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Dependence of Threshold Current on Wavelength and Temperature in 1.3-μm GaInAsP/InP DFB Lasers

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The threshold-wavelength and threshold-temperature dependences of 1.3 μm GaInAsP/InP distributed feedback lasers are discussed. For this purpose, DFB lasers with different grating periods were fabricated on the same wafer. Lasers of this type were found to show laser oscillation with a reasonably low threshold current over a wavelength range of 500 Å. This oscillation region is wider than expected from the previous reports.

1. Introduction

Distributed feedback (DFB) lasers have been extensively studied because of their controlled and stable longitudinal mode operation. They are expected to be used in wavelength multiplexing optical fiber communication systems.

The lasing thresholds of DFB lasers are thought to depend on the oscillation wavelength, which is defined by the period of the surface corrugation (grating period). Even though the performance of GaInAsP/InP DFB lasers has proven to be excellent [1], little attention has been paid to its optimization and in particular to the optimization of grating period to minimize threshold current. This is possibly because of the difficulties of fabricating gratings with controlled periods. In a previous publication, [2] the authors have reported the performance of a computer-controlled interferometer for the fabrication of gratings with excellent controllability and reproducibility. It is now possible to select any desired lasing wavelength within the spectral gain profile by precisely controlling the grating periods of DFB lasers.

This paper reports the first detailed and systematic study of the threshold-wavelength and threshold-temperature dependence of 1.3 μm GaInAsP/InP DFB lasers. Lasers of this type were found to show laser oscillation over a 500 Å wavelength region, which is a somewhat wider range than expexted.

2. Experimental

A schematic diagram of our DFB laser is shown in Fig. 1. At the heart of the structure lies a group of three layers: an n-type quaternary waveguide layer (λ_{PL} = 1.12 μm), an n-type InP buffer layer and an undoped quaternary active layer (λ_{PL} = 1.28 μm). A fine surface corrugation of around 2000 Å period was made on an InP substrate by holographic exposure method followed by chemical etching. The detail of the growth procedure has been reported elsewhere [3]. The threshold current of DFB lasers are affected by many device parameters, such as stripe width, layer thickness and grating depth. To minimize any systematic errors caused by slight variations in device structure, we fabricated DFB lasers with four or five different grating periods on the same wafer, i.e. (1990, 1997, 2004, 2011 Å) or (1989, 1998, 2007, 2016, 2025 Å). The holographic interferometer system, controlled by a personal computer, made it

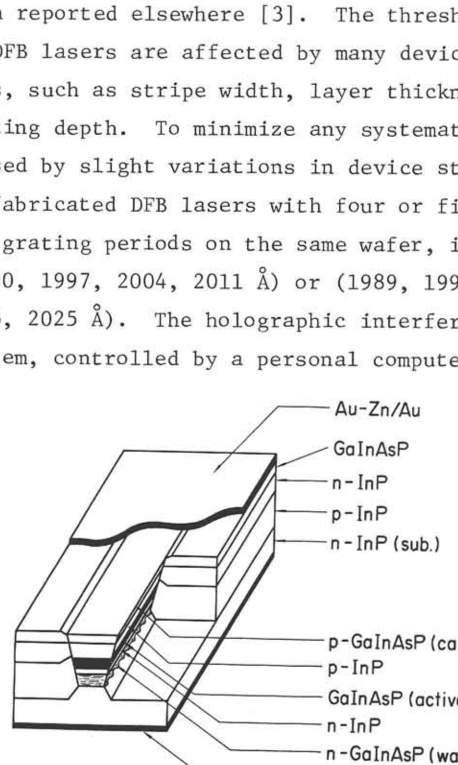

Fig. 1 Schematic diagram of 1.3 μm DFB laser structure.

possible to fabricate the grating with excellent controllability of the grating period less than 0.5 Å.

The grating depth was estimated non-destructively by measuring the diffraction efficiency.

The four or five wavelength DFB laser array was mounted on a Cu heat sink using In solder in a p-side-up configuration.

Typical power output characteristics for continuous current input of the five wavelength DFB laser array is shown in Fig. 2. The spacing of the oscillation wavelengths, about 50 Å, was defined by the 9 Å grating difference. A detailed discussion of wavelength controllability will be given elsewhere [4].

