimizing growth conditions, no intermixing of materials or diffusion of dopants have been observed at the heterostructure interface.For simple fabrication process, we have developed a self-aligned process using T-shaped emitter electrode. This process enabled us to create well-controled spacing of 0.15μm between the emitter area and the base electrode.

We also developed a new base electrode with Pt/Ti/Mo/Ti/Pt/Au structure that reduces the base contact resistivity into low 10-7 Ωcm^2 and withstands annealing up to 400C. Both emitter and base mesa were formed using emitter and base electrode as masks to minimize parasitic capacitances and resistances.

For the thermal stability, we adopted InP sub collector to reduce thermal resistance. The thermal conductivity of InGaAs is 1/20 of that of InP; therefore, the exchange of sub collector material from InGaAs to InP has reduced the thermal resistance of a HBT down to half, increasing the area of safety operation.

A transistor model for circuit simulation was also developed. The model is based on Gummel-Poon model, and , by incorporating self-heating effect and its frequency dependence, DC current error was reduced to less than 5% under normal operating condition.

Results

Fabricated InP/InGaAs HBTs exhibited f_T exceeding 150GHz and f_{max} reaching 300GHz with base and collector thicknesses, W_B and W_C, of 50nm and 400nm. By reducing W_B and W_C down to 30nm and 200nm, f_T reached the very high value of 235GHz; however, the f_{max} was reduced to 100GHz.

Various circuits for optical communication were designed and fabricated. A static 1/2 frequency divider operated up to 44GHz, and its input /sensitivity was less than 500mV, the logic swing of the circuit, at 40GHz. Other circuits such as differential amplifiers and preamplifiers also showed performances high enough to handle 40-Gb/s signal.

Summary

We have developed InP/InGaAs HBTs for ultra high-speed optical communication ICs. By using self-aligned process with T-shaped emitter electrode and incorporating Pt-based new base electrode, the parasitics of the fabricated HBTs were minimized. Several ICs including static frequency divider and amplifiers were designed and fabricated. Those ICs exhibited 40-Gb/s class performances.

References

[1]H. Masuda et al, Proceedings of IPRM'95, p644
[2]K.Watanabe et al, Proceedings of APCC/OECC'99