A Very Low Operation Current InGaAsP/InP Total Internal Reflection Optical Switch using p/n/p/n Current Blocking Layers

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***Abstract*— A very low operation current (20 mA) has been acheived for the first time with an InGaAsP/InP total-internal-reflection optical switch. The optical switch is fabricated on an n^+-InP substrate using p/n/p/n current blocking layers. This switch has a large effective contact area and is a self-aligned structure. This is a promising result for making optical integrated circuits.**

I. Introduction

Carrier-injection-type semiconductor optical switches are promising because of their small device size, no polarization dependence, and ease of monolithic integration with other optical and electrical semiconductor devices. In these switches, efficient current confinement in the reflection region is required to obtain the large refractive index change. So far, the current paths of theses optical switches have been formed by the additional growth of p-type semiconductor [1], by the Zn diffusion process [2], [4]–[5], or by the additional growth of semi-insulating layers [3], respectively. But the operating currents of the previous optical switches were larger than 90 mA [1]–[5].

This letter proposes an optical switch which gives very small operation current. This new optical switch with the p/n/p/n current blocking layers was fabricated using one-step MOCVD growth, selective etching, and Zn diffusion processes.

The schematic of the switch structure is shown in Fig. 1. Carriers are injected in the middle of the intersection region. It is composed of two crossing rib waveguides. The current injection region, which is embedded with Zn diffusion and p/n/p/n current blocking layer, is formed at the intersection. This structure is a self-aligned structure. There are several advantages of the groove–shaped TIR (Total Internal Reflection) switches compared to the previous ones [1]-[5]. Firstly, the injected current can be confined efficiently by the p/n/p/n blocking layers. Secondly, this structure can provide a large p-contact area, leading to small contact resistance. Thirdly, the small width of the waveguide can be obtained easily by minimizing the groove etching width.

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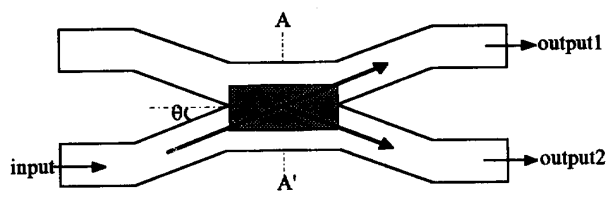
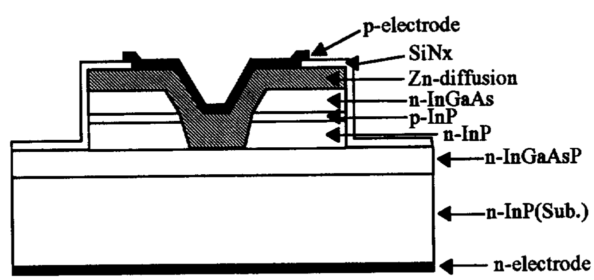


(a)



(b)

Fig. 1. Schematic view of (a) an optical switch using p/n/p/n current blocking junctions and (b) cross section of intersectional region.

II. Device Fabrication

The fabrication procedure of the optical switch is shown in Fig. 2. An n-type InGaAsP core layer (0.8 μm thick, λ=1.3 μm, Nd=1x10^{17} cm^{-3}), an n-type InP cladding layer(0.7 μm thick, Nd=2x10^{17} cm^{-3}), a p-type InP cladding layer(0.3 μm thick, Na=2x10^{17} cm^{-3}), and an n-type InGaAs cap layer(1.0 μm thick, Nd=10^{17} cm^{-3}) were successively grown on the n^+-InP substrate using MOCVD. Next, grooves were formed on the grown wafer by wet chemical selective n-InGaAs etching. These grooves were 3.5 μm wide and 1.0 μm deep. Then, a p-type region was formed using Zn diffusion over the full regions to form a current–restricted structure. The Zn-diffusion front is located at the InP/InGaAsP junction in the groove region, and the current blocking layers of the p^+-InGaAs/n-InGaAs/p-InP/n-InP are formed in the side of the groove region because the Zn-diffusion coefficient in InGaAs are smaller than that in InP. Next, the SiN_x film was deposited on the Zn-diffused

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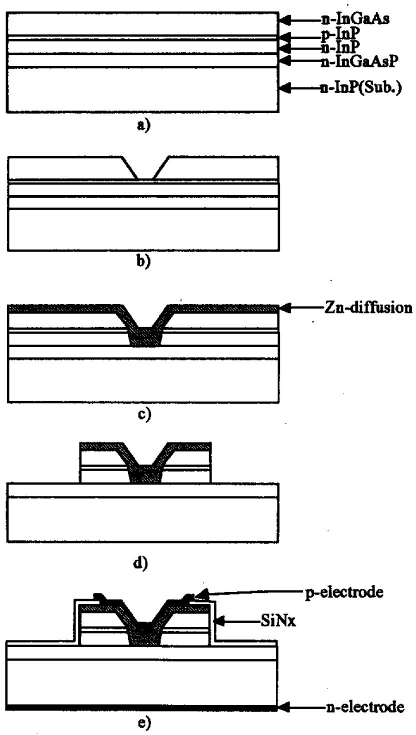

Fig. 2. Fabrication procedure of an optical switch studied in this work.

