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DEVICE OPTIMIZATION OF LASER AND HETEROBIPOLAR TRANSISTOR FOR LASER/DRIVER OEIC

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I. Introduction

The monolithic integration of a laser/driver OEIC which allows high frequency operation up to 5 Gbit/s has been recently reported /1/ applying ridge waveguide lasers and heterobipolar transistors oriented in diagonal direction, all buried in polyimide. As a different approach, monolithic integration of buried heterostructure lasers with invertible HBTs has been demonstrated /2/ using a very flexible concept: combination of etching technique, and selective epitaxy of semi-insulating InP in a low pressure MOVPE step results in burying the laser stripe and in the electrical isolation of electronic and optoelectronic devices on the wafer.
Following this concept, we present an optimization of the respective high speed lasers and the transistors for a transmitter OEIC with a data rate above 5 Gbit/s. To realize these high speed OEICs it is foreseen to reduce parasitic capacities by introduction of semi-insulating substrates.
For this purpose, suitable laser structures on SI-InP substrates were to be developed. In addition, the HBTs had to be optimized to find a suitable compromise between sufficient high speed transistor performance and the high current driving capability necessary to achieve a sufficient laser modulation at high frequencies .

II. Integrable 1.55 μm strained MQW lasers

Our integration concept (Fig. 1) is based on a laser diode of standard SI-BH structure with laterally grown semi-insulating InP current blocking layers. This laser structure offers low threshold currents down to 10 mA, low serial resistance down to 5 Ω, and a low parasitic capacitance of about 2 pF. High small signal 3dB bandwidth up to 13 GHz /3/ and a data rate of 10 Gbit/s NRZ have been achieved /4/. This very promising laser structure had to be modified for application in a transmitter OEIC to allow an electrical access on the lasers n-side on top of the substrate.

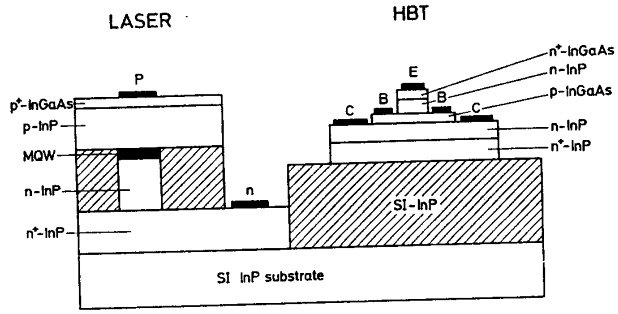

Fig. 1: Concept of the laser/ driver OEIC with SI-BH laser diode and heterobipolar transistor

In first experiments 1.5 μm strained layer MQW lasers have been realized using three low pressure MOVPE steps. In a horizontal reactor with rectangular cross section trimethylalkyls and pure hydrids are used as precursors, hydrogen sulphide as n-type dopant, diethylzinc as p-type dopant and ferrocene for the growth of semi-insulating InP.
A schematic drawing of the laser structure is given in fig. 2. First a 1.0 μm thick highly n-doped InP bottom contact layer is grown on a Fe-doped substrate, followed by the growth of an InP cladding layer and the MQW. This first MOVPE process is carried out at 20 hPa reactor pressure and a growth temperature of 675 °C.
After definition of the lateral structure by etching a narrow mesa, selective regrowth of the current blocking layers in the side wall area is done in a second MOVPE step (50 hPa at 600 °C) using a self-aligned technique. The layer structure is completed by MOVPE growth of the upper cladding layer and a highly p-doped InGaAs top contact layer.
10 μm apart from the mesa a channel is etched in order to contact the n^+-doped InP bottom contact layer. The distance between contact channel and laser mesa must be small to avoid a dramatic increase of serial resistance. For a 300 μm long laser the additional resistance of the bottom contact layer has

been measured to be below 1 Ω. After passivation with PECVD deposited SiO_2 Ti/Pt/Au p-type ohmic contacts and AuSn n-type contacts are formed. The substrate is then thinned down to 100 µm and a solder metal layer is deposited on the substrate side of the wafer. Using rapid thermal processing the contacts are annealed at 450 °C.

