Microwave Characteristics of the TEAT Phototransistor

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Abstract — **Recent results on the photodetector characteristics of waveguide transistor electroabsorption transceiver (TEAT) components in the microwave region are presented. The application of the TEAT as an optoelectronic mixer and transceiver will further be discussed.**

INTRODUCTION

Monolithic integration of optical and electronic devices is of increasing importance for optical networks, as their complexity can greatly be reduced, when intelligent solutions at the transmitter and receiver side can be realized.

We have recently developed a “super-integrated” device where a 1.55µm waveguide electroabsorption transceiver (EAT) is embedded in the layers of a heterostructure bipolar transistor (HBT)[1]. The basic multifunctionality of this combined transistor-electroabsorption-transceiver (TEAT [1][2]) element has been successfully demonstrated. The multifunctionality includes the use of the TEAT as an optical modulator, detector, transceiver, as well as an electrical transistor. The transceiver is able to transmit and to receive optical signals at the same time using different optical wavelengths [3], i.e. WDM techniques. Further we have shown the possibility to fabricate integrated circuits consisting of optical, optoelectronic and electrical components on the same chip using the same layer structure without the need for stacked layers [4] or regrowth techniques [5].

In this paper, we present the phototransistor properties of an advanced type of the multifunctional waveguide TEAT with a semi-transparent InGaAlAs-base. In this concept the dual use of almost every layer of the TEAT provides a layer structure comparable to a standard HBT and – with respect to its layout – a simpler and thinner structure than recently published by the same authors (Fig. 1) [1]. The waveguide is build from the different layers of the HBT. The sub-collector and the InP substrate serve as lower cladding. The optically active guide, which is used to modulate light using the Franz-Keldysh effect and to absorb light in detector operation of the TEAT, is also part of the collector. The upper cladding of the waveguide is split into two parts acting as base and emitter layers. The dual use of almost all transistor layers allows a thinner collector region than in previous designs and therefore higher electrical fields in this region. This provides a better tunability of the absorption by an applied voltage. The base contact not only allows an optimal adjustment of the operating point of the TEAT, but also ad-

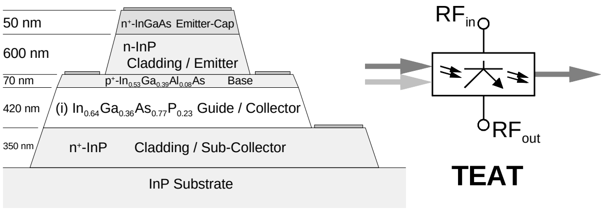

Fig. 1. Cross section of a TEAT and its symbol.

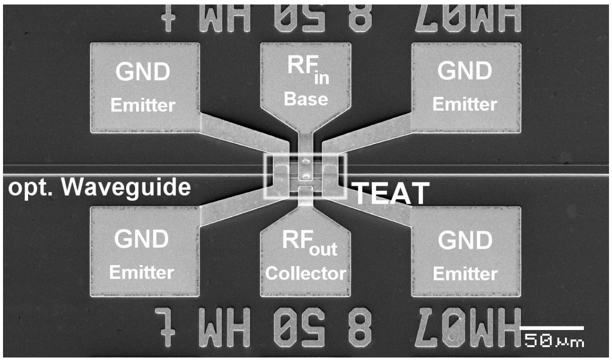

Fig. 2. SEM image of a single TEAT.

vanced functions such as the mixing between electrical and optical signals applied to the optical and the electrical inputs. Therefore the TEAT can also be used as an optoelectronic mixer for up- and downconversion.

As the electrical signal can modulate the cw-light and as the optical signal appears at the electrical output, the TEAT works also as a transceiver.

TECHNOLOGY OF THE TEAT

The TEATs were fabricated using the structure shown in Fig. 1 with the optical waveguide perpendicular to the paper plane. Since the emitter and especially the base layer are part of the upper cladding, they have to be made of materials transparent for light of 1.55µm wavelength, so that the common InGaAs base can not be used. The addition of aluminum is able to increase the bandgap, but on the other hand the transistor function is degraded in terms of current amplification and recombination. We used $In_{0.53}Ga_{0.39}Al_{0.08}As$ as a compromise.

Conventional optical lithography together with wet-etching and metallization in a four mesa process was used for processing the devices [1]. Fig. 2 shows an SEM image of a TEAT with electrical contact pads and the 8µm wide optical waveguide passing horizontally through the device, which is 50µm long. The passive waveguides are approximately 250µm long at each side and are made from the collector layers with a polymeric upper cladding. This allows us to remove the base layer whose material still has a high absorption coefficient due to the high p-doping. The optical waveguides were cleaved to achieve clean facets for coupling to an optical fiber.

