NRZ operation at 40 Gb/s of a compact module containing an MQW electroabsorption modulator integrated with a DFB laser

著者	尾辻　泰一
journal or publication title	IEEE Photinics Technology Letters
volume	9
number	5
page range	572-574
year	1997
URL	http://hdl.handle.net/10097/47730

doi: 10.1109/68.588106

NRZ Operation at 40 Gb/s of a Compact Module Containing an MQW Electroabsorption Modulator Integrated with a DFB Laser

Hiroaki Takeuchi, Ken Tsuzuki, Kenji Sato, *Member, IEEE,* Mitsuo Yamamoto, Yoshio Itaya, Akihide Sano, Mikio Yoneyama, and Taiichi Otsuji

Abstract— **NRZ operation at 40 Gb/s has been successfully performed using a very compact module of a multiple-quantum-well (MQW) electroabsorption modulator integrated with a distributed-feedback (DFB) laser. While the DFB laser is injected with a constant current, the integrated MQW electroabsorption modulator is driven with a 40-Gb/s electrical NRZ signal. A clearly opened eye diagram has been observed in the modulated light from the modulator. And a receiver sensitivity of −27.2 dBm at 10^{-9} has been experimentally confirmed in the bit-error-rate (BER) performance.**

Index Terms—**Distributed-feedback lasers, electrooptic modulation, high-speed devices, integrated optoelectronics, monolithic integrated circuits, optical communication, optical transmitters, quantum-well lasers, quantum-well devices, semiconductor lasers.**

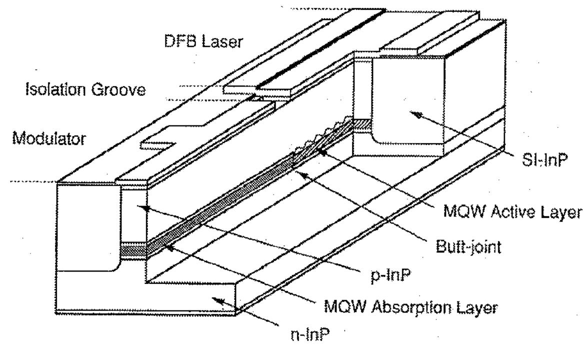

Fig. 1. Schematic view of the MQW electroabsorption modulator integrated with a DFB laser.

I. Introduction

THE ELECTROABSORPTION modulator is very promising for application to future optical transmission systems such as high-speed or wavelength multiplexing systems. It offers many advantages, for example, low-chirp characteristics, small size, and easy integration with lasers and other waveguide devices. For its application to light sources in optical transmission systems, the electroabsorption modulator should be integrated with a single-mode oscillating laser to fully utilize its compactness. Consequently, many studies have been reported on the electroabsorption modulator integrated with a distributed-feedback (DFB) laser. Several integration technologies between the electroabsorption modulator and the DFB laser were used in the previous papers, that is, a stacked-layer technology [1], a butt-joint technology [2], a selective-area-growth technology [3]–[7], and an identical layer technology [8].

The highest bit rate reported so far in transmission experiments using an electroabsorption modulator integrated with a DFB laser was 20 Gb/s [1], [8]. Transmission at much higher bit rate has never been carried out due to the relatively poor bandwidth of the modulator and difficulties of generating a driving electrical signal. In this letter, we describe successful experiments in 40-Gb/s transmission using, for the first time, a compact module of an electroabsorption modulator integrated with a DFB laser. High-speed modulation of the integrated electroabsorption modulator was achieved by optimizing the modulator's structure of the length and the multiquantum-well (MQW) numbers.

Manuscript recieved November 26, 1996; revised December 30, 1996.

H. Takeuchi, K. Tsuzuki, K. Sato, M. Yamamoto, and Y. Itaya are with the NTT Opto-electronics Laboratories, Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-01, Japan.

A. Sano and M. Yoneyama are with the NTT Optical Network System Laboratories, Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-01, Japan.

T. Otsuji is with the NTT System Electronics Laboratories, Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-01, Japan.

Publisher Item Identifier S 1041-1135(97)03228-X.

