Development of the 10Gbit/s 1.3 µm AlGaInAs DFB Laser

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High-speed transmissions of 10Gbit/s have been in demand in recent years, even for short distance transmissions, such as metropolitan networks or service access networks, due to the increase in communications traffic arising from the pervasion of the Internet. Low power consumption and low costs are required for the 10Gbit/s class optical transceivers' light source in the 10Gbit Ethernet and the OC-192. As a result, numerous development activities are taking place to make a direclty modulated DFB laser module without any temperature control. The elements used must have high modulation characteristics that allows them to operate at 10Gbit/s, even if the temperature rises to 85°C. The laser characteristics of the GaInAsP materials that have been in use as raw materials for long-wave band laser elements, greatly deteriorate in high temperatures, therefore, adequate characteristics are not readily available for 10Gbit/s operations in 85°C temperatures. For this reason, lasers using the AlGaInAs1) 2) 3) 4), as an alternative material to the GaInAsP, are drawing a lot of attention. Oki Electric continues to develop DFB lasers using the AlGaInAs. The characteristics of the 10Gbit/s modulation will be provided herein.

Structure of the AlGaInAs DFB laser

A comparison between the characteristics of the AlGaInAs and the GaInAsP, are herein provided.

The difference between the quantum well (QW) of the AlGaInAs and that of the GaInAsP, is the band offset ΔE_C on the electron side, which is larger with the AlGaInAs. The quantum well of the GaInAsP, which is $\Delta E_C = 0.4\ \Delta Eg$, as shown in Figure 1, is small in comparison to the quantum well of the AlGaInAs, which is $\Delta E_C = 0.72\ \Delta E_g$, and has a large band offset that makes it able to capture more electrons. For this reason, the electrons leaking from the quantum well in high temperatures can be inhibited, making it possible to create lasers with superior temperature characteristics, in terms of both CW and modulation characteristics. Further, since the band offset on the side of the hole is smaller, even when the number of quantum wells is increased to raise the level of modulation characteristics, it is difficult for non-uniform infusions to occur at the holes with a large effective mass. This makes it easy to create a design suitable for high-speed modulations.

The structure of the AlGaInAs-DFB laser is shown in Figure 2. Since the AlGaInAs material oxidizes easily, it must be processed to form a structure which does not expose the surface layer to air, while keeping the device capacitance, resistance, and threshold current low. For this reason, a ridge waveguide structure was adopted. Further, since the ridge structure is made through the growing of crystals once only, it is a structure which is optimally suited to lower costs.

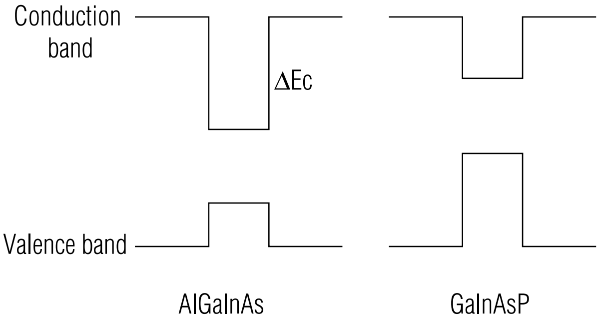

Fig. 1 Band structures

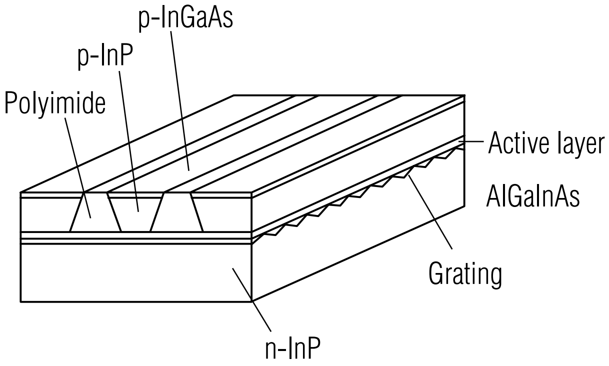

Fig. 2 Laser structure

The MQW, clad layer, and contact layer were grown by metalorganic vapor phase epitaxy (MOVPE) on the n-type InP substrate on which the grating (diffraction grating) was made. The raw materials used were mainly from the Group III of organic metals, such as triethyl gallium (TEG), trimethyl indium (TMI), trimethyl aluminum (TMA); and Group V arsine (AsH_3), Phosphine (PH_3); as well as from dopant dimethyl zinc (DMZn) and disilane (Si_2H_6). The growth temperature was set to 630°C, which is the most suitable temperature for AlGaInAs. The MQW is composed of the AlGaInAs quantum well with a 1% compression strain (λ_g = 1.4µm, d = 6nm) and the AlGaInAs barrier layer with a 0.2% tensile strain (λ_g = 1.0µm, d = 10nm). The number of quantum wells was set to ten, in order to achieve high-speed operations.

