40 Gb/s EA modulator

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The colossal increase in data communications traffic over recent years, with an expanding Internet population and a steady advance from transmission of simple text, to images, to animated images, has created demands for expanded capacity in optical communications systems. The amount of data carried by a single fibre can be increased by raising the signal transmission speed, or adopting wavelength division multiplexing to use a plurality of transmission wavelengths, and capacity enhancement initiatives combining both of these approaches are also being developed.

Increases in transmission speed from 2.5 Gb/s to 10 Gb/s have been achieved on the back of accelerated performance in electronic and optical devices, and a 10 Gb/s optical communications system has already been released as a product for practical application. In recent years, high-speed devices with 40 Gb/s capability have been gradually reaching the stage of practical implementation, and developers have been working in real earnest on 40 Gb/s fibre-optic communications systems suitable for in-field use.

A key element in achieving 40 Gb/s system performance is the optical modulator used to convert the electrical signals to optical signals. The EA modulator, which is a semiconductor device, has the advantages of compactness and easy integration with other optical devices, such as semiconductor lasers. Much is expected of this type of modulator, and below, we look at the 40 Gb/s EA modulator1) that has been developed by Oki.

Overview of the EA modulator

Light can be modulated in a data signal by using either a direct modulation method or an external modulation method. In direct modulation, a modulated light signal is obtained by supplying an electrical signal to a semiconductor laser, which forms the light source. The operating frequency of the semiconductor laser is limited by the response speed of the carriers in the lasing semiconductor, and at the very most, it can reach about 10 Gb/s, which is not sufficient for 40 Gb/s modulation. External modulation, on the other hand, uses a uniform light source output, which is then modulated by a separate optical modulator. Typical examples of this optical modulator include an LN modulator based on an electro-optical effect (see TIPS) which uses ferroelectric lithium niobate $LiNbO_3$: hereinafter, LN, and an electroabsorption (EA) modulator which is based on a semiconductor electroabsorption effect (see TIPS). These are both very rapid physical phenomena, which permit operation at 50 GHz or above.

The LN modulator is characterized by low wavelength chirp (see TIPS), and is widely used in long-haul fibre-optic transmission systems operating at 2.5 Gb/s and 10 Gb/s. However, it does have drawbacks, including its high operating voltage of around 5 – 6 V, and a relatively bulky size. EA modulators, by contrast, are compact and run at low voltages of 2 – 3 V, as well as affording easy integration with the light source, and so on. Recent trends towards system miniaturization and lower power consumption have strengthened demands for compact, power-efficient modulators, and in this light, EA modulators are eagerly anticipated for use in 40 Gb/s communications systems.

Module structure

The EA modulator is a semiconductor device similar to a semiconductor laser, but in actual use, it must be fitted with input /output fibres, and the like. Below, an EA modulator fitted with optical fibres, etc. will be called the “EA modulator module”, and the semiconductor section alone will be called the “EA device”.

Fig. 1 shows an external photograph of an EA modulator module. It is 21 x 13 x 11 mm^3 in size, and is fitted with two input fibres, two output fibres, and a high-frequency connector.

The structure of this EA modulator module is illustrated in Fig. 2. The optical coupling between the EA device and the optical fibres uses a two-lens system, and there are two optical couplings : one for

