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4 × 4 Photonic Switch Array with Gain and High Contrast

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We first demonstrate a new 2-D array semiconductor photonic switch which realizes direct amplification and absorption of the optical signal. Its operation is based on gain and loss in the GaAs. Be+ and B+ implantation are used to make a vertical current path and an electrical isolation layer, respectively. This switch has the features of optical gain of 4 dB, high contrast of 9.6 dB, wide optical bandwidth of 30 nm, and low applied voltage of 2.2 V, and a planar structure.

I. Introduction

Parallel signal processing is one of excellent features of photonic processing systems. In order to construct the photonic parallel processing system, 2D-array photonic devices must be realized. Semiconductor laser diode arrays have already reported, which can be used as the optical signal source in this system [1, 2].

Semiconductor photonic switch arrays have been also studied, and many attractive results have reported [3, 4, 5]. However, up to the present, the performances of these switches still leave room for improvement, e.g., low contrast, narrow optical bandwidth, highly applied voltage, etc. Besides, most of these switches cannot amplify the optical signals so that some optical amplifier must be added for processing. The laser diode switch [6] can amplify the optical signal, however, its structure is not suitable for 2-D array.

In this paper, we first demonstrate a new 2-D array photonic switch which realizes direct amplification and absorption of the optical signal. The operation principle is based on gain and loss in the semiconductor material with direct bandgap. Therefore, switch-on and switch-off of the optical signal can be controlled by injection current. The optical signal is perpendicularly injected into and emitted from the top surface. Furthermore, this switch improves upon the other performances.

II. Device structure and fabrication

Figure 1 shows the cross-sectional view of the switch. A multilayer reflector (MLR) consisting of 15 pairs of n-$Al_{0.15}Ga_{0.85}As$ (624 Å, 1×10^{18} cm^{-3}) and AlAs (732 Å, 1×10^{18} cm^{-3}), a n-$Al_{0.35}Ga_{0.65}As$ (0.3 µm, 1×10^{18} cm^{-3}) carrier confinement layer, a p-GaAs (3 µm, 4×10^{17} cm^{-3}) active layer, a n-$Al_{0.35}Ga_{0.65}As$ (0.3 µm, 5×10^{17} cm^{-3}) current blocking layer, and a p-$Al_{0.15}Ga_{0.85}As$ (0.5 µm, 1×10^{19} cm^{-3}) window cap layer are grown on a n-GaAs substrate. The injected current flows into the active layer through Be+ implanted region. The AR film is deposited on the top surface to reduce the insertion loss of the optical signal. For electrical isolation, boron ions are implanted between each switch so that a planar structure is achieved.

Figure 2 shows the cross-sectional view of the epitaxial wafer. It is grown by metalorganic vapor phase epitaxy. The uniformity if each layer is within ± 4%.

The fabrication process is shown in Fig. 3. The higher-temperature process is done before the lower-temperature process. In order to make the p-type current path through n-AlGaAs current blocking layer, Be+ ions are selectively implanted. The mask consists of a photoresist, an insulator, and a metal. After removing the mask, flash lamp annealing for 10 seconds at 900 ℃ is done for activating the ions. Then, an n-type ohmic contact metal consisting of Au/Ge/Ni is evaporated on the rear surface and sintered at 450 ℃. B+ ions are selectively implanted between each switch. The mask consists of a photoresist. Then, the AR film consisting of single SiN layer is deposited and patterned. A p-type ohmic contact metal consisting of Ti/Au is evaporated on the top surface, patterned by dry etching, and sintered at 380 ℃. The isolation layer made by B+ ion

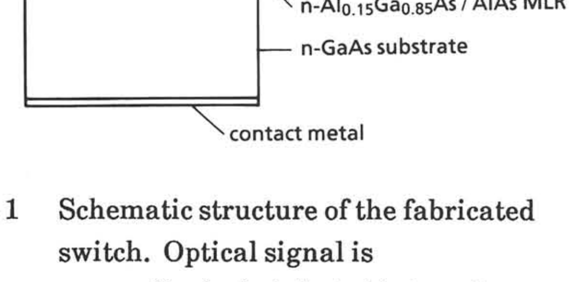

Fig. 1 Schematic structure of the fabricated switch. Optical signal is perpendicularly injected into and emitted from the top surface.