Once the growth was completed, reversed mesa formation, polyimide embedding, and p as well as n electrodes, were formed, the cleavage was spread, and finally the reflection film was implemented. The length of the element was set to 250µm, with a consideration for the CW and modulation characteristics. The reflection film was set to 1% on the front facet, and 83% on the rear facet.

CW characteristics

Optical output and electric current characteristics for 25°C and 85°C are shown in Figure 3. An optical output of 20mW and more is obtained with good linearity, even at 85°C. The threshold current I_{th}, and slope efficiency η, as well as the drive current I_{op} with an optical output of 10mW, for temperatures 0, 25°C and 85°C, are shown in Table 1. The characteristic temperature T_0, which indicates the temperature dependency of the threshold current, was 96K for the range of 25°C to 85°C, while the fluctuation ($\Delta\eta$) of the slope efficiency was 70%. The GaInAsP laser, T_0 = 46K and $\Delta\eta$ = 65%, shows that the temperature characteristics for the AlGaInAs material is superior. Further, the spectrum data for the drive current I_{th} + 20mA at 25°C and 85°C are shown in Figure 4. A side mode suppression ratio of 40dB or more was obtained, confirming that favorable singular wavelength characteristics exist over a wide temperature range.

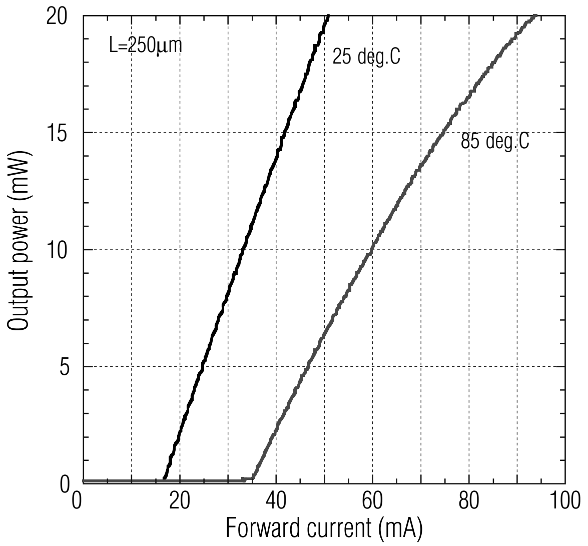

Fig. 3 Optical output and current characteristics for 25°C and 85°C

Table. 1 Temperature dependency of optical output and current characteristics

Temperature (°C)	Ith(mA)	SE(W/A)	I_{op}@10mW(mA)
0	14	0.49	34
25	15	0.48	36
85	28	0.35	57

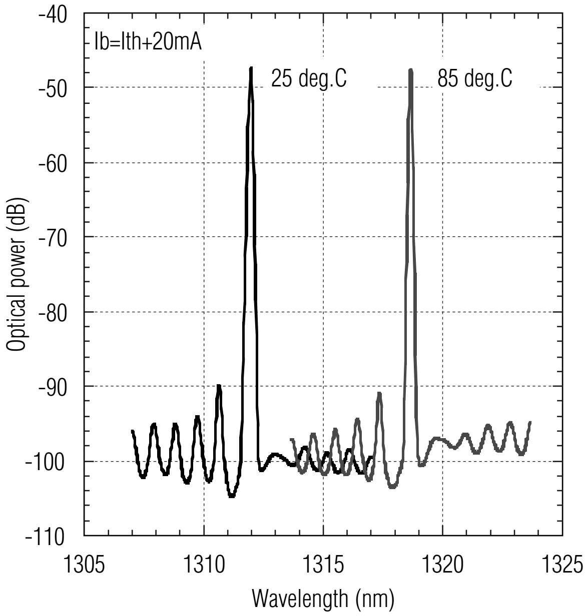

Fig. 4 Spectrum characteristics for 25°C and 85°C

High-speed modulation characteristics

Small signal response characteristics for 25°C and 85°C are shown in Figure 5. An evaluation was carried out by mounting a laser chip onto the AlN carrier with a 50Ω transmission line. Measurements were taken with an optical network analyzer. The bias current Ib was set to I_{th} + 50mA for both 25°C and 85°C.