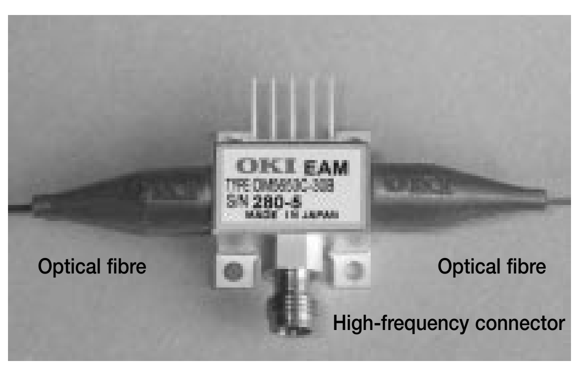


Fig. 1 External photograph of EA modulator module

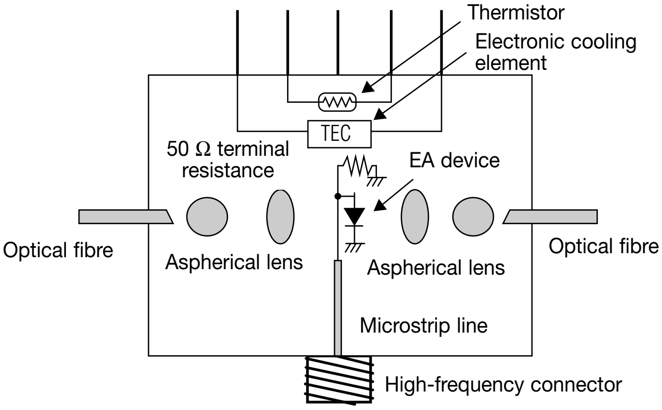


Fig. 2 Structure of EA modulator module

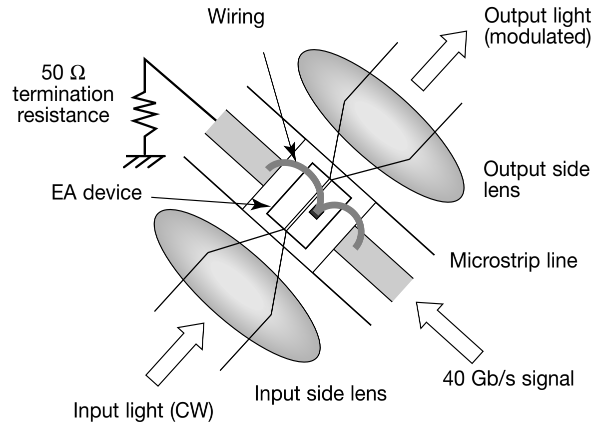


Fig. 3 Mounting structure for EA device

the input side and one for the output side. Aspherical lenses are used and very good coupling efficiency is obtained. In order to handle high-speed signals of the order of 40 Gb/s, a high-frequency connector is used to input the electrical signal, and a 50 W microstrip line is used for the signal line. The electrical signal terminates at the 50 W resistance, thereby suppressing electrical reflection. Moreover, a thermistor and electronic cooling element are built into the EA device to ensure temperature stability. The high reliability required in communications components is guaranteed by fixing the lenses and optical fibres with YAG welds, whilst using solder bonds for the other parts. The main components are housed inside a hermetically sealed metal package.

Fig. 3 shows the mounting structure of the EA device. Light is condensed by the input side lens to about 1μm, input to the EA device, modulated by electrical signals and then guided to optical fibres by the output side lens. The electrical signal system is, on the other hand, wired by the microstrip line to reduce halfway electrical reflection.

Characteristics of EA modulator module

The main requirements of an optical modulator in a fibre-optic communications system are:

- low insertion loss
- broad modulation bandwidth
- large extinction ratio (ratio between intensity when light ON and light OFF)
- low wavelength chirp.

In a 40 Gb/s optical communications system, the broad modulation bandwidth and low chirp characteristics are especially important.

Fig. 4 shows the structure of an EA device. An optical absorption layer for performing optical modulation is formed on top of the InP semiconductor substrate by crystal growth. Both ends of the device are coated with antireflection film to suppress unwanted reflections. The size of this EA device is approximately 250 x 200 x 80 μm^3.

The modulation bandwidth of an EA device is generally restricted by the element capacitance, so reducing this capacitance is a key factor in realizing high-speed operation. Element capacitance is governed by the junction capacitance of the optical absorption layer and the physical phenomena of the pad electrodes, so it is vital that these capacitances are constrained.

Junction capacitance can be restricted by adopting a ridge structure for the optical waveguide, in order to eliminate unnecessary semiconductor junctions. Furthermore, if the length of the section containing the optical absorption layer (light absorbing section) is shortened, then the junction capacitance falls accordingly, but since this also reduces the extinction ratio, it may become difficult to achieve the required extinction ratio. Therefore, the structure of the optical absorption layer was optimized to ensure the extinction ratio needed, in a short absorption section. This made it possible to reduce the length of the optical absorption section performing optical modulation to around 100 μm. On the other hand, handling considerations during assembly require provision of low-loss optical wave guides on either side of the absorption section, resulting in a total device length of about 250 μm. The physical phenomena of the pad electrodes was limited by reducing the size of the electrodes and embedding the lower sides of the electrodes in polyimide having a low dielectric constant. By adopting this device structure, the modulation bandwidth can be expanded.