For the implementation of circuits on-chip resistors can be realized by isolated films using the sub-collector layer. Because all components are fabricated in the same process, optoelectronic circuits can directly be realized without additional effort [2].

The devices are experimentally studied as transceivers using an optical link as shown in Fig. 3. The modulation part is shown on a light gray background, the part of the setup for the measurement of the detector characteristics on a dark gray. Two tunable lasers (bottom left) at slightly different wavelengths are mixed to generate a heterodyne signal, which is detected by the TEAT. The detected signal is measured by an electrical spectrum analyzer (bottom). A third laser (top left) at a larger wavelength is applied to be modulated by the TEAT with the electrical signal of an RF-synthesizer (top). The modulated optical signal is amplified by an EDFA, filtered by an optical bandpass to remove spontaneous emission, and detected by a fast photodiode. Its output is connected to a second spectrum analyzer (right). Optical coupling into and out of the cleaved wave-

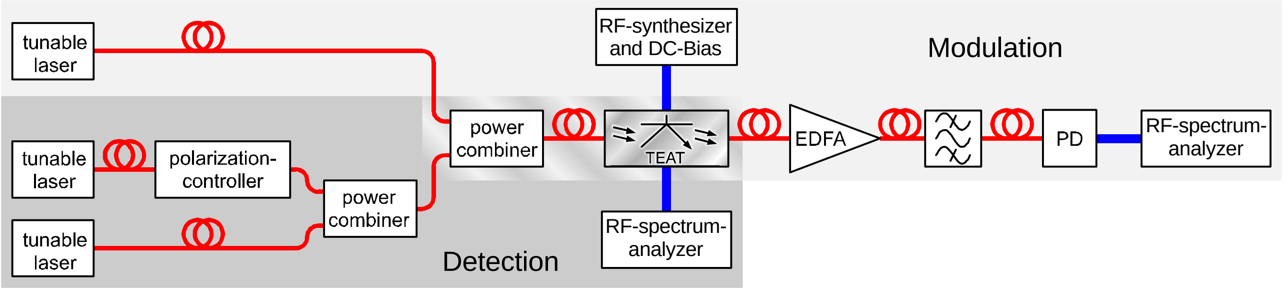

Fig. 3. Setup for opto-electronic transceiver measurements (PD: photodetector).

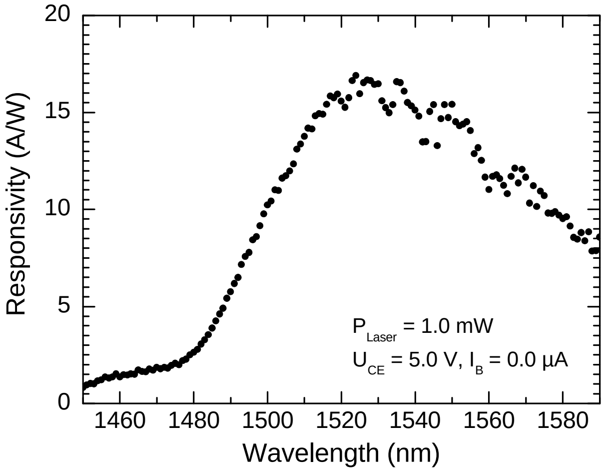

Fig. 4. DC-responsivity of a TEAT vs. optical wavelength.

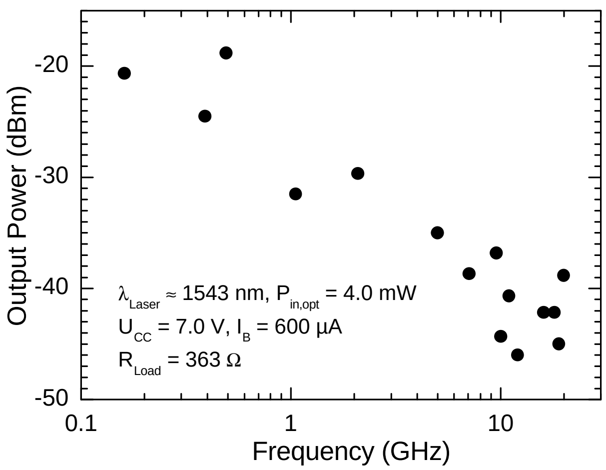

Fig. 5. Frequency response of the TEAT.

guide is done using a tapered lensed single-mode fiber. The optical losses from the input fiber to the output fiber add up to approximately 30dB, which include back reflection at the facets, mode mismatch between fiber and waveguide, and absorption losses in the passive optical waveguide.

Electrical probing of the samples is done using coplanar wafer probes and the TEAT is operated in a common emitter amplifier circuit with a collector load resistor.

DC-measurements of the detection characteristic were performed using just one tunable laser which is coupled into the TEAT while the photocurrent through the device is measured.

