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Wavelength Tunable Laser Module Integrated with InP Mach-Zehnder Modulator

Ken Tsuzuki, Nobuhiro Kikuchi, Hiroaki Sanjo, Yasuo Shibata, Hiromi Oohashi and Hiroshi Yasaka
NTT Photonics Laboratories, NTT Corporation
3-1, Morinosato Wakamiya, Atsugi-shi, Kanagawa Pref., 243-0198, Japan
e-mail: ktsuzuki@aecl.ntt.co.jp

Abstract *We have developed a compact and high speed InP Mach-Zehnder modulator by employing a novel n-i-n structure. We have also developed a compact wavelength tunable transmitter by integrating a wavelength tunable laser array and the n-i-n InP Mach-Zehnder modulator.*

Introduction

The recent increase in data traffic on the Internet has led to the need for large capacity and highly functional photonic networks. High-speed optical modulators are key components for systems where high-speed optical signals must be transmitted through long-haul optical fibers. We devised a novel waveguide structure as an alternative way of fabricating a compact Mach-Zehnder (MZ) modulator with a low driving voltage [1,2]. Our modulator has an n-i-n isotype heterostructure designed to eliminate the electrical and optical signal losses caused by the p-type cladding layer. We obtained a half-wavelength voltage ($V\pi$) of 2.2 V with a 3-mm-long phase-shifting region. And we confirmed 40-Gbit/s operation with a push-pull driving voltage of 1.3 V_{pp}.

Small size transponders, which include wavelength tunable lasers and small size external modulators, are indispensable to reducing the cost and size of ROADM systems [3,4]. We also report a compact 10 Gbit/s tunable laser module that we realized by the hybrid integration of a wavelength tunable DFB laser array (TLA) and an n-i-n MZ modulator [5]. It can operate at 80 channels in the full C-band wavelength region. The modulator characteristics have little wavelength dependence. As a result, fixed operation of the MZ modulator driving condition can be achieved even when the output wavelength is switched.

In this paper we summarize our recent activities on the InP based MZ modulator.

40 Gbit/s Mach-Zehnder modulator

A semiconductor Mach-Zehnder modulator consists of two n-i-n phase-shift waveguides. The n-i-n structure offers 50-Ω impedance matched signal lines and velocity matching for electrical and optical signals. These features enable us to realize high-speed and small size MZ modulators. The device chip size is 4.5x0.8 mm. The 6-dB bandwidth of electrical S_{21} is over 40 GHz and that of S_{11} is less than -15 dB at frequencies up to 50 GHz. The fabricated modulator chip was installed in a compact package as shown in Fig. 1. Two RF-input V-connectors for dual driving are placed on one side for ease of connection with the differential output modulator driver. The package is 21x17 mm in size and the footprint size is the same as that of conventional DFB laser modules. Figure 2 shows the eye diagram obtained for the operation of a non-return-to-zero (NRZ) 2^{31}-1 pseudo random bit sequence at 40 Gbit/s. A 1.3-V_{pp} differential driving voltage was supplied to the dual ports of the modulator.

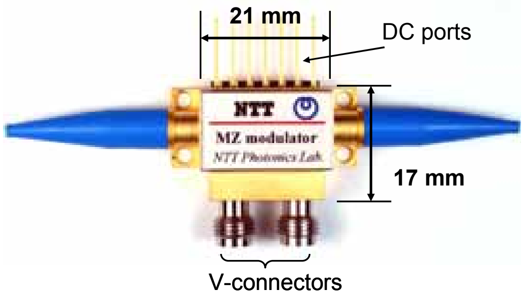

Figure 1. Photograph of a 40-Gbit/s n-i-n MZ modulator module.

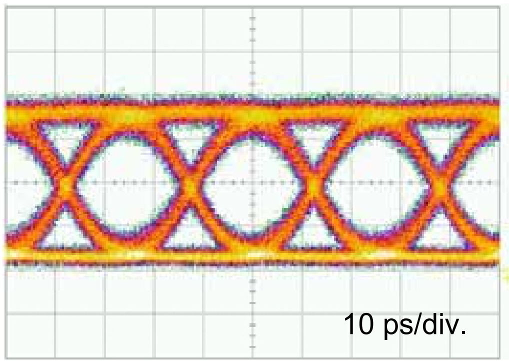

Figure 2. 40-Gbit/s eye diagram in a push-pull drive configuration with a driving voltage of 1.3 V_{pp}.

