Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 595-597

B-5-2

Pixels Consisting of Double Vertical-Cavity Detector and Single Vertical-Cavity Laser Sections for 2-D Bidirectional Optical Interconnections

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We have proposed a structure for optical pixels consisting of a double vertical-cavity detector and single vertical-cavity laser section. This pixel can be formed by a simple fabrication process, and the characteristics of the laser and detector sections can be independently optimized. The peak absorptivity of the double vertical-cavity detector section is about five times that of the single vertical-cavity laser section, and the bandwidth of the former is about five times that of the latter.

1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) and VCSEL-based optical functional devices such as VC-VSTEPs[1] are promising for two-dimensional optical interconnections and information processing. In particular, the advantages of InGaAs strained quantum wells for active layers are that their threshold current is low, and that GaAs substrates are transparent to the output laser light. This enables a junction-down configuration, resulting in good heat dissipation. To integrate the detector function into both VCSELs and VCSEL-based optical functional devices for bidirectional optical interconnections, the detector section must have sufficient sensitivity to the input laser light.

We have reported VCSELs used as both lasers and detectors[2,3]. However, there is essentially a trade-off between low threshold current on one hand, and high detector efficiency and wide detector bandwidth on the other hand. Narrow detector bandwidth and laser heating causes fluctuation in the detector efficiency.

To solve these problems, we propose here a pixel which has both laser and detector functions as shown in Fig.1. The laser and detector sections have a similar structure, except for a half-wave spacer layer, inserted between the bottom distributed Bragg reflector (DBR) and the middle DBR in the detector section. This layer forms a double vertical cavity in conjunction with the top DBR[4]. The small structural difference between the laser and detector sections makes it possible to independently optimize both functions, and they can be densely integrated owing to the simple fabrication processes.

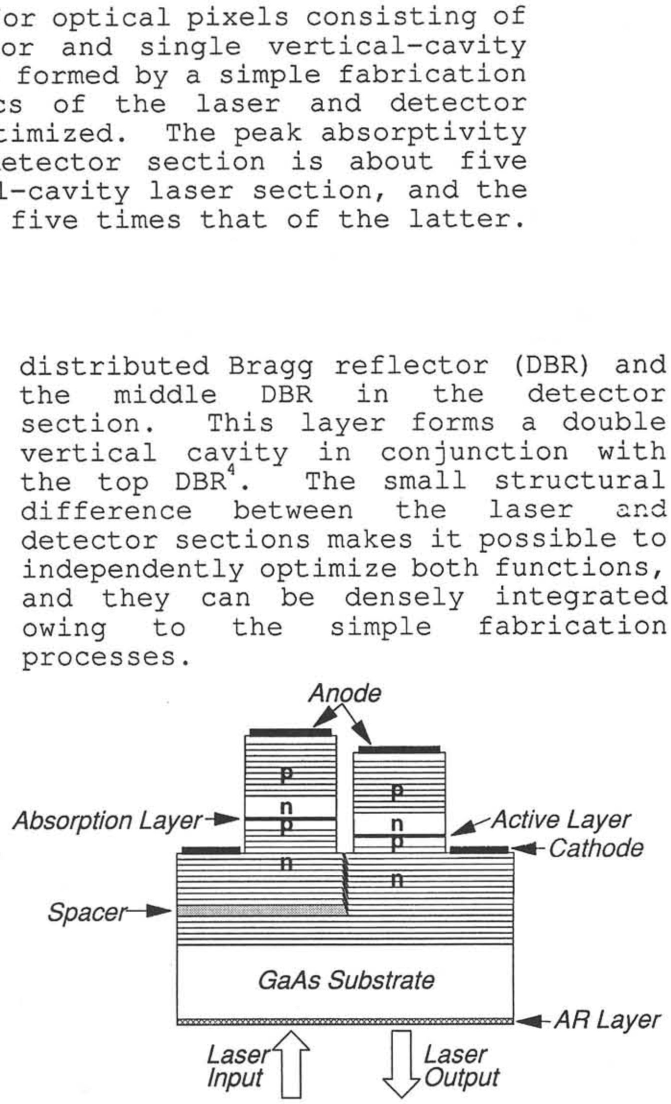

Fig. 1 Pixels consisting of double vertical-Cavity detector and single vertical-Cavity laser sections.