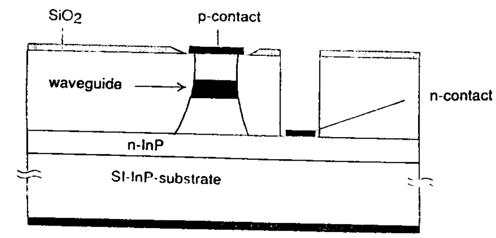

Fig. 2: Schematic view: the lateral structure of the 1.55µm strained layer MQW laser on SI substrate

The performance of the MQW laser devices was characterized by measurement of the light output (cw). Compared to lasers on n-doped substrates the yield is not reduced by the introduction of the semi-insulating substrate. Low threshold currents down to 16 mA and a differential quantum efficiency of 15% have been observed for the SI substrate based MQW lasers [fig. 3]. Applying a laser drive current of 100 mA the optical output power is nearly 10 mW, which makes them well suited for the further application in a laser/driver OEIC.

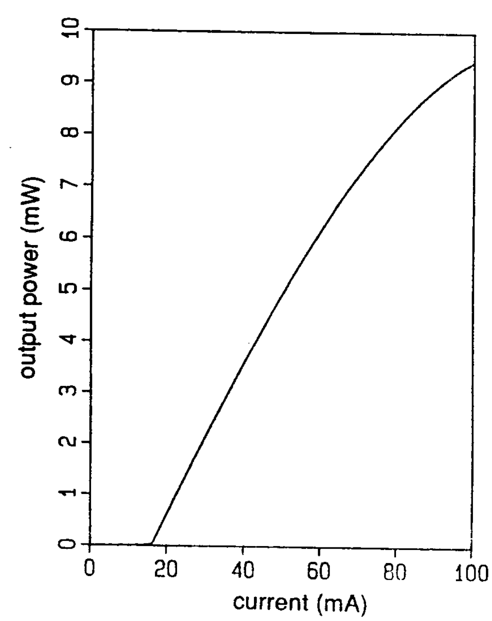

Fig. 3: Optical output power versus drive current for a 1.5 µm strained layer MQW laser on SI substrate

III. Integrable Double Heterostructure Bipolar Transistors

The bipolar transistors in a transmitter OEIC have to fulfill several partly contradictiory requirements, e.g. high current drive capability, sufficient high emitter-collector breakdown voltage, high transit frequency and a sufficiently high current gain.

Earlier work of our group has been focussed on DHBTs with very high current amplification above 25000 /5/. These transistors had a moderately doped base layer which allowed only moderate transit frequencies below 1GHz. For an improvement of the transistor´s frequency behaviour an increase of the base doping and a geometry with a smaller emitter area were inevitable, however, on the prize of a reduced current amplification.

The layer structure of the heterobipolar transistor is grown on semi-insulating substrate using low pressure MOVPE again. It consists of a highly n^+-doped InP subcollector, an InP collector, a p-type InGaAs base layer, a n-type InP emitter and a highly n-doped InGaAs contact layer.

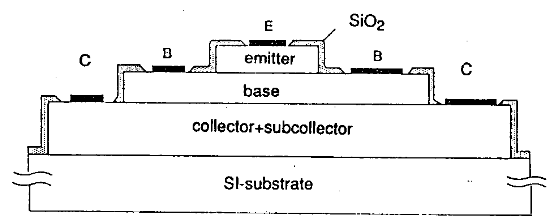

Fig. 4: schematic cross section of a DHBT

HBT devices with one and two base finger geometry have been realized with a not self-aligned technology. The lateral transistor geometry [fig. 4] is defined by standard photolithography and three selective wet chemical etch steps. After passivation with PECVD deposited SiO_2 a Ti/Pt/Au contact is used for the base metallisation and AuSn/Ti/Pt/Au for emitter and collector contacts. The contacts are annealed at 450°C. In the last step the metallisation for the contact pads and the electrical interconnections is deposited. DC and small signal frequency response measurements of the DHBTs are carried out on the wafer.