II. Device Design and Fabrication

The structure of the electroabsorption modulator integrated with a DFB laser is schematically shown in Fig. 1. For achieving high-speed operation of an electroabsorption modulator, shorter modulator length and smaller electric capacitance are desirable. But a reduction in the modulator length yields a smaller extinction ratio in the attenuation characteristics. This is quite problematic in practical use. We expected to overcome the problem by equipping a modulator with a larger number of pairs in a modulator's MQW's. We introduced an MQW absorption layer with 14 wells in the integrated modulator.

In the fabrication process, six pairs of strained InGaAsP MQW's were grown on an n-type (100) InP substrate as an active layer of a DFB laser by low-pressure metalorganic vapor phase epitaxy. The well was 6.7-nm-thick InGaAsP with commpressive strain and the barrier was 15.1-nm-thick InGaAsP with a photoluminescence wavelength of 1.25 μm. This MQW active layer was etched off down to the substrate except in the DFB laser region. Then, additional InGaAsP MQW's, with a well of 9.7-nm-thick InGaAsP and a barrier of 5-nm-thick InGaAsP, were selectively grown as an absorption

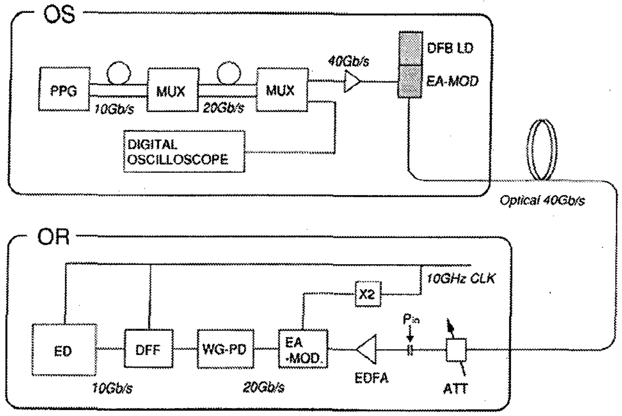

Fig. 2. BER experimental setup.

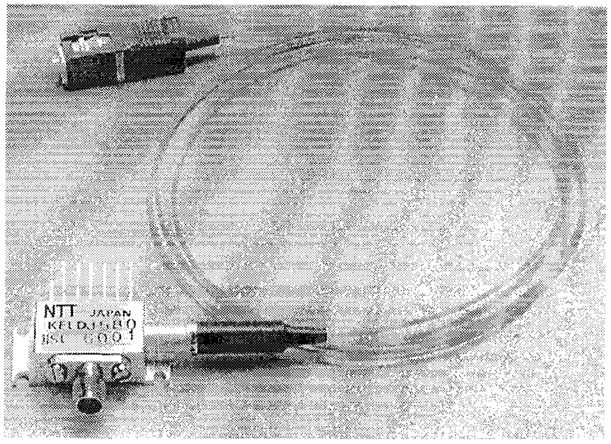

Fig. 3. Photograph of the light source module.

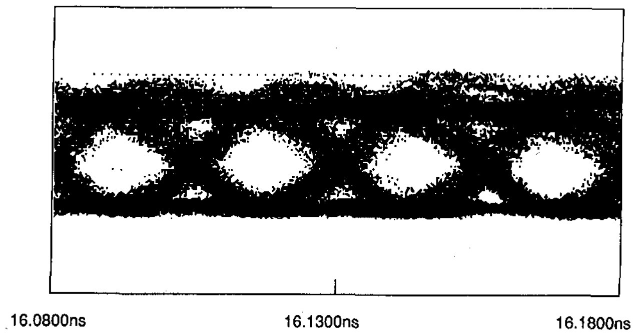

Fig. 4. 40-Gb/s eye diagram.

layer of the modulator. The well was compressively strained by 0.5% and the barrier was tensilely strained to compensate the strain of the MQW's. Thus, a butt-joint configuration was formed between the the DFB laser and the electroabsorption modulator. The butt-joint configuration produced a high-coupling efficiency of 95% and allowed us to optimize the modulator's MQW's almost at will. After a corrugation grating was made in the DFB laser, a p-type InP cladding layer and p-type contact layer were grown successively. The modulator and the DFB laser were buried in Fe-doped InP to reduce electric capacitance and to make the surface plane. This Fe-doped InP buried structure has the advantage of yielding high-optical power due to low-thermal resistance and is expected to be very reliable in long-term operation [11]. Then, an isolation groove was formed between the DFB laser and the modulator, followed by electrode formation. The devices were cleaved into a chip, in which the length of the modulator and the DFB laser were 90–100 μm and 450 μm, respectively. The facets were coated with an antireflection film for the modulator and with a high-reflection film for the DFB laser. Finally, the integrated light source was packaged into a compact module with an SMF pigtail for measurements.