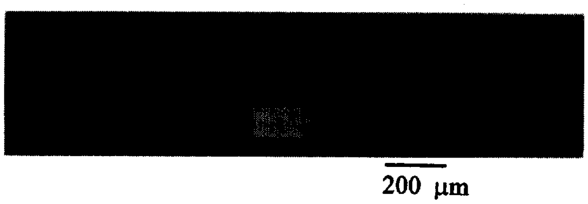

Fig. 3. Photograph of the fabricated InP/InGaAsP optical switch.

surface, and the rib waveguide was formed using wet selective InGaAs and InP etching. Then the SiN_x masks were removed and a new SiN_x film was deposited. This SiN_x film was used as a passivation layer. Rectangular open windows were formed in the SiN_x film on the tops of the current injection regions. Then a p-side and an n-side electrode were formed on the top and bottom-sides of the wafer, respectively. A photograph of the fabricated optical switch is shown in Fig. 3. The input and output facets of the switch were made by cleaving. The width of the waveguide was 7 μm while that in the intersecting region was controlled to be 17 $\mu\Omega$. The total length of the switch was 3 mm. The crossing angle of the fabricated optical switch is6°.

III. Switching Charateristics

Input light was provided by a singlemode fiber-pigtailed InGaAsP/InP laser operating at 1.55 μm, and coupled directly to the input waveguide. For the measurement of near-field patterns, a magnified image of the output facet was displayed on a TV monitor by means of an infrared-sensitive camera using a 40X objective lens. But, to measure the output light intensity, the output waveguide was coupled directly to the multimode fiber. In Fig. 4, the switching charateristic vs. injection current is shown for the switch of a 6° crossing angle under CW condition. The observed output intensity profiles are shown in Fig. 5. The switched state was obtained for a 20–mA injection current. This value is much less than those reported to date [1]-[5] and corresponds to a current density of 2.3kA/cm^2. The area of the current path is 250x3.5 μm^2. In Fig. 4, the light output intensity of "output1" and "output2" is crossed at about 3 mA. It shows that the operation current can be reduced to less than 20 mA. The crosstalk was -8.2 dB for 0 mA, and -9.7 dB for 20 mA, respectively. The total insertion loss was about 20 dB.

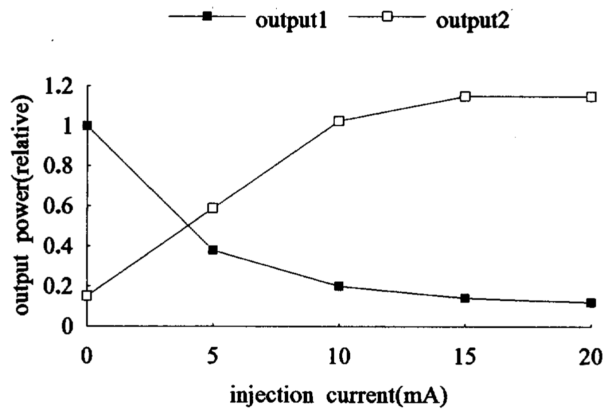

Fig. 4. Switching characteristics vs. injection current under CW operation.

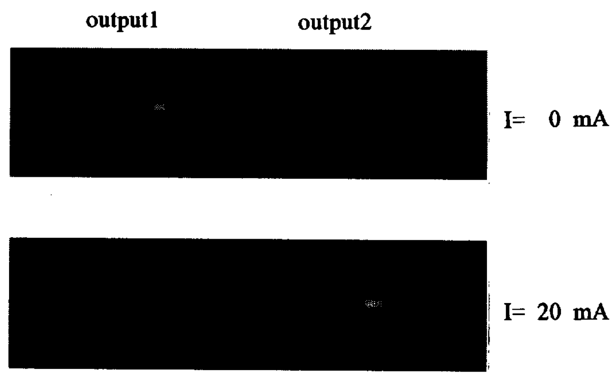

Fig. 5. Near field patterns at the output facets.

IV. Conclusion

A new InGaAsP/InP multimode optical switch with p/n/p/n blocking layers is proposed and fabricated, showing very low operation current. These optical switches are thought to be one of the most promising structures.

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