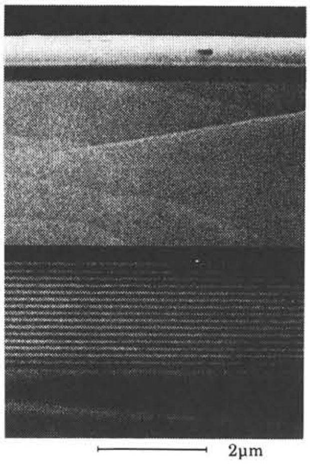

Fig. 2 Cross-sectional view of the epitaxial wafer. Active layer is 3 μm thick. MLR consists of 15 pairs of AlGaAs / AlAs thin layers.

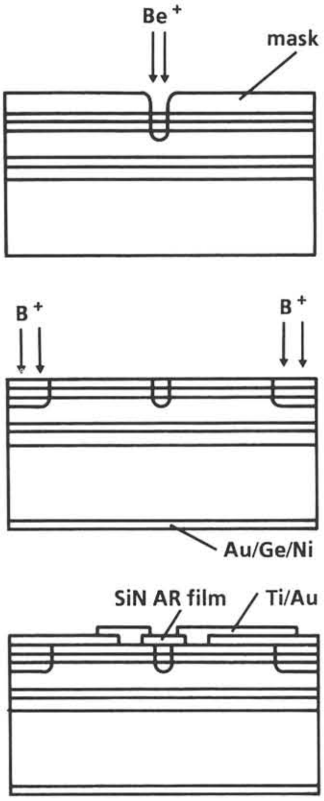

Fig. 3 Fabrication process. [upper] Be+ ions are implanted and activated by flash lamp annealing. [middle] n-type ohmic contact is formed, and then B+ ions are selectively implanted. [lower] AR film and p-type ohmic contact are formed.

implantation is stable against sintering process at 380 ℃.

Figure 4 shows the top view of the fabricated 4 × 4 array. The diameter of Ti/Au window is 6 μm. The area of p-type ohmic contact is about 170 μm^2.

III. Characteristics

A GaAs active layer is used as the switching medium because it can amplify or absorb optical signals when the current is injected or not injected, respectively. The optical signal is injected perpendicularly into the top surface. When the current is injected, the optical signal is amplified in the active layer and is reflected by MLR. The reflected signal is amplified again in the active layer and is emitted from the top surface. On the other hand, when the current is not injected, the optical signal is absorbed in the active layer and is reflected by MLR. The reflected signal is absorbed again in the active layer so that the optical signal from the top surface is very weak. Since the contrast is determined by the gain and absorption coefficients of the GaAs active layer, the optical bandwidth is about 30 nm. In order to reduce the operation current, the diameter of the current path is designed to be 2 μm.

Figure 5 shows the reflectivity profile of the MLR, when the epitaxial layers on the MLR are removed. The periods of the thin layers are determined by considering the stability of the reflectivity against the variation of the wavelength of the optical input. The measured reflectivity is more than 90 % within a wavelength range of 70 nm.

The optical signal with the wavelength of 879 nm is generated by a GaAs laser diode, and focused on the top surface by a lens. The optical signal emitted from the switch is detected by a Si photodiode through a half mirror as shown in Fig. 6.

Relation between signal gain and injection current is shown in Fig. 7. The signal gain means the ratio between the optical output and the optical input. The light input of -21 dBm is injected into the switch. At 0 mA, the signal loss is 5.6 dB. When current is injected, the loss becomes lower. Then, the loss becomes zero at 8 mA. The maximum signal gain of 4 dB is achieved at 22 mA. Therefore, the contrast achieved is 9.6 dB. This operation is done within

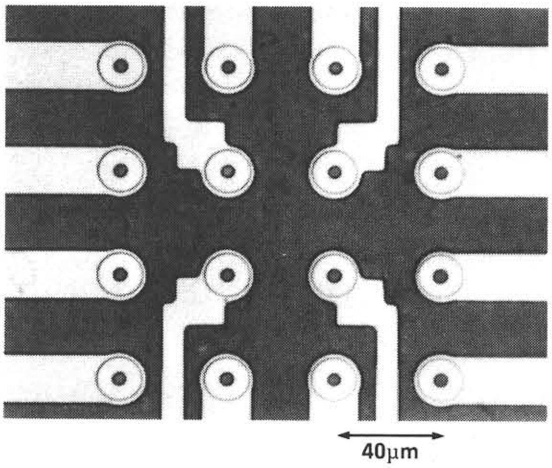

Fig. 4 Top view of the fabricated array. 16 switches are monolithically fabricated in a single chip. White lines are contact wires.

