A Panel-Type Semiconductor Optical Modulator by Using Electron Depleting Absorption Control

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Operation of a newly proposed panel-type (or surface-illuminated type) semiconductor optical modulator based on absorption control by electron depleting around the p-n junctions is demonstrated. Performance of 61% on/off extinction ratio for 5.5V variation of the applied voltage was obtained in a panel-type device having 39 p-n junctions.

1. Introduction

Progress of panel-type (or surface-illuminated) optical modulators made of semiconductor materials is a key subject to realize the parallel optical processing. Operating mechanisms in almost panel-type semiconductor optical modulators are based on the quantum confined stark effect (QCSE effect) which is induced by applied electric field in multiple quantum well structures [1]-[4], because large changes in the optical absorption efficient and the refractive index due to QCSE effect are expected. However, paneltype modulators with QCSE effect tend to require high driving voltages (>10V).

On the other hand, a possible mechanism to be modulator called electron depleting absorption control (EDAC) has been proposed by authors [5],[6]. Advantageous features of this mechanism are possible operation with low voltage and less saturation in absorption for strong light. In this paper, a preliminary operation of a panel-type EDAC modulator is reported. An extinction (or on/off) ratio of 61% was obtained for 5.5V variation of the applied voltage.

2. Mechanism of EDAC Optical Modulator

The basic idea of EDAC (electron depleting absorption control) optical modulator is schematically illustrated in Fig.1. The optical absorption due to the electron transition from the valence band to the conduction band is controlled by the number of electrons (or holes) located in the conduction (or valence) band in the direct transition type semiconductor materials. The optical absorption hardly occurs if the conduction band is filled with electrons as shown in Fig.1(a), but occurs by sweeping out the electrons from the conduction band as shown in Fig.1(b). Then, two states of transmission (or on) and cut off (or off) are switched by the electron density in the conduction band. The n-type bulk material is considered to be state (a), and whose depleted portion around a p-n junction is state (b). The width of the depleted portion is varied with applied voltage on the p-n junction.







Fig.2 Structure of panel-type EDAC optical modulator

Fig.3 Experimental set-up

3. Device Structure and Fabrication

Structure of the panel-type device is illustrated in Fig.2, where the optical beam incidents perpendicular to the p-n junction planes. Because the optical beam suffers absorption loss in the depletion layers and is transparent outside of the depletion layers, the intensity of the transmitted light through this device is controlled by varing thickness of the depletion layers. Since thickness of the depletion layer around a single p-n junction is only sereral tens of nm, a large number of p-n junctions are required to get sufficient on/off ratio in a panel-type device. The number of pn junctions was 39 in this device. For low operating voltage, the applied voltage was supported each p-n junction through p and n GaAs regions which locate in transverse direction.

Triple times of the crystal growth with a method of liquid phase epitaxy were adopted to realize this structure. At the first, 39 p-n junctions were formed by growing 20 pairs of n⁺-GaAs and p⁺-GaAs layers on a Cr-doped GaAs substrate. The wafer was formed to a mesa structure by chemical etching after the first growth. The second growth was to form p-GaAs buried layer, where a selective growing technique with SiO₂ mask was adopted. The third growth was for n-GaAs buried layer. Metals of Au-Zn and Au-Ge were evaporated as the electrodes for p-type side and n-type side, respectively. The size of a device is 700 × 1000 μ m².

4. Operating Characteristics

Measuring set up is shown in Fig.3. The optical source of this measurment is a tungsten-halogen lamp radiating incoherent light whose wavelength was selected by a monochrometer. The light was guided into the panel-type device with a multi-mode fiber.

Intensity variation of the transmitted light with variation of the applied voltage is shown in Fig.4. We define here the on/off ratio be

$$\delta = (1 - T_{min}/T_{max}) \times 100[\%],$$

where T_{min} and T_{max} are the minimum and the maximum intensity of transmitted light, respectively, under variation from -5 to +0.5V. Performance of 61% on/off ratio was obtained in the device. Wavelength dependences of the on/off ratio and insertion loss are shown in Fig.5 with circles and filled dots, respectively. Profile of the spontaneous emission with larger forward bias than 1V is also shown in the figure with a broken line. The wavelength at the peak of the on/off ratio is shorter than that of the spontaneous emission. This correspondence indicates that large change of the optical absorption occurs by electron transition between energy levels in the band structures, which well supports the mechanism of our device.







Fig.5 Wavelength dependence of the on/of ratio, insertion loss and the sponteneous emission

5. Conclusion

Operation of a panel-type optical modulator based on the electron depleting absorption control was examined. Performance of 61% on/off extinction ratio was observed with 5.5V variation of the applied voltage in a panel-type device. Promising features of our EDAC modulator are to get high on/off ratio without increasing the applied voltage and to get wide wavelength range for operation. Larger on/off ratio will be obtained by increasing the number of p-n junctions.

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