ELectronics EXpress

IEICE Electronics Express, Vol.2, No.23, 578–582

High-speed optical switching of InAlGaAs/InAlAs multi-mode interference photonic switch with partial index-modulation region (MIPS-P)

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Abstract: Advanced photonic networks require high-speed switching in nano-second order switching time, low power consumption and low crosstalk, etc. For these purposes we proposed a semiconductor multi-mode interference photonic switch with partial index-modulation regions (MIPS-P) which can operate by current injection for refractive index change and is expected as a high-speed optical switch. In this letter we have experimentally confirmed small-current and low-crosstalk operation by using InAlGaAs/InAlAs, which is effective for injected carrier confinement. And also high-speed switching operation in a switching time of about 1.5 ns has been demonstrated, for the first time, at a repetition rate of 10 MHz.

Keywords: high-speed optical switch, MMI waveguide, InAlGaAs, plasma effect, packet switching

Classification: Photonics devices, circuits, and systems

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DOI: 10.1587/elex.2.578
Received October 19, 2005
Accepted November 14, 2005
Published December 10, 2005

ELectronics EXpress

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1 Introduction

Advanced photonic networks have been highly spotlighted in accordance with an explosive growth of internet traffic in recent years. For these networks, optical cross connect (OXC) has been implemented, in which microelectromechanical system (MEMS) optical switch and so on have been developed to route high-speed optical signals without conversion to electric ones. The typical switching times of these optical switches are in the order of milisecond (ms) or sub ms, which are only effective for stream optical signals. However, to meet the demand for transferring and routing burst and packet optical signals, which need much higher switching speed in nano-second (ns) order, development of high-speed optical switches is definitely required. For this purpose, we proposed a semiconductor multi-mode interference photonic switch with partial-index modulation regions (MIPS-P) [1, 2, 3, 4] which operates by current injection via plasma effect and can be expected to exhibit high-speed switching with ns-order response time. As for the material aspect, the MIPS-P using InGaAsP/InP has been investigated so far [3, 4], but it gave poor carrier confinement due to rather small hetero-barrier height energy of the conduction band rendering larger switching current.

In this letter, we fabricated an InAlGaAs/InAlAs MIPS-P with larger hetero-barrier height for effective carrier confinement, and experimentally demonstrated low current and high-speed switching operation with a switching current of 24 mA and a response time of about 1.5 ns or less by applying voltage pulses at 10 MHz repetition rate.

2 Structure and Operation Principle

A schematic structure of a MIPS-P is shown in Fig. 1. The MIPS-P consists of a multi-mode interference (MMI) waveguide whose length was chosen to be $L = 3L_\pi$, where L_π is the beat length given by $L_\pi = 4n_{MMI}{W_e}^2/3\lambda_0$ [5], and access waveguides at input and output side ends. And a partial index-modulation region was formed with a half-width at a mid-length and half-side position in the MMI waveguide to modulate refractive index by carrier injection via plasma effect. As for the layer structure of the waveguide, we adopted InAlGaAs/InAlAs double heterostructure, since it has large hetero-barrier height of the conduction band, which is essential to suppress carrier overflow for efficient refractive index change. The thicknesses of each

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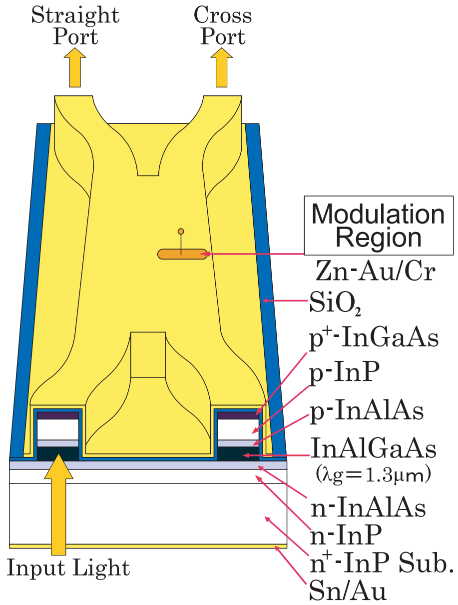

Fig. 1. Schematic structure of InAlGaAs/InAlAs MIPS-P

layer were as follows: that of an InAlAs under-barrier layer was 0.1 μm, an InAlGaAs waveguide layer 0.6 μm, an InAlAs over-barrier layer 0.05 μm, a p-InP cladding layer 1 μm, and a p^+-InGaAs cap layer 0.05 μm. The wafer was grown by metal-organic vapor-phase epitaxy (MO-VPE) on an n^+-type InP substrate.

The length and width of the MMI waveguide were 1440 μm and 12.5 μm, respectively, the length and width of the partial index-modulation region were 150/100 μm and 3.5 μm, respectively, a width of the access waveguide was 2.5 μm, and a total device length was about 2.5 mm. The waveguide was a ridge structure. The waveguide was fabricated by conventional photolithography and successive reactive ion etchings using CH_4/H_2 and Cl_2 gases, respectively.

The operation principle of the MIPS-P has been explained so far [2]. An appropriate current injection into the partial index-modulation region giving the phase shift π to the propagating light can switch the output light from the straight port, otherwise from the cross port, since the MMI waveguide length is chosen to be $L = 3L_\pi$ [5].

3 Measurements

Switching characteristics of the InAlGaAs/InAlAs MIPS-P were evaluated statically and dynamically. The wavelength of an input signal light was 1530 nm.

