Compact Optical Devices with Low Power Consumption

Wataru Kobayashi and Masahiro Nada

Abstract

At NTT Device Technology Laboratories, we have been developing an optical transmitter that can improve energy efficiency and emit an optical signal at the same intensity level with half the previous power consumption. We have also been developing an optical receiver that improves the minimum optical received power with the same signaling rate. This can provide us with long distance transmission without an optical amplifier. In this article, we introduce an optical transmitter and an optical receiver with functions for respectively changing an electrical signal to an optical signal and an optical signal to an electrical signal.

Keywords: compound semiconductor device, AXEL, APD

1. Optical transmitter

An optical transmitter in an optical network system changes electrical signals to optical signals. The recent increase in data traffic has inevitably increased the power consumption of optical network systems. Therefore, optical transmitters need to be more energy efficient.

Generally, an optical transmitter has two functions. One is to emit light, and the other is to modulate light, which means converting an electrical "0" and "1" signal to an optical signal. There are two main ways of modulating light. One is to modulate the intensity level of the optical power, and the other is to modulate the phase of the optical signal. An electro-absorption (EA) modulator integrated distributed feedback (DFB) laser (EA-DFB laser) is widely used as an optical intensity modulated laser.

At NTT Device Technology Laboratories, we proposed a semiconductor optical amplifier assisted extended reach EA-DFB laser (AXEL) to greatly reduce the power consumption of an EA-DFB laser [1]. The concept of the AXEL is shown in **Fig. 1**. A conventional EA-DFB laser (Fig. 1(a)) supplies a large injection current to the DFB laser section to increase the intensity of the emitting light, but most of the power of the generated light is lost because of the insertion loss of the EA modulator. This means that most of the supplied power consumed by the EA-DFB laser is used to compensate for the loss at the EA modulator section, resulting in poor energy efficiency.

In contrast, an AXEL can improve the energy efficiency by dividing the DFB laser section into two parts: one for generating light and the other for amplifying modulated light, as shown in Fig. 1(b). Therefore, we can configure the EA-DFB laser while suppressing the effect of the insertion loss of the EA modulator section and achieve energy-efficient operation with this configuration.

Eye diagrams, the modulated output power, and the power consumption of the AXEL and an EA-DFB laser when the power consumption is nearly equal are shown in **Fig. 2**. The AXEL can provide us with transmission through a 100-km single-mode fiber thanks to its improved optical power. Here, the wavelength of the AXEL is 1.55 μm. The advantage of the AXEL is that it can emit modulated light at the same intensity level with half the power consumption and provide a 3-dB increase in modulated optical power with the same power consumption.

Silicon (Si) photonics is currently considered an attractive candidate for the next-generation optical transmitter. The required optical power varies with the required transmission distance, but the concept of

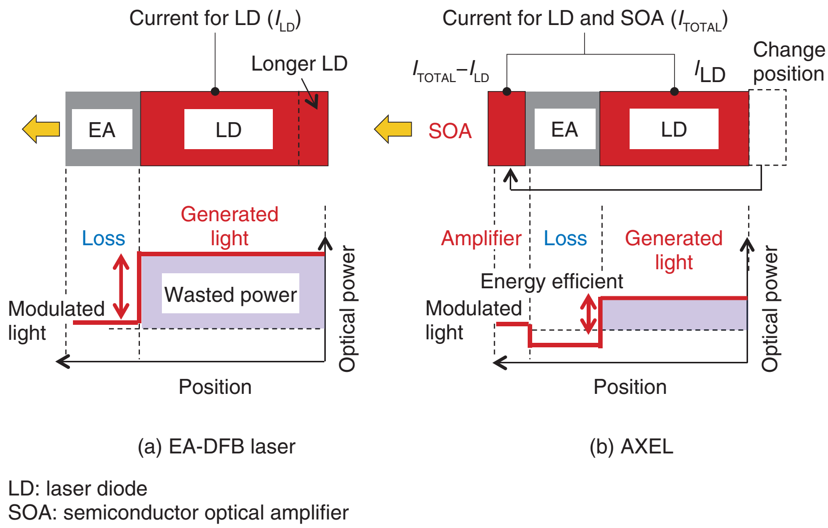

Fig. 1. Concept of AXEL.

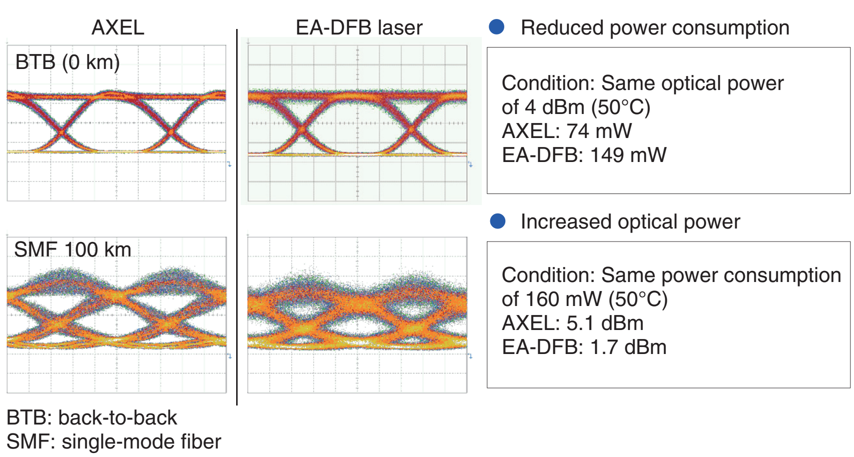

Fig. 2. Advantages of AXEL.

the AXEL can be applied to a wide optical power range, and therefore, we also expect the AXEL to be employed as an optical light source in Si photonics.