Figure 3 shows the emission spectrum just a little above the threshold current for our DFB laser. The spontaneous peak, or lasing wavelength for Fabry-Perot mode operation, of the DFB laser wafers used in this experiment was found to lie between 1.27 and 1.28 μm.

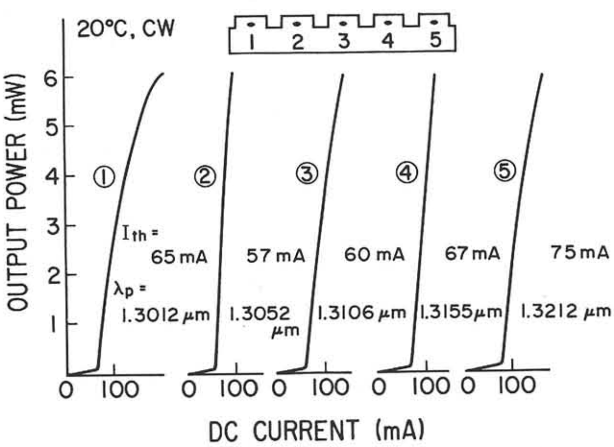

Fig. 2 Typical output power versus current for 5-wavelength DFB array lasers.

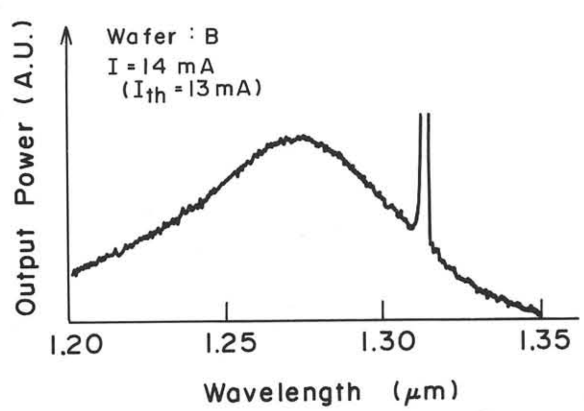

Fig. 3 Output spectrum of a DFB laser just above threshold.

3. Results and Discussions

3-1 Threshold-Wavelength Dependence

Fig. 4 shows the dependence of threshold current on wavelength for several 5-wavelength DFB array lasers fabricated from the same wafer. The diffraction efficiencies of the surface gratings, measured before crystal growth, are also shown in this figures. When corrected for the variations in grating depth, estimated from the diffraction efficiency, the threshold currents were found to be nearly independent of wavelength. Figure 5 shows the dependence of threshold current on

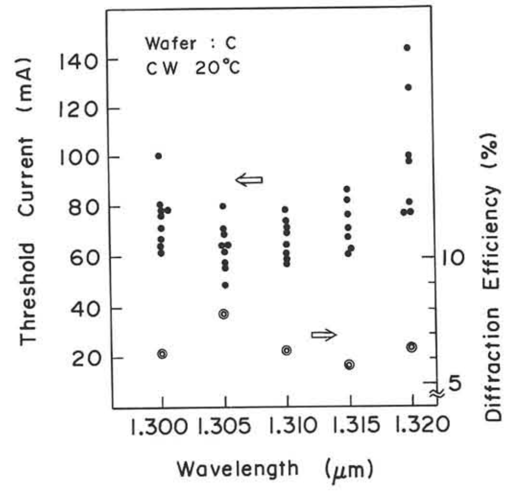

Fig. 4 Threshold-wavelength dependence of 5 wavelength DFB laser array.

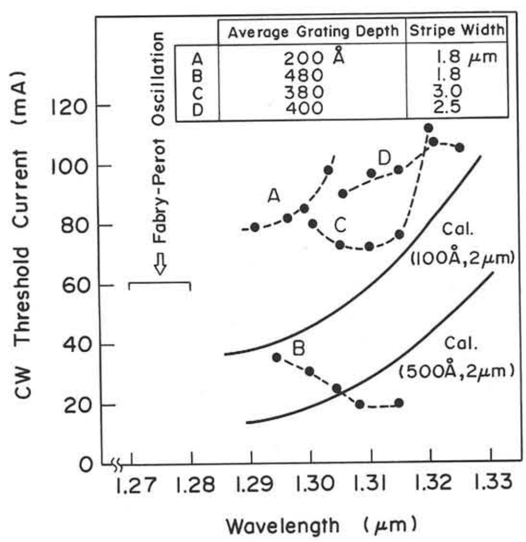

Fig. 5 Experimental threshold-wavelength dependence for four different wafers and calculated ones.

