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**Invited**

# Monolithic Laser Light Sources for Advanced Optical Communications

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It is demonstrated that the monolithic integration of an electro-absorption modulator and a DFB laser gives high speed and very low chirp light sources for very high bit-rate intensity modulation systems. For coherent communication systems, a monolithic 3-electrode long cavity λ/4 shifted DFB laser is shown to provide narrow linewidth, tunability, flat FM response and high power.

## 1. Introduction

Highly advanced performances are required for very high bit-rate intensity modulation systems and for coherent communication systems. For very high speed intensity modulation systems ranging from 2Gb/s to 10Gb/s, light sources with very small wavelength chirp are required to facilitate long distance transmission. For coherent communication systems such as CPFSK (continuous phase frequency shift keying) or DPSK (differential phase shift keying) systems, lasers must exhibit a very narrow linewidth below 1MHz, wavelength tunability, flat FM response and high output power. The conventional DFB laser can not satisfy these requirements. One of the way to achieve these advanced performances is to use external elements such as modulators and mirrors. However, it is far more advantageous to develop a simple monolithic device that can provide necessary performances.

Here, we demonstrate two examples as monolithic light sources. One is a monolithic integration of two devices. An electro-absorption modulator and a DFB laser are monolithically integrated into one chip[1,2]. This device realized a high speed response and a very small chirp. In this example we can see key technologies necessary to integrate different type of device into one chip. The other example is a 3-electrode long cavity λ/4 shifted DFB laser[3] for coherent communication systems. This laser exhibited narrow linewidth, wavelength tunability and flat FM response. This example shows that we can extract varieties of advanced performances from a monolithic DFB laser by exploitation of new operating principle.

## 2. Monolithic electro-absorption modulator/DFB laser light source

Fig.1 shows the schematic structure of our device[1]. The lasing wavelength is 1.55 μm. The photoluminescence wavelength of the absorption layer is adjusted to be 1.40μm. There are three key technologies in fabricating this monolithic device: (1) the electrical isolation between the forward biased DFB laser and the reverse biased modulator, (2) AR-coating

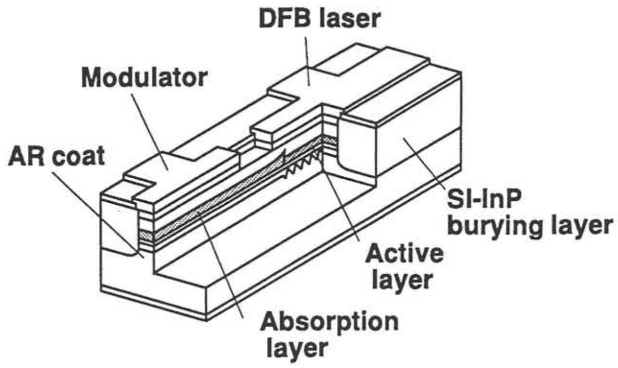


Fig.1 Schematic structure of electro-absorption/DFB laser light source.

technology to prevent reflection from the facet of the modulator, (3)waveguide design and its fabrication technology to get large optical coupling between the two devices.

For the electrical isolation, we used semi-insulator embedding growth technology. The isolation resistance of 500kΩ to 2MΩ is obtained. For AR-coating we used SiN film to get the reflectivity of below 0.5 %. These isolation resistance and the reflectivity are sufficient to prevent the electrical and optical interference of the two devices[4]. To get high coupling efficiency we used a butt-joint with a guiding layer and a very thin InP layer which are common for the DFB laser and the modulator. The coupling efficiency calculated for the actual dimensions of the butt-joint was about 85 %, and the value coincided very well to the experimentally estimated value.