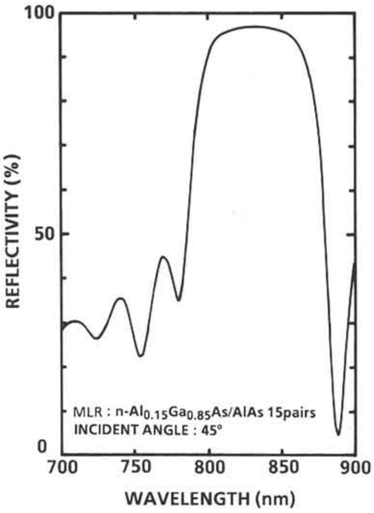

Fig. 5 Reflection spectrum of multilayer reflector. The reflectivity is more than 90 % within a wavelength range of 70 nm.

the applied voltage of 2.2 V.

IV. Conclusion

We demonstrated a new 4 × 4 array semiconductor photonic switch which realizes direct amplification and absorption of the optical signal. Its operation is based on gain and loss in the semiconductor bulk with direct bandgap. This switch has the features of optical gain of 4 dB, contrast of 9.6 dB, optical bandwidth of 30 nm, and applied voltage of 2.2 V, and a planar structure.

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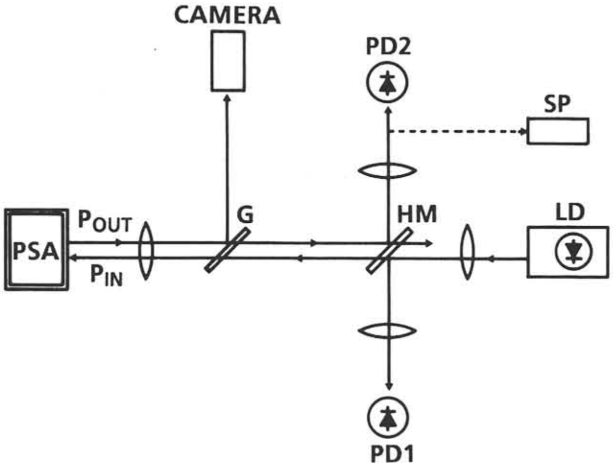

Fig. 6 Schematic diagram of measurement system. PSA is the photonic switch array. LD, SP, HM, G, and CAMERA are a laser diode, an optical spectrum analyzer, a half mirror, a glass, and an infrared camera monitoring the near field pattern, respectively. PD1 and PD2 are photodiodes monitoring optical input P_{IN} and output P_{OUT}, respectively.

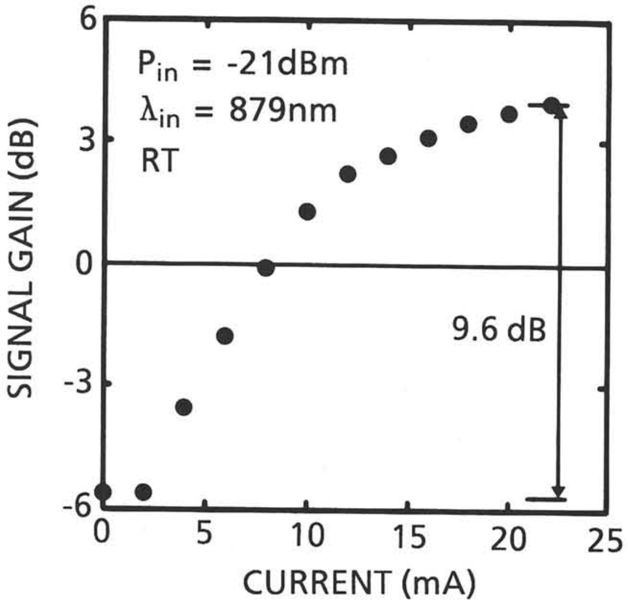

Fig. 7 Signal gain vs. current characteristic. Signal gain of 4 dB is obtained. The contrast is 9.6 dB.