wavelength for four different wafers. Each data point corresponds to the mean value of wavelength and threshold current for DFB lasers fabricated with the same grating periods from the same wafer. The average grating depth and stripe width, which also affect the threshold current, are shown in this figure, too.

3-2 Threshold-Temperature Dependence

Figure 6 shows the threshold-temperature dependence of a five wavelength DFB laser array. The temperature at which the minimum threshold current occurred was found to be a function of wavelength. The longer the wavelength of DFB laser, the higher the temperature for minimum threshold current. The 5-wavelength DFB laser array showed CW lasing operation throughout the temperature range from 5 to 50°C. The maximum temperature at which CW oscillation could be obtained is limited by thermal dissipation.

Figure 7 shows another example of threshold current-temperature dependence. LD "E" oscillated at a wavelength close to the peak of the spontaneous emission at 20°C, as shown in the inset of this figure. On the other hand, LD "F" had a lasing wavelength offset to the longer side of the spontaneous emission peak. This wavelength offset appears to be correlated with a reduction in threshold current. LD "E" did not show any CW oscillation above 30°C.

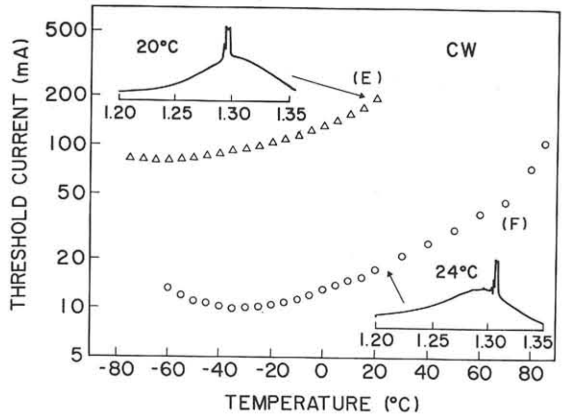

Fig. 7 Threshold-temperature dependence of DFB lasers in comparison with different relative positions of oscillation wavelength and spontaneous emission peak.

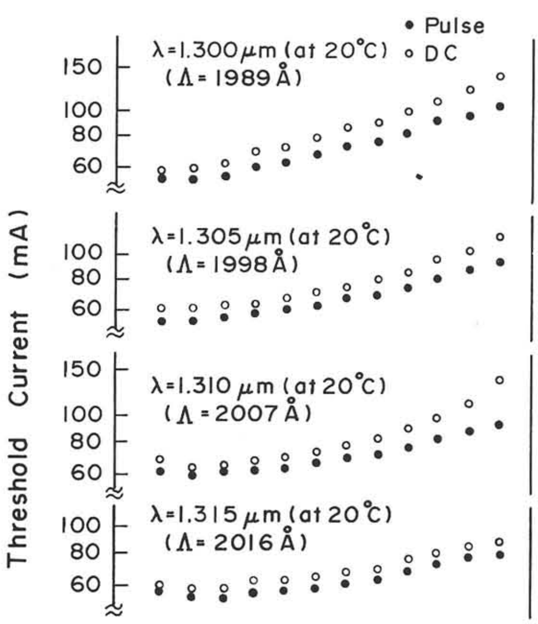

Fig. 6 Typical threshold-temperature dependence of 5 wavelength DFB laser array.

3-3 Discussions

The threshold current of GaInAsP/InP DH lasers has been discussed by M. Asada et al. [5]. Their results can be used for Fabry-Perot type lasers showing laser oscillation at the gain peak. In contrast, the lasing wavelength of DFB lasers is determined to a first approximation by the grating period, and so a wavelength dependent gain must be used to calculate their threshold current. It can be written as

$$G = G_p - [(\lambda_p - \lambda_m)/G_0]^2 \quad . \tag{1}$$

All the symbols are given, along with numerical values, in Table 1. The numerical value of G_0, 2.1 $nm \cdot cm^{\frac{1}{2}}$, was obtained [6] by fitting eq. (1) to the theoretical gain curve for GaInAsP near λ_p = 1.3 μm.