III. BER Experimental Setup

Back-to-back transmission experiments at 40 Gb/s were carried out using the setup shown in Fig. 2 [12]. It is made up of a optical sender (OS) block and a optical receiver (OR) block. The high-speed light source module is used in the OS block. A 10-Gb/s nonreturn-to-zero (NRZ) electrical signal from a pulse pattern generator (PPG) was first multiplexed to 20 Gb/s and then multiplexed again up to 40 Gb/s [13]. The multiplexed 40-Gb/s driving signal was applied to the light source module through an electrical amplifier. The peak-to-peak voltage of the driving signal was estimated to be 3 V. The waveform of the 40-Gb/s electrical signal was observed with a digtal oscilloscope. After about 5-m fiber transmission, the 40-Gb/s modulated light from the light source module was optically demultiplexed down to 20 Gb/s with an elecroabsorption modulator driven by a 20-GHz clock signal. The 20-Gb/s light was directly detected with a waveguide pin-photodiode. The input optical power at the pin-photodiode was controlled to be constant. Finally, the 20-Gb/s electrical signal was demultiplexed to 10 Gb/s in a detection circuit and led into an error detector. The receiver sensitivity was measured at the point just before the EDFA of the receiver.

IV. Experimental Results

The fiber pigtailed module as shown in Fig. 3 used in the 40 Gb/s NRZ experiments had an integrated modulator with a length of 90 μm. The optical output from the module was about +4 dBm at a DFB injection current of 70 mA and a modulator applied voltage of 0 V. The wavelength spectra exhibited a longitudinal single mode at 1.551 μm with a side-mode-suppression ratio (SMSR) of 48 dB.

The eye diagram of the 40-Gb/s modulated light from the light source module is shown in Fig. 4. A clearly opened eye diagram was observed, except for relative broadening of the ON state, which was due to the nonlinear attenuation of the modulator. The dynamic extinction ratio estimated from the observed eye diagram was about 10 dB. It was smaller than the static extinction ratio by about 3 dB. The bit-error-rate (BER) performance of the back-to-back transmission is shown in Fig. 5 for each of the demultiplexed 10-Gb/s four channels. The receiver sensitivity, measured at the bit-error rate (BER) of 10^{-9}, was from -27.2 to -25.2 dBm. An error-free back-to-back transmission for each channel was confirmed down to the BER of 10^{-12}.

V. Summary

We have successfully performed 40-Gb/s NRZ transmission experiments using, for the first time, a compact fiber pigtailed

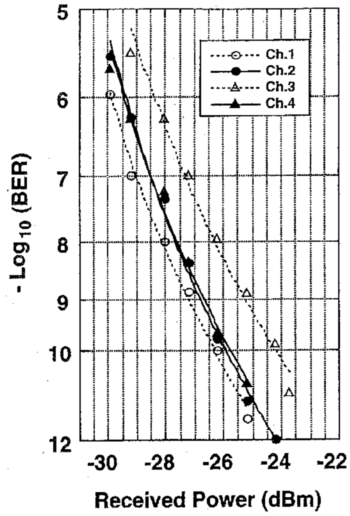

Fig. 5. 40-Gb/s BER performance.

module of an MQW electroabsorption modulator integrated with a DFB laser. We developed a high-speed electroabsorption modulator with good extinction ratio by optimizing the structure of the electroabsorption modulator as to the modulator length and the well numbers of the MQW's. A butt-joint configuration between the modulator and the DFB laser was employed for making it easy to perform the above optimization. After the device was packaged into a compact module with an SMF pigtail, a multiplexed 40-Gb/s driving electrical signal was applied to the integrated modulator and a clearly opened eye diagram was observed in the output from the module. Error-free performance was confirmed and receiver sensitivity measured at the BER at 10^{-9} was from -27.2 to -25.2 dBm in the back-to-back BER measurements.

REFERENCES

[1] K. Wakita, K. Sato, I. Kotaka, M. Yamamoto, and T. Kataoka, "20 Gbit/s, 1.55 μm strained-InGaAsP MQW modulator integrated DFB laser module," *Electron. Lett.*, vol. 30, no. 4, pp. 302–303, 1994.

