Up to 40 Gbit/s Operation of Laser-Integrated Electroabsorption Modulator Using Identical InGaAlAs Quantum Wells

Philipp Gerlach*

The modulation performance of InP-based 1.3 μm wavelength laser-integrated electroabsorption modulators using an identical InGaAlAs quantum well stack in both device sections is investigated. A typical device shows a threshold current of 22 mA, 35 dB side-mode suppression ratio and about 25 GHz modulation bandwidth. Open eye diagrams at 10 Gbit/s non-return-to-zero (NRZ), 20 Gbit/s return-to-zero (RZ) and 40 Gbit/s NRZ modulation have been measured.

1. Introduction

Electroabsorption modulators (EAMs) are attractive devices for modern telecommunication systems owing to their potential for high-speed modulation [1], high extinction ratio at low driving voltage, low chirp as well as small size. To avoid high coupling losses, EAMs can be monolithically integrated with other semiconductor components such as distributed feedback (DFB) laser diodes (LDs) [2] or semiconductor optical amplifiers (SOAs). Using the same active layer in all device sections, critical technological steps like selective epitaxy or quantum well intermixing are avoided which greatly simplifies device fabrication.

2. Device Design

Investigated devices are based on a 2 μm wide ridge-waveguide structure grown on a semi-insulating InP wafer. The devices contain ten 5 nm thick InGaAlAs quantum wells (QWs). They have a 370 μm long DFB-LD section and a 130 μm long EAM section, which are electrically isolated by an etch trench. Local DFB gratings in the LD section have been realized by holographic lithography followed by epitaxial overgrowth. A second mesa has been etched to get access to n-InP from the top side. In order to minimize the effective capacitance, the mesa width in the EAM section is only 2 μm and thus as narrow as the ridge-waveguide. The back and front facets are high-reflection (HR) and anti-reflection (AR) coated, respectively. A schematic of a device is shown in Fig. 1. Within the LD

*Work performed in collaboration with Infineon Technologies AG, Munich, Germany
the QWs provide gain under forward bias and in the EAM the absorption changes under reverse bias due to the quantum confined Stark effect. The design of an identical active layer in the LD and the EAM is challenging because low threshold current in the LD and low residual absorption in the EAM appear to be contradicting design criteria [3]. Further details concerning device fabrication are found in [4]. Simulated and measured modal gain and absorption spectra are displayed in Fig. 2. The operating wavelength of 1309 nm is defined by the DFB grating. Positive detuning with respect to the gain peak has been chosen.

3. Static Characteristics

The optical output power has been coupled into a standard single-mode fiber (SSMF) using a lens-integrated isolator with 50% coupling efficiency. The fiber-coupled optical
power is shown in Fig. 3. The threshold current amounts to 22 mA and the static extinction is 4 dB for a voltage swing of 2 V. An optical output spectrum at 25 mA is depicted in Fig. 4, exhibiting a side-mode suppression ratio of more than 35 dB.

4. Modulation Response

![Fig. 5: Photograph of DFB-LD–EAM. Total device length is 500 µm.](image)

![Fig. 6: Measured electro-optical response at 35 mA laser current and −1.5 V EAM bias as well as simulated response.](image)

Because even at 40 GHz modulation the electrical wavelength is much shorter than the length of the EAM, we consider the EAM to be lumped and assume travelling wave effects to be negligible. To measure the electro-optical response, a constant LD current of 35 mA and an EAM bias of −1.5 V is applied to the LD and EAM contact pads, respectively. The p-contact pads, as well as the n-ground pads can be seen in the photograph in Fig. 5. The coplanar EAM pad is connected by a 50 Ω microwave probe. The determined modulation response is shown in Fig. 6 and indicates the 3-dB modulation bandwidth to be about 25 GHz. A simulation result at low optical input power is plotted in the same diagram, where the simulation model from [5] has been employed.

5. Non-Return-to-Zero Modulation at 10 Gbit/s

Figure 7 shows the schematic setup which has been used to measure large-signal modulation. For data rates of 10 Gbit/s NRZ modulation a pattern generator which is specified up to 12.5 Gbit/s operation is used as a pseudo-random bit sequence data source. On the receiving side a photoreceiver module with an electrical bandwidth of 40 GHz is connected to a wideband sampling oscilloscope. As can be seen in Fig. 8, an open eye diagram with fast transition times of about 25 ps is measured.
6. Return-to-Zero Modulation at 20 Gbit/s

A commercial RZ signal source operating at data rates above 10 Gbit/s is not available in the department. Therefore the pattern generator indicated in Fig. 7 is exchanged by the multiplexer setup depicted in Fig. 9. It splits the 10 Gbit/s signal and delays one of them in order to multiplex two different, almost uncorrelated signals up to a data rate of 20 Gbit/s. Another multiplexer with a constant zero at one of its inputs converts these 20 Gbit/s NRZ signals to 40 Gbit/s RZ signals. Incorporating this multiplexer system, an open optical eye diagram shown in Fig. 10 has been achieved.

Fig. 9: Schematic multiplexer setup for the generation of electrical RZ signals at a data rate of 20 Gbit/s.

Fig. 10: Measured optical eye diagram at 20 Gbit/s RZ data rate. LD current and EAM bias are 70 mA and $-2$ V, respectively.
7. Non-Return-to-Zero Modulation at 40 Gbit/s

An electrical 40 Gbit/s NRZ signal is generated by a two-stage multiplexer system which is schematically shown in Fig. 11. An additional 40 GHz bandwidth amplifier is used and its saturated output (see Fig. 12) is attenuated to 1 V\textsubscript{pp} and fed with a microwave probe to the ground–signal–ground contacts of the EAM (see Fig. 5). The EAM is biased by means of a second microwave probe which is connected to a bias tee and an RF load terminating the electrical path. Data transmission with an open eye diagram according to Fig. 13 has been achieved at low optical power using averaging. At present, the eye opening is limited by the 3-dB modulation bandwidth of 25 GHz which is expected to increase with a more advanced microwave design in the future.

![Fig. 11: Schematic multiplexer setup for the generation of electrical NRZ signals at a data rate of 40 Gbit/s.](image)

![Fig. 12: Measured eye diagram of the electrical NRZ signal at a data rate of 40 Gbit/s.](image)

![Fig. 13: Measured optical eye diagram of the NRZ signal at a data rate of 40 Gbit/s. Laser current and EAM bias are 50 mA and −1 V, respectively.](image)
8. Conclusion

We have demonstrated that monolithically integrated DFB-LD–EAMs using an identical InGaAlAs QW structure show sufficiently fast transitions for 40 Gbit/s applications. The eye opening is well correlated to the simulated and measured electro-optical response. Due to the small signal-to-noise ratio (SNR) at the detector, quasi error-free data transmission has not been achieved up to now. Incorporating an additional SOA, which might be monolithically integrated as well, an improved SNR is to be expected from future device generations.

References