The threshold current density can be expressed as

$$J_{th} = \frac{eB}{A^2} d \left\{ AN_0 + \left[\frac{(\lambda_p - \lambda_m)}{G_0}\right]^2 + \alpha_{ac} + \frac{1-\Gamma}{\Gamma}\alpha_{ex} + \frac{2\alpha_{th}}{\Gamma} \right\}^2 \quad . \tag{2}$$

The calculated threshold current dependence on wavelength is shown also in Fig. 5 for DFB lasers with a stripe width of 2 μm, a cavity length of 300 μm, and a grating depth of 100 or 500 Å.

Table 1 List of symbols and values used in calculation

G	gain	
G_p	gain at the peak of the gain curve	
G_0	parabolic gain fitting factor	$= 2.1\ \mathrm{mm \cdot cm^{\frac{1}{2}}}$
λ_p	wavelength of peak gain	
λ_m	oscillation wavelength of DFB mode	
e	electronic charge	
d	active layer thickness	
B	recombination coefficient	$= 8 \times 10^{-11}\ \mathrm{cm^3/S}$
A	gain parameter	$= 2.5 \times 10^{-16}\ \mathrm{cm^2}$
N_0	electron density to achieve polulation inversion	$= 4.5 \times 10^{17}\ \mathrm{cm^{-3}}$
α_{ac}	loss in the active layer	$= 140\ \mathrm{cm^{-1}}$
α_{ex}	loss in other layers	$= 20\ \mathrm{cm^{-1}}$
Γ	confinement factor	
α_{th}	threshold gain of DFB laser	

It can be seen that the agreement between theoretical and experimental results is not good. This might be caused in part by variation in grating depth. Theoretically the wavelength dependence of threshold current comes from the wavelength dependent gain profile. The lasing bandwidth which we observed for our DFB lasers, especially on the longer wavelength side of the maximum gain peak, was larger than might be expected from the measurement in F-P lasers with external grating feedback made by W. T. Tsang et al. [7]: we found that DFB lasers with oscillation wavelengths up to 350 Å longer than the maximum gain wavelength had threshold currents below 20 mA. As shown in Fig. 7, however, the DFB lasers with oscillation wavelengths shorter than the maximum gain seem to have a relatively high threshold current. A number of studies on frequency selective feedback (FSF) lasers have been reported [8], including the measurement of threshold current as a function of FSF lasing wavelength. All the curves reported for FSF lasers were asymmetric with respect to the maximum gain position. A rapid increase of threshold current with wavelength occurred on the long wavelength side. This behaviour is opposite to that shown by our DFB lasers. The reason for the discrepancy is not clear at present. However, even with external FSF the laser seems to be strongly influenced by the diode end facet. Consequently the threshold current increases as the feedback frequency is moved away from the gain peak.

Experimentally we found the gain was sufficient to give reasonably low threshold laser operation over a wider bandwidth than expected from FSF experiments. Our results indicate that to minimize threshold current DFB lasers should be designed to operate on the long wavelength side of peak gain.

The bandwidth of 1.3 μm GaInAsP/InP DFB lasers is also larger than that observed for GaAlAs/GaAs DFB lasers [9]. These results suggest that the GaInAsP/InP DFB laser is suitable for use in wavelength multiplexing communications applications.

4. Concluding Remarks

Threshold-wavelength and threshold-temperature dependence of 1.3 μm GaInAsP/InP DFB lasers were studied systematically. In order to avoid errors caused by slight variations in device structure, DFB lasers with different grating periods were fabricated on the same wafer. 1.3 μm DFB lasers were found to show lasing operation with low threshold current over a rather wider wavelength region than expected, particularly on the long wavelength side of the gain peak. These results show that the 1.3 μm GaInAsP/InP DFB laser has great potential for use as a wavelength multiplexing source.

The present research effort is part of a major research and development project on optical measurement and control systems, conducted under a program set up by Ministry of International Trade and Industry's Agency of Industrial Science and Technology.

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