Favorable modulation characteristics were confirmed. The relaxation oscillation frequency fr in excess of 9 GHz and the 3dB bandwidth of 12GHz were obtained. As fr is

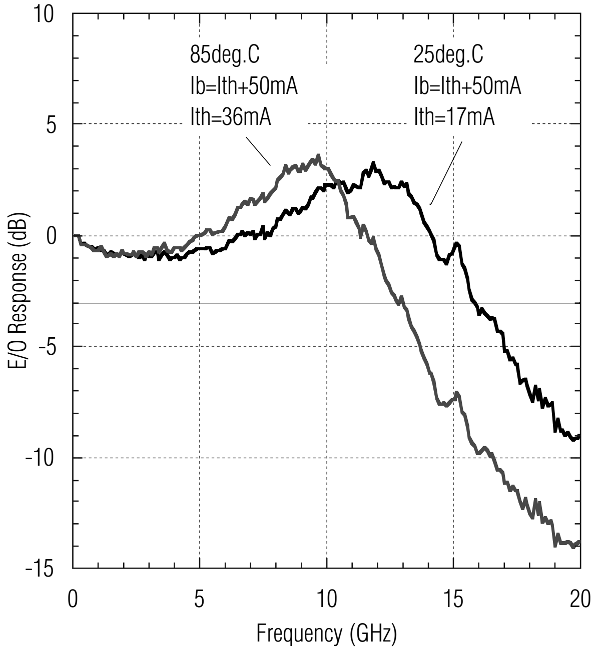

Fig. 5 Small signal response characteristics for 25°C and 85°C

(a) 25°C, with filter

(b) 25°C, without filter

(c) 85°C, with filter

(d) 85°C, without filter

Fig. 6 Eye patterns at 25°C and 85°C

proportional to (Ib - Ith)$^{1/2}$ the incline of the line, Δ fr/ΔI, is a critical index for evaluating high-speed characteristics.

The $\Delta f_r/\Delta I$ of the prototyped laser was 1.8GHz/mA$^{1/2}$ and 1.2GHz/mA$^{1/2}$ for 25°C and 85°C respectively, while the fluctuation due to temperature was 67%. The $\Delta f_r/\Delta I$ of the GaInAsP laser was 1.6GHz/mA$^{1/2}$ and 1.0GHz/mA$^{1/2}$ for 25°C and 70°C respectively, with a fluctuation of 63%. It is therefore apparent that the modulation characteristics of the AlGaInAs laser in high temperatures, are superior when compared to those of the GaInAsP laser.

Back-to-Back eye patterns are shown in Figure 6. The modulation speed was 10.3125 Gbit/s (pseudo-random pattern 2^{31}-1) and a 10Gbit Ethernet standard mask was used. The displays in (a) and (c) represent the waveforms with an electric filter inserted, while (b) and (d) represent waveforms without filter insertions. The bias current and modulating current necessary to attain a extinction ratio of 4.5dB include 40mA and 34mApp for 25°C, as well as 70mA and 37mApp for 85°C. Favorable eye openings were obtained without mask hits for a mask margin of 10%, indicating that their practical use should not cause any problem. As described thus far, although the characteristics are adequate for the 10Gbit Ethernet standard, they are still not adequate for the SONET standard of the OC-192. We shall therefore, continue with our efforts to optimize the MQW structure, the well count, and element length.

Outlook for the future

This element is to be mounted on the Transmitter Optical Subassembly (TOSA) module, which complies with the MSA standards (industry organization standard) of the XFP and the XPAK, which are currently being developed. In the future, we expect that lasers with superior high temperature characteristics will become more necessary and important, as package sizes become more compact. This will make the structures of elements difficult for designing the thermal diffusers. We intend to proceed with our commercialization of the product for the 85°C - 10Gbit Ethernet and telecom markets, by utilizing the high temperature characteristics of the AlGaInAs laser that was introduced in this paper.

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TIPS Basic Glossary

Direct modulating-type (method)

A method used to modulate the optical output is by directly modulating the electric current infused in the semiconductor laser.

Relaxation oscillation frequency

The phenomena of the oscillating optical output, when pulsed current is infused in a semiconductor laser, is called a relaxed oscillation. The frequency of this oscillation is called the relaxated oscillation frequency. This phenomena occurs in the transient response characteristics of the optical density and carrier density, and exists in the active layer structure. The response characteristics decline rapidly when this frequency value is exceeded.

Band offset

The band offset is the difference in the amount of energy generated in the conduction band and the valence band, when semiconductors with varying energy gaps are joined together.

DFB laser (Distributed Feedback laser)

The distributed feedback-type laser is a laser with an internal diffraction grating, which is capable of generating a single wavelength oscillation.

T_0

This is the characteristic temperature of the threshold current, Ith. When this value is large, it implies that the temperature dependency is smaller.

$T_0 = (T2 - T1) / \mathrm{In}\ (Ith2 - Ith1)$

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