2. Structure

An SEM view of the double vertical-cavity detector section is shown in Fig. 2. The layers are grown on a GaAs substrate by molecular beam epitaxy (MBE) as follows: a 7.5-period

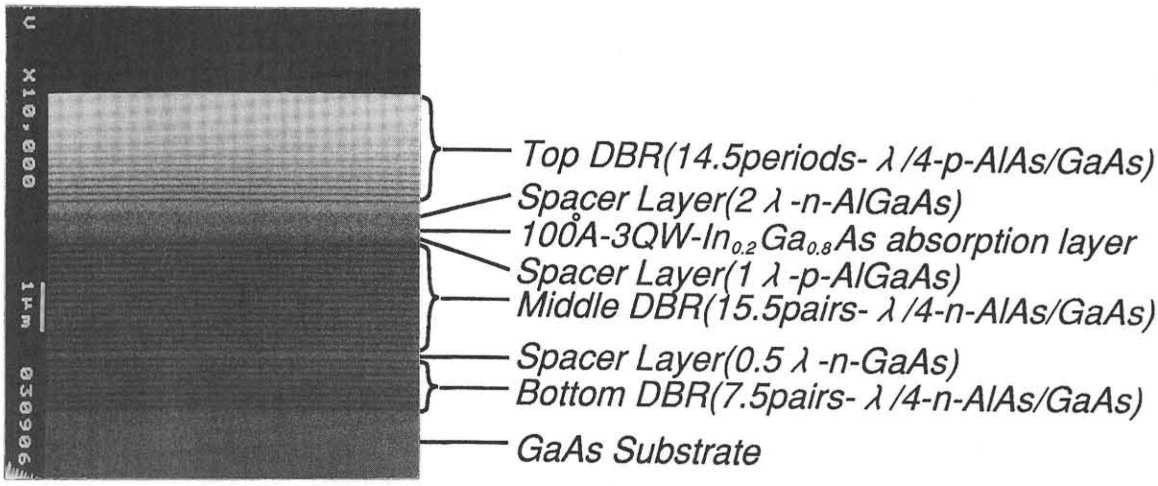

Fig. 2 Cross-sectional SEM view of the double vertical-cavity detector section.

n-doped (Si: 2×10^{18}cm^{-3}) quarter-wave GaAs/AlAs stack for the bottom DBR, a half-wave GaAs spacer layer, a 15.5-period n-doped (Si: 2×10^{18}cm^{-3}) quarter-wave GaAs/AlAs stack for the middle DBR, three 100 Å undoped $In_{0.2}Ga_{0.8}As$ strained quantum well absorption layers positioned at the peak of the electric-field standing-wave pattern inside a three-wave $Al_{0.4}Ga_{0.6}As$ spacer, and a 14.5-period p-doped (Be: 3×10^{18}cm^{-3}) quarter-wave GaAs/AlAs stack for the top DBR. After growing up to the spacer layer on the substrate, this layer is chemically etched and removed in the laser section. Then the upper layers are grown for both the laser and detector sections by a second MBE growth.

3. Design

To achieve a high detector efficiency and wide detector bandwidth without increasing the lasing threshold for the laser section, we designed the pair numbers for top, middle and bottom DBRs by simulating the absorptivity spectra.

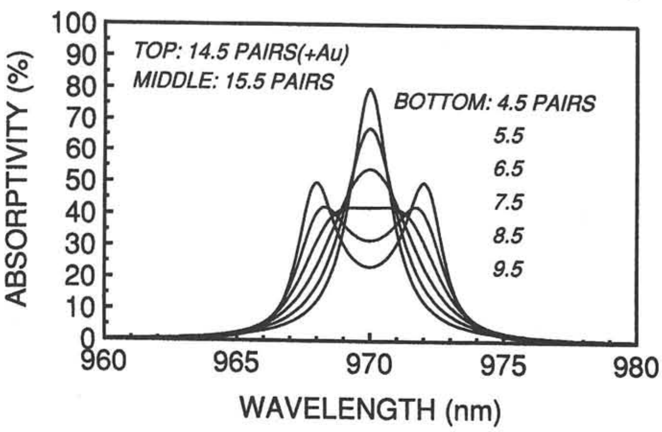

Fig. 3 Calculated absorptivity spectra of the double vertical-cavity detector section.

Figure 3 shows a calculated absorptivity spectra for the bottom DBR from 4.5 to 9.5 pairs, when the top and the middle DBRs are 14.5 and 15.5 pairs, respectively. The pair number of the top DBR is determined to achieve sufficient reflectivity with the support of reflection from the gold electrode. The absorption spectra shows flat wavelength dependence at 7.5 pairs for the bottom DBR. Therefore, in the structure of the detector section we used the pair numbers which require the structure of the laser section to be 14.5 and 22.5 pairs for the top and the bottom DBR, respectively. This structure also optimizes lasing characteristics such as lasing threshold and slope efficiency.