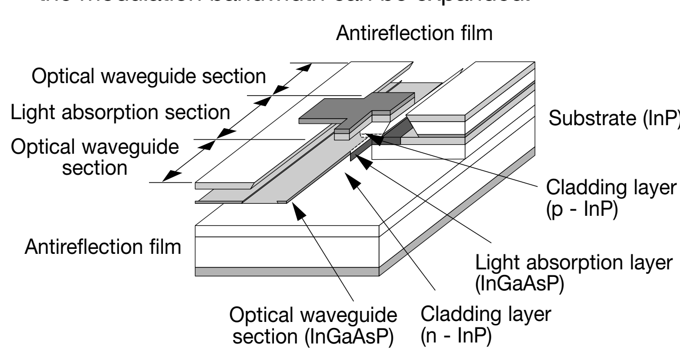


Fig. 4 Structure of EA device

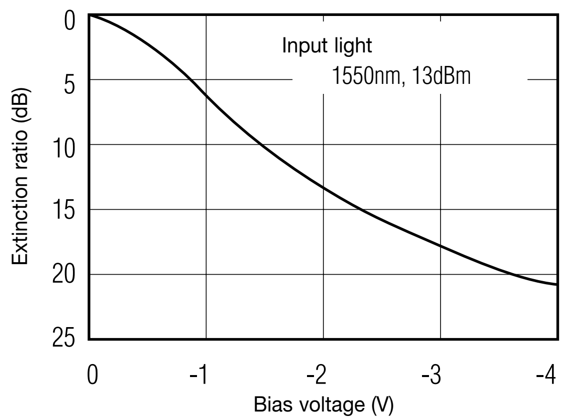


Fig. 5 Extinction characteristics

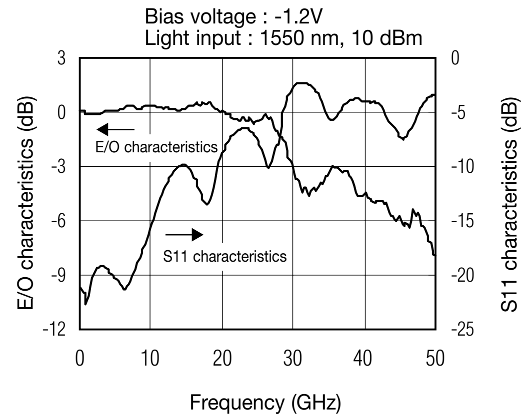


Fig. 6 Frequency characteristics

In respect of wavelength chirp, we analyzed and optimized various structures for the optical absorption layers with the aim of achieving low chip characteristics.

In order to exploit the full characteristics of this optimized EA device, a highly reliable system involving aspherical lens optics and anti-reflective signal lines was used to mount the device in a module, as described above.

The main characteristics of this EA modulator module are discussed below.

Fig. 5 shows the extinction characteristics with respect to bias voltage. An extinction ratio of approximately 20 dB is achieved at –4V bias voltage. Furthermore, the insertion loss at 0V bias is about 9 dB. The frequency characteristics of this module are shown in Fig. 6, which plots the optical modulation characteristics (E/O characteristics) and the reflection characteristics of the electrical input (S11 characteristics). When modulating a 40 Gb/s signal, a frequency of approximately 30 GHz is required with a 3 dB E/O characteristics band, and these conditions are fully satisfied by this module. Fig. 7 shows the wavelength chirp characteristics. Wavelength chirp is generally assessed by a figure called the "α parameter" (see TIPS), and desirably α is close to zero. As the graph shows, in this case, α reaches 0 at a bias voltage of around –1V, which means that if the modulation signal is supplied at a bias voltage in the region of –1V,

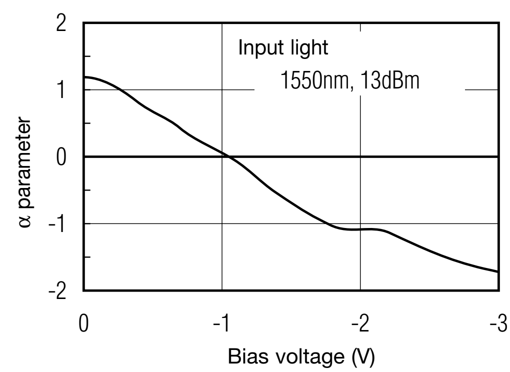


Fig. 7 Chirp characteristics

then the device will operate in the low-α region, and hence low wavelength chirp can be expected.

Let us look now at experimental results for modulation of a 40 Gb/s NRZ signal, using the measurement system shown in Fig. 8. The 40 Gb/s NRZ signal is obtained by electrically synthesizing the output of a signal generator producing four channels of 10 Gb/s NRZ signals. Fig. 9(a) is the eye pattern of the electrical signal input to the EA modulator module, and Fig. 9(b) shows measurement of the optical signal modulated by the EA modulator module, after conversion to an electrical signal. The bias voltage in the EA modulator