[2] H. Soda, K. Nakai, and H. Ishikawa, "Frequency response of an optical intensity modulator monolithically integrated with a DFB laser," in *Proc. ECOC'88*, 1988, pp. 227–230.

[3] K. Komatsu, T. Kato, M. Yamaguchi, T. Sasaki, S. Takano, H. Shimizu, N. Watanabe, and M. Kitamura, "High-performance modulator/integrated light sources grown by an in-plane band-gap energy-control technique," in *Tech. Dig. OFC'94*, vol. 4, 1994, pp. 8–9.

[4] M. Aoki and H. Sano, "High-performance modulator/integrated light sources grown by an in-plane band-gap energy-control technique," in *Tech. Dig. OFC'95*, vol. 8, 1995, pp. 25–26.

[5] J. E. Johnson, P. A. Morton, T. Nguyen, O. Mizuhara, S. N. G. Chu, G. Nykolak, T. Tanbun-Ek, W. T. Tsang, T. R. Fullowan, P. F. Sciortino, A. M. Sergent, K. W. Wecht, and R. D. Yadvish, "10-Gbit/s transmission using an integrated electroabsorption-modulator/DFB laser grown by elective-area epitaxy," in *Tech. Dig. OFC'95*, vol. 8, 1995, pp. 21–23.

[6] H. Haisch, W. Baumert, C. Hache, E. Kühn, M. Klenk, K. Satzke, M. Schilling, J. Weber, and E. Zielinski, "10 Gbit/s standard fiber TDM transmission at 1.55 μm with low chirp monolithically integrated MQW electroabsorption modulator/DFB-laser realized by selective area MOVPE," in *Proc. ECOC'94*, 1994, pp. 801–804.

[7] J. A. Fells, M. A. Gibbon, G. H. B. Thompson, I. H. White, R. V. Penty, A. P. Wright, R. A. Sauders, C. J. Armistead, and E. M Kimber, "Improving the system performance of integrated MQW laser modulators with negative chirp," in *Tech. Dig. OFC'95*, vol. 8, 1995, pp. 23–24.

[8] A. Ramdane, D. Delprat, A. Ougazzaden, Y. Sorel, J. F. Kerdiles, M. Henry, and C. Thebault, "High performance strained layer integrated laser-modulator for 20 Gbit/s transmission," in *Proc. ECOC'96*, 1996, pp. 3. 191–3. 194.

[9] I. K. Czajkowski, M. A. Gibbon, G. H. B. Thompson, P. D. Greene, A. D. Smith, and M. Silver, "Strain-compensated MQW electroabsorption modulator for increased optical power handling," *Electron. Lett.*, vol. 30, no. 11, pp. 900–901, 1994.

[10] K. Morito, R. Sahara, K. Sato, Y. Kotaki, and H. Soda, "High power modulator integrated DFB laser incorporating strain-compensated MQW and graded SCH modulator for 10 Gbit/s transmission," *Electron. Lett.*, vol. 31, no. 12, pp. 975–976, 1995.

[11] S. Matsumoto, M. Fukuda, K. Sato, Y. Itaya, and M. Yamamoto, "Highly reliable 1.55 μm GaInAsP laser diodes buried with semi-insulating iron-doped InP," *Electron. Lett.*, vol. 30, no. 16, pp. 1305–1306, 1994.

[12] A. Sano, T. Kataoka, H. Tsuda, A. Hirano, K. Murata, H. Kawakami, Y. Tada, K. Hagimoto, K. Sato, K. Wakita, K. Kato, and Y Miyamoto, "Field experiments on 40 Gbit/s repeaterless transmission over 198 km dispersion-managed submarine cable using a monolithic mode-locked laser diode," *Electron. Lett.*, vol. 32, no. 13, pp. 1218–1220, 1996.

[13] T. Otsuji, M. Yoneyama, Y. Imai, S. Yamaguchi, T. Enoki, Y. Umeda, and E. Sano, "46 Gbit/s multiplexer and 40 Gbit/s demultiplexer IC modules using InAlAs/InGaAs/InP HEMT's," *Electron. Lett.*, vol. 32, no. 7, pp. 685–686, 1996.