Fig. 2 shows typical light output versus current characteristics for various applied voltage to the modulator. Owing to the large coupling efficiency, high output power of more than 15 mW is obtained. The light output that remains even for -5V of bias is due to the radiation mode generated at the butt-joint. We can couple only to the guided light by putting a single mode fiber at the front facet and an extinction ratio of about -13 dB can be obtained. Fig. 3(a) shows the modulation waveform under 10 Gb/s NRZ modulation. Clear eye opening is

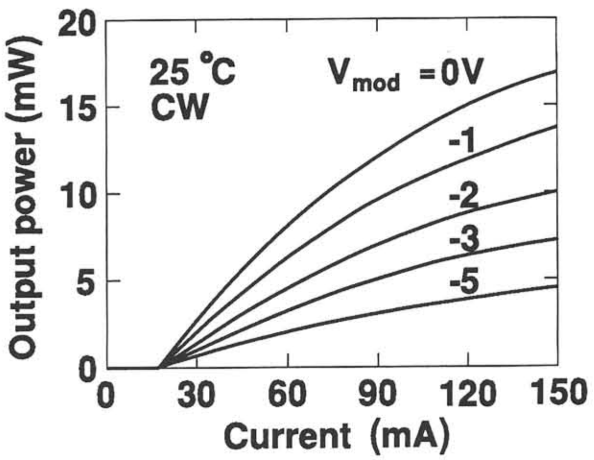


Fig.2 Light output versus current characteristics.

obtained. Fig.3(b) shows a spectrum under modulation. The full width at half maximum is 0.1 Å. The transmission experiment at 10 Gb/s showed that we can transmit even for the large dispersion of 230 ps/nm within the penalty of 0.5 dB[5].

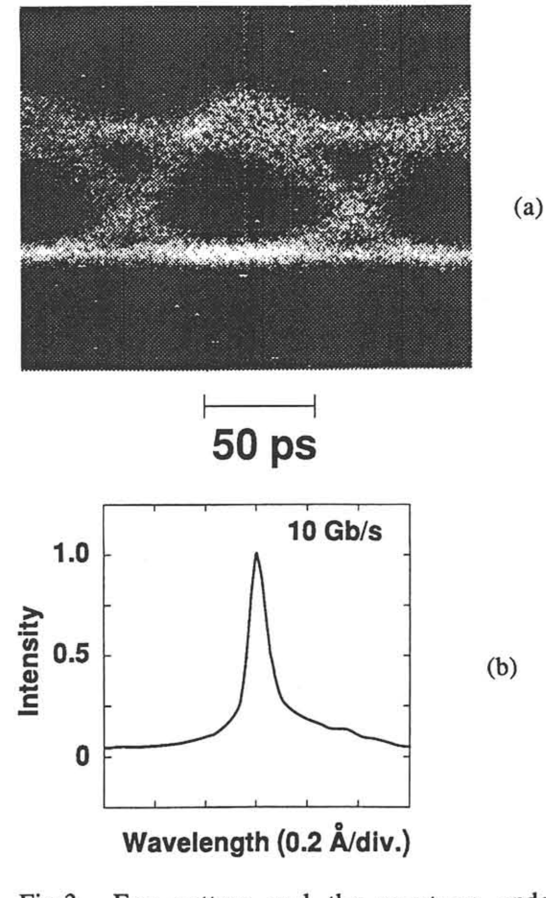


Fig.3 Eye pattern and the spectrum under 10 Gb/s NRZ modulation.

### 3. 3-electrode long cavity λ/4 shifted DFB laser

Fig. 4 shows a schematic structure of the device[3]. To attain narrow linewidth, the cavity length is 1.2mm. There is a λ/4 shift in the corrugation at the center of the cavity. Three electrodes are on the p-side of the laser chip. By controlling the current to the center electrode and to the sides, we can tune the wavelength.

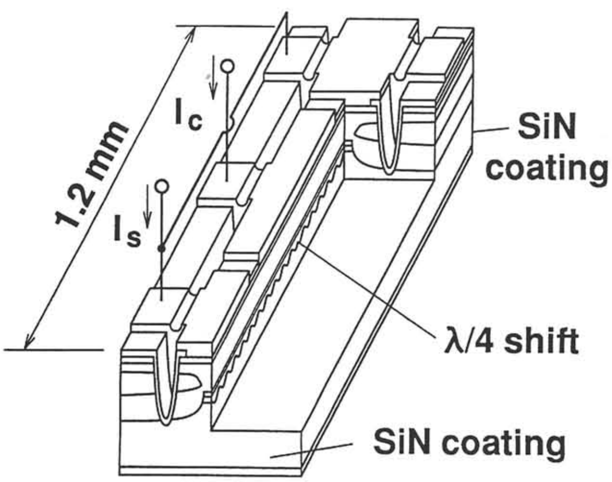


Fig.4 Schematic structure of 3-electrode long cavity λ/4 shifted DFB laser.

