Integration of heterostructure bipolartransistors with electroabsorption waveguide modulators and applications

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Abstract

There is a continuous development in the monolithic integration of electronic and optical devices to add functionality and improve performance. For a short review on heterostructure bipolar transistors (HBTs) combined with lasers or photodetectors see e.g. [1]. The following work focuses on the combination of HBTs and electroabsorption waveguide modulators (EAMs). One way is to stack the two layer structures for each device on top of each other [2], resulting in two separate devices, which have to be processed one after the other. A different possibility merges the modulator into the layer stack of the HBT. This was done for a GaAs-based HBT, where a carrier-injected optical intensity modulator is implemented in the base layer [3]. In our InP-based approach we insert the waveguide into the collector region and use the electric field for band gap changes in the guide material for modulation (Franz-Keldysh effect, FKE). The resulting layer stack enables a new type of merged device (HBT-EAM). This corresponds to a modulator with an integrated amplifier and therefore the demands on a driver circuit can be reduced. Additionally, optical waveguides, modulators and bipolar transistors can be processed as single devices from the same layer.

If the HBT of the merged device is operated in the common emitter configuration with load resistance it is able to switch the build-in EAM (Fig. 1). When the transistor is in off-state, the base-collector diode is reverse biased, which results in a high electric field inside the collector, i.e. in the region of the optical waveguide, thus the optical power is absorbed. If the collector current is increased, the transistor switches to the on-state, which reduces the electric field inside the waveguide, therefore the absorption coefficient decreases and the waveguide gets transparent.

To optimize HBT and EAM operation design-rules include various trade-offs. Cladding layers have to be chosen thick enough not to degrade the HBT-collector. Furthermore low back-doping of the upper cladding/collector improves the electric field in the guide, but declines transistor operation, which can be avoided by the addition of a composite collector at the base/collector transition. The choice of high band gap material in the upper cladding, needed for waveguiding, also improves breakdown voltage $BV_{CE}$. The resulting layer system grown by MOVPE is shown in Fig. 2.

From this layer structure isolated transistors and modulators as well as merged devices and basic application circuits were processed simultaneously using optical lithography with conventional wet-chemical etching and metallization steps (Fig. 3). The HBT’s with an emitter area of $3*10^3 \mu\text{m}^2$ show collector currents of 5mA and current gains up to 50 with collector-emitter voltages above 6V. High-frequency values are $f_t=30\text{GHz}$ and $f_{max}=25\text{GHz}$. Mesa waveguide modulators (EAM’s) with $20\mu\text{m}$ length and $9\mu\text{m}$ width exhibit a 3dB cut-off frequency of 10GHz (at 1.55\mu m). The HBT-EAM (in HBT-configuration) show values of $f_t=23\text{GHz}$ and $f_{max}=20\text{GHz}$. Optoelectronic DC-measurements of a HBT-EAM (in common-emitter configuration) are illustrated in Fig. 4. The device achieves an optical contrast of more than 4dB at a base current switched from 6mA to -2mA at $V_{CE}=-10\text{V}$.

As an application a circuit where two HBT-EAMs are combined as a differential amplifier is presented (Fig. 5a). The two devices are fed with light by an on wafer Y-beam splitter, which results in a light-switch. An electrical measurement at 2.55GHz is shown in Fig. 5a.


Fig. 1: HBT-EAM in common emitter configuration. The EAM is implemented in the HBT-collector and is driven according to $V_{CB}$.

Fig. 2: Multifunctional layer-stack, which combines HBT and EAM.

Fig. 3: SEM-graph of a HBT-EAM in a four mesa process: "W" denotes the waveguide.

Fig. 4: Optical contrast of a HBT-EAM in common-emitter configuration. The transistor is switched off completely only with small negative $I_B$ due to absorption of light.

Fig. 5: a) Two HBT-EAMs connected as a differential amplifier; b) time-domain measurement at 2.55GHz. Output is loaded with 50Ω because of sampling oscilloscope. Open-loop gain is around 10.