Wavelength tunable transmitter

The full C-band tunable laser source that we employed is our wavelength tunable DFB laser array (TLA) [6]. The TLA is an attractive candidate for practical use because the main structure is based on the conventional DFB laser, which is widely used in existing optical network systems. It can provide one wavelength from a wide wavelength tuning range when we select one DFB laser and control its temperature. The characteristics of these DFB lasers do not exhibit any abrupt change, such as mode hopping. This is an important feature for a working optical communication network system.

Figure 3 shows a photograph of the wavelength tunable transmitter module. It consists of a TLA, an n-i-n MZ modulator and a wavelength locker. The TLA and the MZ modulator are co-packaged in a compact module, which is 41 mm (L) x 13 mm (W) x 9 mm (H) in size. The TLA and MZ modulator are mounted on the same metal carrier and thermo-electric cooler (TEC). These two devices are coupled by using lenses via an isolator. The output from the MZ modulator is coupled into a fiber pigtail after passing through the wavelength locker mounted on another TEC. All of the lenses are welded with a YAG laser, which secures long-term stability.

The inset in Fig. 4 shows the 10-Gbit/s eye diagrams we obtained back-to-back and after transmission through 100 km of single-mode-fiber (SMF) in the 1530 to 1560 nm wavelength range. For this measurement, we fixed the driving and bias voltages of the MZ modulator at constant values even when the output wavelength was switched. The bias voltages were kept at -3.3 and -2.8 V for the two arms of the modulator. The driving voltages were fixed at 0.75 and 2.25 V for the push-pull operation. The modulation signal has a negative chirp under this driving condition. Clear eye opening can be obtained from 1530 to 1560 nm without changing the driving condition of the MZ modulator under a back-to-back condition and even after a 100-km SMF transmission.

The bit error rate (BER) performance measured back-to-back and after 100 km SMF transmission is also shown in Fig. 4. The power penalties after transmission through a 100-km SMF were less than 3 dB for all wavelength channels.

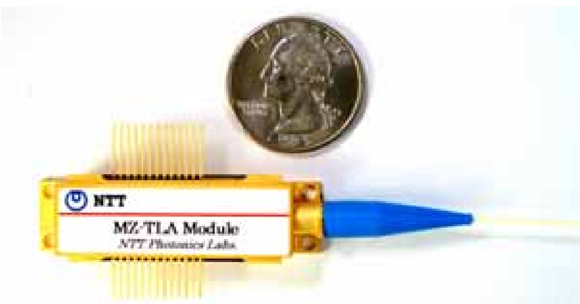

Figure 3. Photograph of a wavelength tunable laser module integrated with an n-i-n MZ modulator.

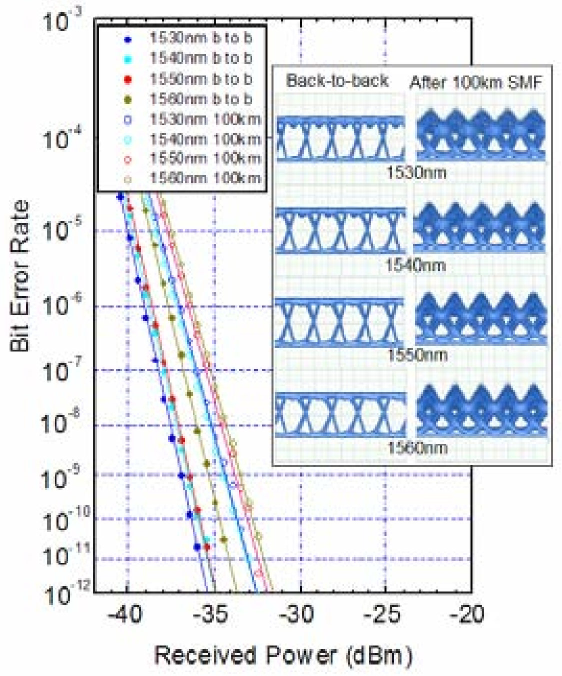

Figure 4. BER performance at various wavelengths. Insets are back-to-back and 100 km SMF transmission eye patterns for various output wavelength signals.

Conclusion

We developed a compact push-pull drive n-i-n MZ modulator, and confirmed 40-Gbit/s operation with a push-pull driving voltage of 1.3 V_{pp}. We also fabricated a compact wavelength tunable transmitter by the hybrid integration of a TLA and an n-i-n MZ modulator in a small package. The low wavelength and temperature dependent characteristics of the modulator enabled it to be operated with a fixed driving condition even when the output wavelength was switched over the wide wavelength range of the C-band. A 100-km SMF transmission was also demonstrated with the module, and a low power penalty of less than 3 dB was confirmed for the entire output wavelength range of 1530 to 1560 nm.

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