Figure 2 shows the relative output intensities from the cross and straight ports as a function of dc injection current for the device with a partial index-modulation region length of 150 μm. Rather long partial index-modulation region was chosen by taking an attainable refractive index change into account. Switching was attained with a small current of 24 mA corresponding

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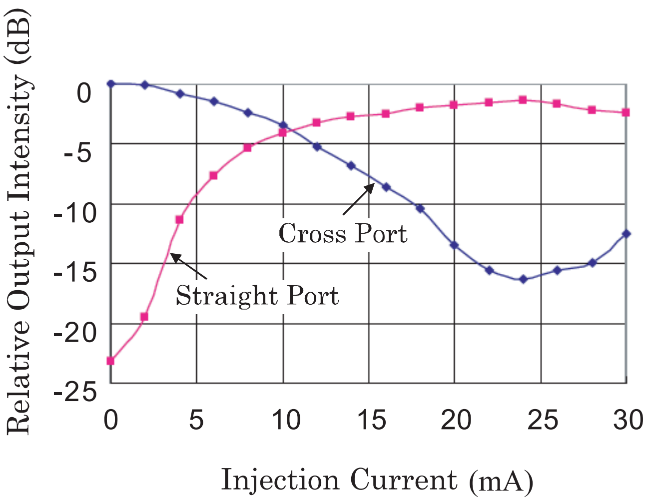

Fig. 2. Static switching characteristics of InAlGaAs/InAlAs MIPS-P

to a current density of about 4 kA/cm^2, while the current for 3 dB-power splitting operation was 10 mA. These operation currents were smaller than those for an InGaAsP/InP MIPS-P [3] due to more efficient carrier confinement for an InAlGaAs/InAlAs DH waveguide. The crosstalks were −24 dB in the case of no modulation and −15 dB in the case of modulation. The degradation of crosstalk under current injection may be attributed to mismatch of the light distribution and the index-modulation region, and it can be improved by making the index-modulation region be shorter and/or be positioned more appropriately.

Dynamic switching characteristics were measured by applying forward voltage pulses to the index-modulation region with a repetition rate of 10 MHz and a duty ratio of 50%. The rise and fall times of the applied voltage pulse were 2.6 ns and 3.0 ns, respectively. The index-modulation region length was made shorter to be 100 μm in this case for lower crosstalk under modulation, as mentioned above. The output light waveforms from the cross port are shown in Fig. 3. The fall and rise times of the switched output light were as small as 1.5 ns. It is noted that the rise of the applied voltage corresponds to the fall of the output light, and vice versa due to the output measured from the cross port. Smaller response times of the output light compared to those of the applied voltage are attributed to that the measured voltage waveform included diffusion voltage component of about 1 V. A response time determined by RC-time constant roughly estimated by the index-modulation region area and the series resistance of about 40 Ω was much smaller than the measured ones. From this reason, the measured switching speed seems to be limited by carrier lifetime.

4 Conclusion

We fabricated the MIPS-P with InAlGaAs/InAlAs which has large hetero-barrier height of conduction band for improving carrier confinement and resultant large refractive index change. As a result, we realized superior op-

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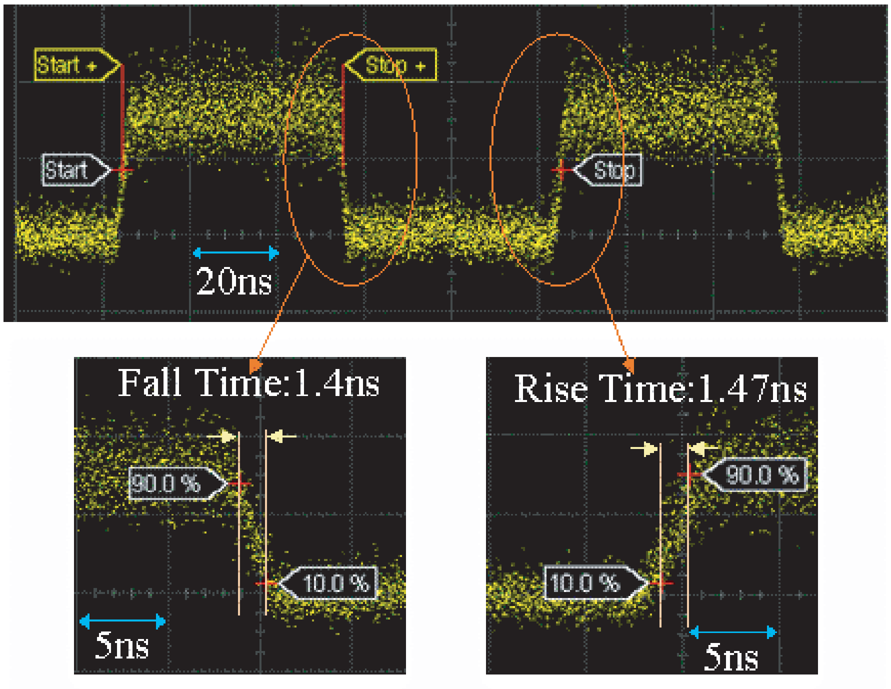

Fig. 3. Output light waveforms from the cross port under modulation of 10 MHz

tical switching with a small current of 24 mA and low crosstalk of −24 dB and −15 dB without and with modulations, respectively. Fast switching with switching times of as small as 1.5 ns was confirmed. These results indicate that the MIPS-P is expected as a high-speed optical switch in the future ultra-fast burst and packet photonic switching networks.

Acknowledgement

This research was partially supported by Waseda University Grant for Special Research Projects.

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