4. Result

Figure 4 shows the photocurrent spectra of the double vertical-cavity detector and the single vertical-cavity laser section (dots) together with the calculated absorptivity spectra (solid lines). In this experiment, both detector and laser sections were made separately. The peak absorptivity of the double vertical-cavity detector section is about five times that of the single vertical-cavity laser section, and the bandwidth of the former is about five times that of the latter. The bandwidth of the double vertical-cavity detector section is approximately 5 nm. This permits a temperature change of approximately 80°C in the laser section, because the dependence of the lasing wavelength on temperature is 0.63Å/°C. At shorter wavelengths below the absorption peak,

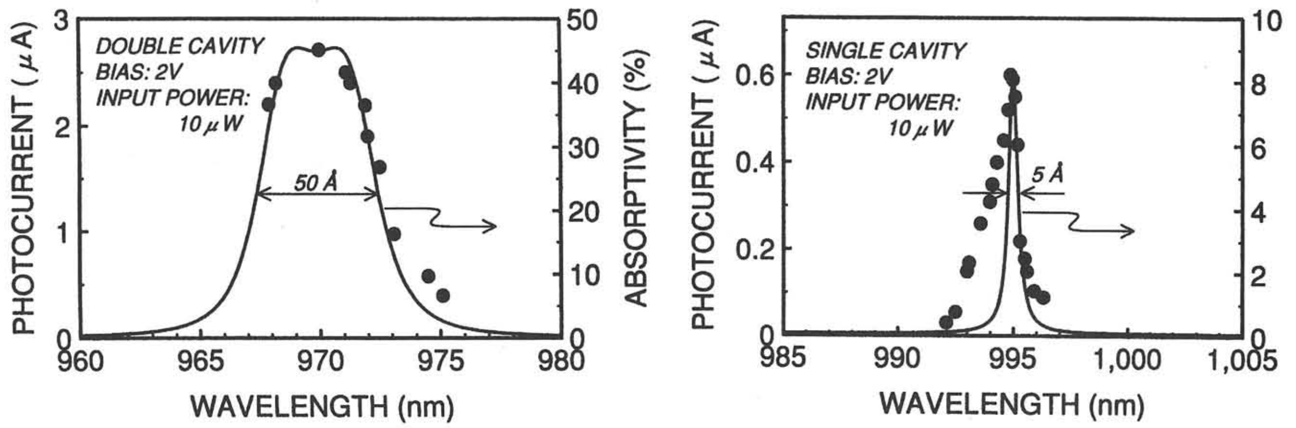

Fig. 4 Photocurrent spectra of the double vertical-cavity detector and the single vertical-cavity laser section together with calculated absorptivity spectra.

the difference between the measured and calculated values for the single vertical-cavity laser section is due to the influence of the higher transverse modes.

Figure 5 shows emission spectra of the double vertical-cavity detector and single vertical-cavity laser section, corresponding to Fig. 4, measured at room temperature and at the injection current of 10 mA. The spectral line-width of the laser section, 1.5 Å, is limited by the resolution of the monochromator; therefore the laser section is already lasing. The spectral line-width of the detector section, approximately 60 Å, is as wide as that of the absorption spectrum; this proves it to be a spontaneous emission spectrally restricted by the cavity mode. It does not lase with less than 50 mA of injection current, but the slope efficiency is as high as 0.03 W/A.

5. Conclusion

In conclusion, we have proposed a structure for optical pixels consisting of a double vertical-cavity detector and a single vertical-cavity laser section. These pixels can be formed by simple fabrication processes, and the characteristics of the laser and detector sections can be independently optimized.

Acknowledgements

We are grateful to Mitsuhito Sakaguchi, Kohroh Kobayashi, and Kiyoshi Asakawa for their continued encouragement and support throughout the research, and to Kaori Kurihara and Atsuko Yasuda for their invaluable support.

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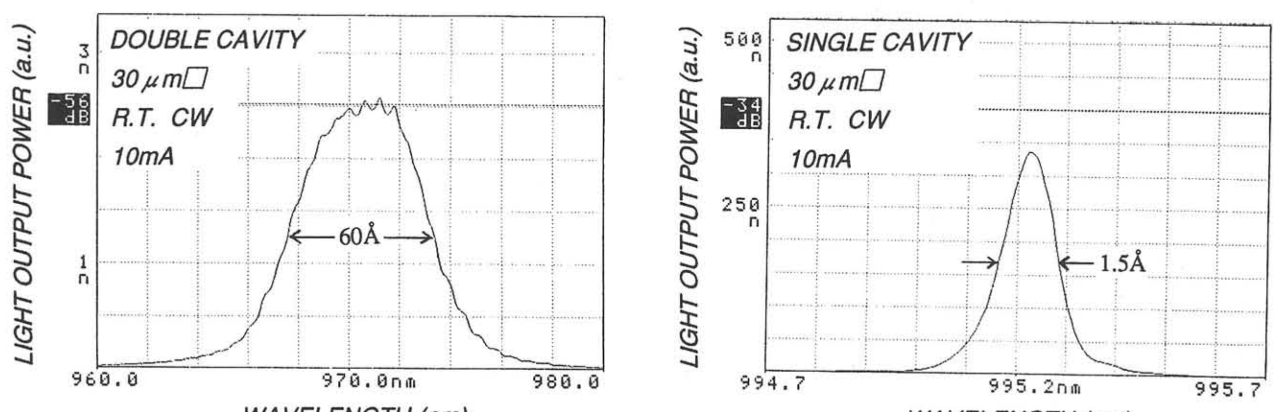

Fig. 5 Emission spectra of the double vertical-cavity detector and the single vertical-cavity laser section.