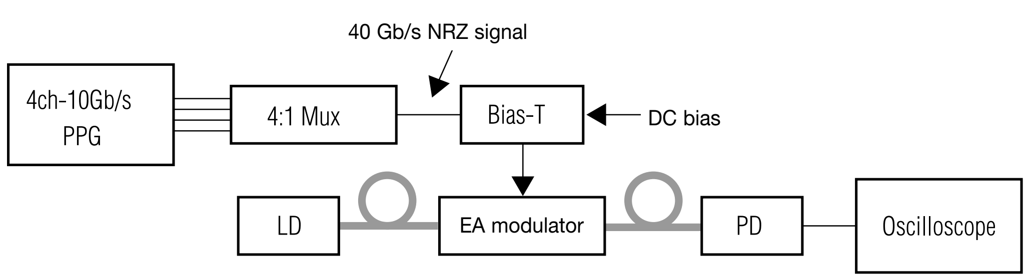
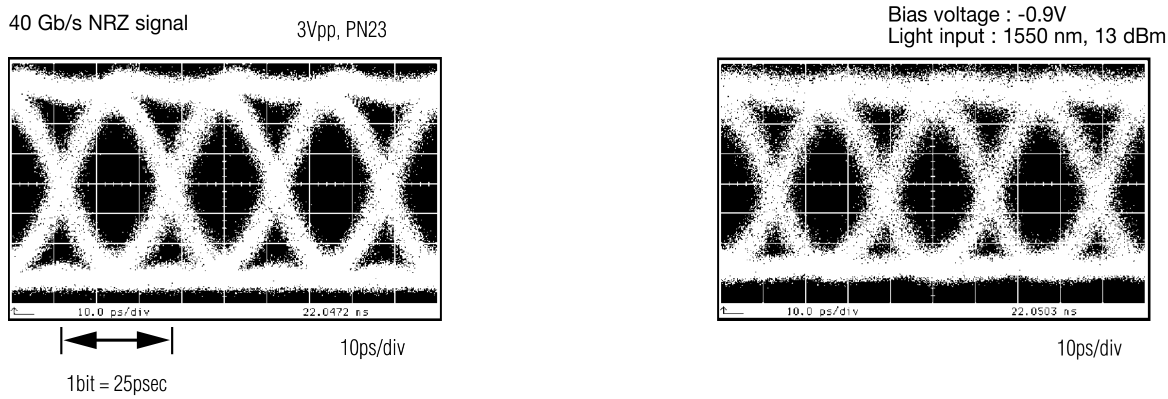


Fig. 8 Measurement system of 40 Gb/s signal modulation experiment



(a) Input electrical signal waveform

(b) Modulated signal waveform

Fig. 9 Modulation experiment with 40 Gb/s signal.

module was –0.9V. The eye pattern is clean, with little degradation from the input electrical signal. Furthermore, a satisfactory extinction ratio during optical modulation (dynamic extinction ratio) of about 10 dB was obtained.

These results demonstrate that the EA modulator module has suitable characteristics for transmission of a 40 Gb/s signal.

Towards the next EA modulator modules

In this paper, we have presented the structure and characteristics of our 40 Gb/s EA modulator module, and established its compatibility with 40 Gb/s fibre-optic communications systems.

Yet we will be seeking even greater performance and functionality in our future EA modulator modules. Performance can be upgraded by broadening the frequency bandwidth, for instance, to achieve compatibility with 42.8 Gb/s signal rates containing error correction codes, and making further improvements in wavelength chirp characteristics. We will be seeking to optimize the parameters of both EA devices and EA modulator modules in such a way.

Our search for enhanced functionality centres on the development of an EA-DFB laser which integrates an EA device with a DFB laser, along with EA modulators with built-in driver ICs, where the EA device and the IC driving that device are mounted in the same package. The EA-DFB laser has almost achieved the basic characteristics required, already.[2)]

As well as aiming to improve EA modulator performance, we hope to contribute actively to the construction of practical 40 Gb/s fibre-optic communications systems.

References

1) N. Mineo, et. al.: More than 50 GHz bandwidth electroabsorption modulator module, OECC 2000 Technical digest, PD2-7, June 2000

2) Wada, Kawanishi: “EA modulator module integrated with semiconductor laser for 40 Gb/s optical communications,”

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Electro-optical effect

A change in the refractive index when an electric field is applied. LN is known to produce a large electro-optical effect.

Electroabsorption effect

When an electric field is applied, the band structure of the semiconductor changes, causing the amount of light absorption to vary. More specifically, by applying an inverse bias voltage to the EA modulator, the light absorption is increased so that no light is transmitted. Therefore, when no voltage is applied, light is transmitted (ON), and when the negative voltage is applied, the light is shut out (OFF), thereby permitting light modulation.

Wavelength chirp

Chirp is wavelength fluctuation arising in the ascending or descending part of an optical pulse. The speed of light in an optical fibre varies at different wavelengths (wavelength dispersion), and an optical pulse with large wavelength chirp will cause waveform distortion during transmission, which impedes long-distance communications.

α parameter

This value represents the ratio between the respective changes of the refractive index and the light absorption rate. If the refractive index does not alter when the voltage changes (a = 0), then the wavelength will not change and no chirp occurs. However, if the refractive index does alter, then effectively, the wavelength is caused to change due to a shift in the light phase, and hence wavelength chirp will arise.