Increasing the base doping of a 0.2 µm thick base layer to $2 \cdot 10^{19}$ cm^{-3} we observed an increase of transit frequency, but also a decrease of the current gain β down to 25.

A base doping of $5 \cdot 10^{18}$ cm^{-3} appears as a good compromise between the high frequency behaviour and DC characteristics. The output characteristic of such a transistor is shown in fig. 5. An emitter-collector breakdown voltage above 5V , an offset voltage of 200 mV and a maximum differential current gain of β=120 have been achieved. The collector current of this transistor exceeds 100 mA, leading to a high current drive capability. With these dc data the transistors should be sufficient for application in a transmitter OEIC.

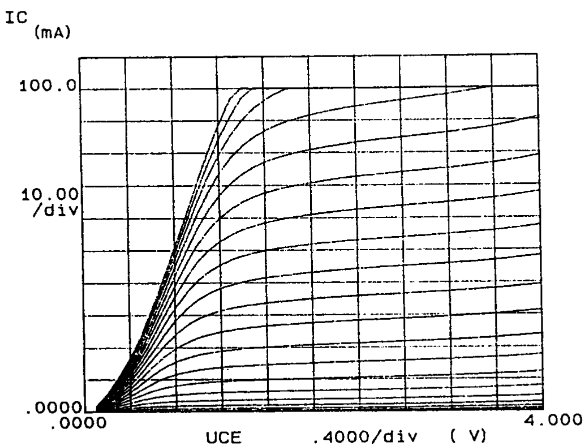

Fig. 5: Common emitter characteristic I_C-V_{CE} of an integrable heterobipolar transistor. Base current steps: 100 µA.

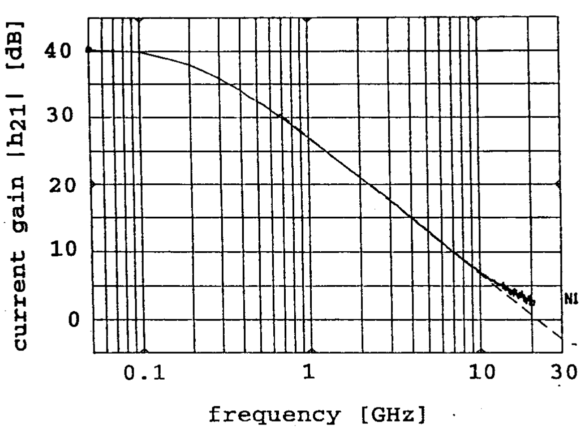

Fig. 6: Frequency dependence of current gain $|h_{21}|$ measured at a collector current of 50 mA

Measurements of small signal frequency response showed a current gain cutoff frequency of f_T= 22 GHz, f_{max}= 7 GHz and a current gain of 40 dB at low frequencies. The improvement of our transistor's transit frequency to 22 GHz and the remarkable current drive capability should enable the realisation of a laser/driver OEIC with a data rate in the range of 5 Gbit/s.

IV. Summary

At the 1991 Conference on "InP and related compounds" we have reported the integration of a SIBH laser and an invertible heterobipolar transistor as an emitter follower in a 600 Mbit/s OEIC on n-doped InP substrate /2/. By optimisation of the transistor's base doping and the transistor geometry an improvement of the frequency behaviour has been achieved. The DC characteristic should be sufficient for the application in an integrated circuit. Together with the results of the 1.5 µm SIBH laser on semi-insulating InP this appears as a good base for the realization of a transmitter OEIC consisting of a laser and a differential amplifier electronic circuit including resistors and capacitors.

Acknowledgement

The work described in this paper was partially financed by Deutsche Bundespost Telekom.

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