2. Optical receiver

An optical receiver converts an optical signal launched from a laser to an electrical signal after the optical signal has passed through some waveguides and optical fibers. For efficient conversion, the optical receiver must have high sensitivity because the intensity of the received optical signals weakens due to certain losses in the waveguides and optical fibers. We have developed high-speed and high-sensitivity optical receivers and photodetectors for long-haul transmission [2]. Conventional photodiodes (PDs) made with semiconductors consist of p-type and n-type contact layers and an absorption layer. An optical signal injected into the PDs is converted to electrons and holes in the absorption layer.

In contrast, an avalanche photodiode (APD) provides higher sensitivity than PDs. This is because it contains a multiplication layer in addition to the conventional PD structure. In the multiplication layer, secondary electrons and holes are produced by bombarding atoms with accelerated electrons and holes.

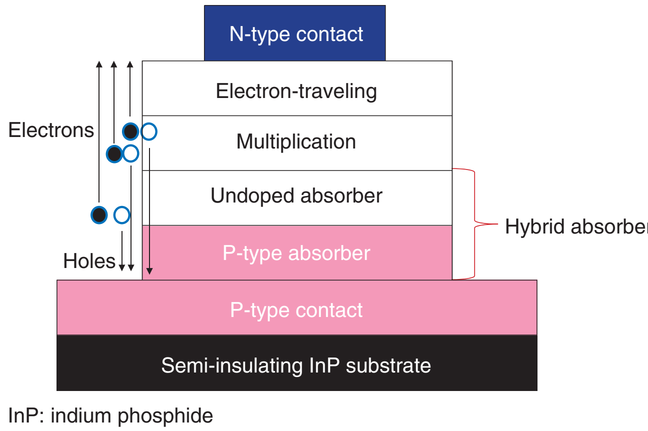

Fig. 3. Schematic view of APD.

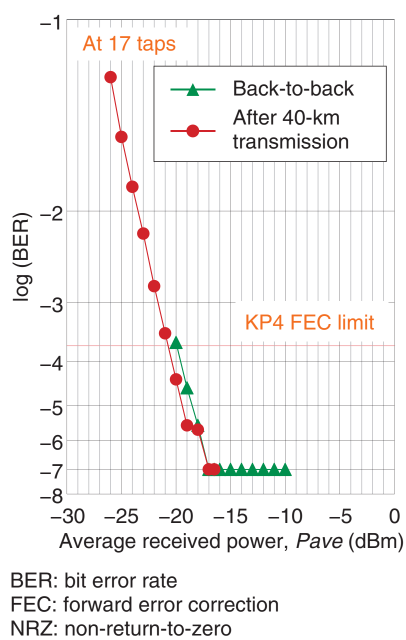

Fig. 4. Bit error rate of APD-based optical receiver at 56-Gbit/s NRZ signal.

The successive generation of secondary electrons and holes in the multiplication layer results in the amplification of the electrical signals against the weak optical input signals. This is why the APD can provide higher sensitivity than PDs.

A schematic view of the compound semiconductor-based APD developed by NTT is shown in **Fig. 3**. One unique feature of our APD is a hybrid absorber that consists of p-type and undoped absorber layers. The hybrid absorber enables operation at higher speed and with higher sensitivity compared to the conventional absorber. The results of a demonstration of our APD used for 56-Gbit/s, 40-km transmission with a non-return-to-zero signal are shown in **Fig. 4**.

Recent progress in Si fabrication technology has opened the way to large-scale monolithic integration of optical components, including PDs and APDs, along with optical waveguides and modulators. Since our approach with compound semiconductor materials has an advantage in high-speed and high-sensitivity operations due to the flexibility of device design and material characteristics, merging our technology for high-performance APDs with Si photonics will make it possible to provide more compact optical receivers with higher performance and lower power consumption.

3. Future plans

This article introduced NTT's optical transmitter and receiver technology for future large-capacity optical-fiber communication systems. As the data transmission capacity continues to increase, it will be necessary to further reduce the size and power consumption of optical transmitters and receivers. In the future, Si photonics might make it possible to integrate optical transmitters, receivers, and electrical integrated circuits on the same Si platform. This would contribute to further lowering power consumption and reducing the size of optical transceivers. Our goal is to achieve major breakthroughs in high-speed and low-power consumption optical transmitters and receivers. We are striving to reach this goal by seeking ways to successfully merge Si photonics technology and compound semiconductor device technologies.

References

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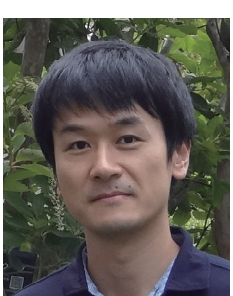

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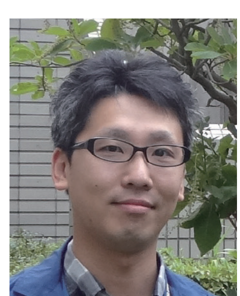

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