MEASUREMENTS

At first the DC responsivity was measured for a wavelength range from 1450nm to 1590nm. A peak responsivity of 17A/W was measured at wavelengths around 1525nm for an operating voltage of the device of U_{CE}=5.0V (Fig. 4). This shows the internal amplification of the TEAT operated as a phototransistor. A TEAT design not shown here with highly absorbing InGaAs-base even shows a responsivity of up to 105A/W.

RF measurements were accomplished by using the detection part of the setup in Fig. 3 with an average optical input power of 6.0dBm. Optical losses in the passive waveguide and at the fiber chip coupling are not removed from the given data but can be estimated to be approximately 11dB. A DC bias of U_{CC}=7.0V and I_{BE}=600µA was applied also using an external collector load resistor of R_{Load}=363Ω. Fig. 5 shows the frequency response of the TEAT for detector operation at this operating point. The electrical output power drops from an initial value of about -20dBm at approximately 10dB per decade in the considered range.

For transceiver experiments the whole setup shown in Fig. 3 has been used. An RF-signal of f = 5.25GHz for modulation of a cw-beam (λ_{mod}=1550nm, $P_{cw,mod}$=-3.6dBm) was applied at the transceivers electrical input by an RF-synthesizer. The optical heterodyne signal applied to the optical input had a center wavelength of 1543nm and a difference frequency of Δf=5.51GHz at an average power of 1.6dBm. These frequencies are very interesting for wireless LAN applications. In Fig. 6 the spectrum of the transmitted signal can be seen, being modulated by the TEAT and detected by a fast photodiode. The peak value of the detected signal achieves -59.5dBm. Here one has to take into account, that the spectrum is an uncorrected result where losses and the sensitivity of the photodiode are not taken into account. The responsivity of the photodiode is only 0.27A/W for an average optical input power of the photodiode of 445µW. Fig. 7 shows the spectrum of the electrical output. The modulation signal dominates the spectrum because of the amplifier setup as given by a

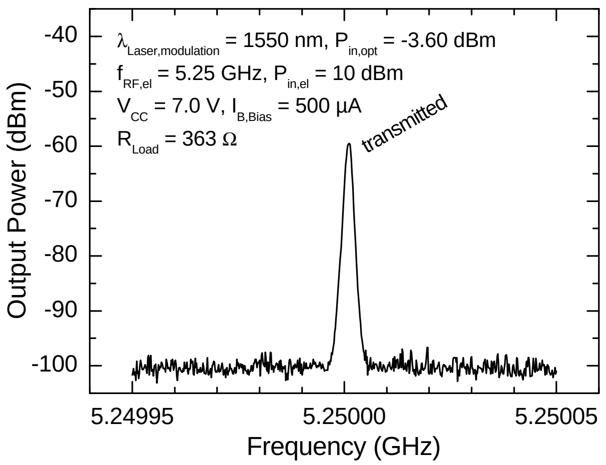

Fig. 6. Electrical spectrum for transceiver operation of the TEAT: measured modulated optical output using a photodiode and an electrical spectrum analyzer.

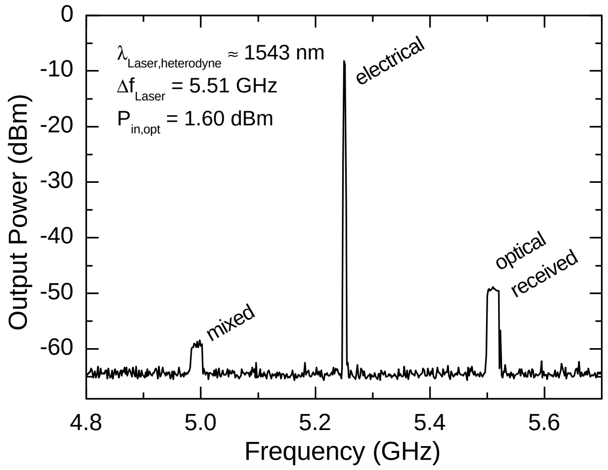

Fig. 7. Electrical output of the TEAT in the transceiver mode for the received optical signal, the electrical signal for modulation and the mixing product of both.

suitable operating point of the TEAT. On the right hand side of this peak the received optical signal is found at a level 40dB lower with a signal to noise ratio of 15dB. On the left hand side of the peak appears a mixing product between the electrical and the optical signal at a 10dB lower level. A further mixing product not shown here appears at the difference frequency of 260MHz of the detected signal and the electrical input signal.

CONCLUSION

We presented experimental results on the detector characteristics of an advanced type of waveguide transistor electroabsorption transceiver (TEAT). Further we demonstrated the function of the device as a transceiver for simultaneous modulation and detection as well as an optoelectronic mixer.

ACKNOWLEDGEMENT

The authors would like to thank the Deutsche Forschungsgemeinschaft (DFG) for financial support.

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