The wavelength tuning this device is based on a new principle. Because of the λ/4 shift in the corrugation, the optical field is concentrated at the center of the cavity. When carriers are injected uniformly to the active layer, there occurs a spatial hole burning at the center. This gives rather high threshold carrier density. When larger current is injected to the center of the cavity, the spatial hole burning is compensated and the threshold carrier density reduces. This causes the increase in the refractive index and results in the shift of the lasing wavelength to the longer side. This is the red shift tuning.

Fig.5 shows the linewidth and the lasing wavelength and output power as a function of the center current $I_c$. The current to the side

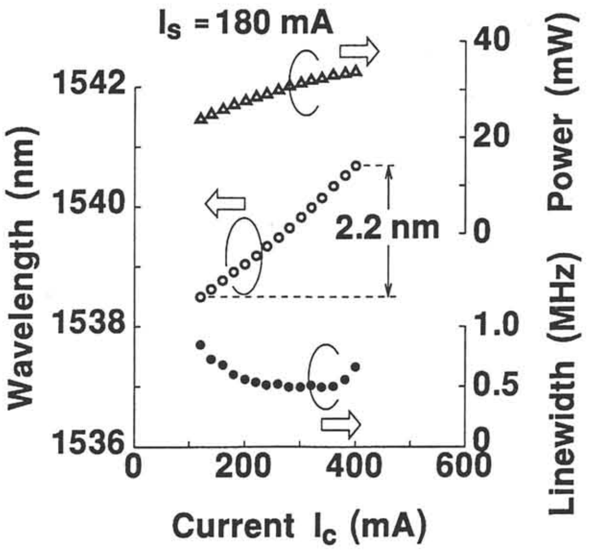


Fig.5 Wavelength, linewidth and output power characteristics.

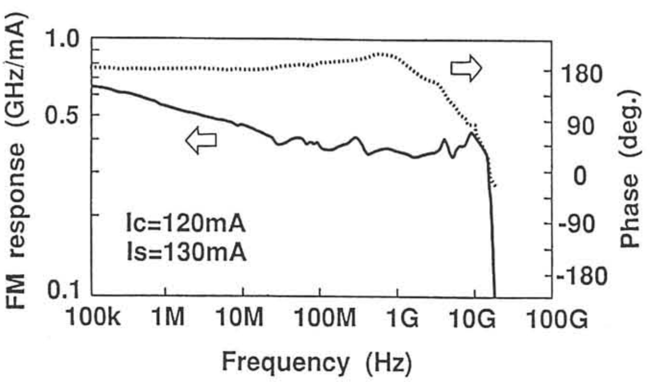


Fig.6 FM response.

electrode is fixed to be 180 mA. We can confirm a red shift tuning. The entire tuning range maintaining the single mode operation was 2.2 nm. As an increase of the center current the linewidth reduces. This indicates the loss reduction by the compensation of the spatial hole burning. The very narrow linewidth below 1 MHz is owing to the long cavity structure. Fig.6 shows the FM response when modulation signal is imposed on the center current. In the conventional DFB laser, there occurs a dip in the FM response at the low modulation frequency. This is due to the compensation of the FM response due to thermal effect and the carrier effect. The carrier effect in the usual DFB laser is the blue shift. In our device, owing to the red shift modulation mechanism, FM response do not show the dip at low frequencies.

This device is based on the new operating mechanism that the spatial hole-burning specific to the DFB laser is controlled by the multiple electrodes. We can realize varieties of field distribution while maintaining the sufficient threshold gain differencecs between modes by the design of the corrugation[6]. There is still a possibility of extracting new performances from the DFB laser.

4. Conclusions

Two examples are demonstrated as a monolithic devices for advanced communication systems. The electro-absorption modulator/DFB laser light source is an example of integration of different type of the devices. Owing to the integration, the monolithic light source capable of transmitting for large dispersion even at 10 Gb/s has been realized. The 3-electrode long cavity $\lambda/4$ shifted DFB laser exhibited a fairly good performance for coherent communication systems. We succeeded in extracting advanced performances from a DFB laser by an exploitation of a new operating principle.

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