Polarization-Independent and Low-Current Operation of InAlGaAs/InAlAs Mach-Zehnder Interferometer-Type Photonic Switch with Hybrid-Waveguide Structure for Optical Packet Switching

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Abstract *We demonstrated a polarization-independent Mach-Zehnder interferometer-type photonic switch with very-low-current of about 5mA. Furthermore, a few nano-second switching response time was also confirmed which suits for application to optical packet switching.*

Introduction

High-speed photonic switches (PSs) in nano-second (ns)-order response are key devices to construct a highly-efficient optical network system such as optical packet switching (OPS). So far, many kinds of PSs for OPS have been proposed with various materials such as lithium niobate (LN)[1], (Pb, La)(Zr, Ti)O_3 (PLZT)[2], polymers[3], silicon[4] and compound semiconductors [5-8]. We have developed a Mach-Zehnder (MZ) interferometer-type PS (MZ-PS) based on multi-mode interference (MMI) 3dB couplers with InAlGaAs/InAlAs compound semiconductor structure for not only high-speed but also low-power consumption operation which is crucial to reduce increasing power consumption in recent network system. This material system is suitable for refractive index modulation by carrier injection because of its more efficient carrier confinement than common InGaAsP/InP. As a result, very-low-current of 3.5mA for a conventional all-middle-mesa waveguide structure which was difficult to realize polarization-independent operation. In this paper, we show design policies for a polarization-independent MZ-PS and its experimental confirmation.

Device design

For polarization-independent operation, we propose a new configuration for MZ-PS shown in Fig.1, namely, different etching depths are adopted for MMI 3dB couplers and other parts of the device. For MMI couplers, deep etching depth reaching down to an InP structure, so-called “high-mesa” structure, is adopted. On the other hand, a phase-shifter and access waveguides are formed with a shallower etching structure in which etching stops in the middle of a guiding layer, namely, “middle-mesa” structure. High-mesa MMI couplers can contribute low-crosstalk characteristics of MZ-PS. Propagation modes are more strongly confined in the waveguide than in middle-mesa ones, which leads to a sharp contrast of interference among the propagated modes. As a result, clear self-imaging effect can be obtained which avoid light output at an unintended output port, giving low crosstalk. Furthermore, such low-crosstalk characteristics are tolerant against the properties of

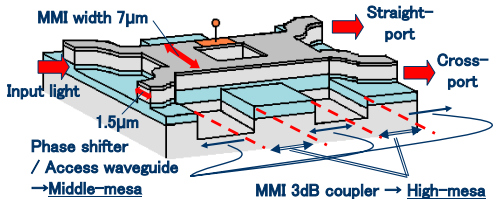

Fig. 1: Schematic structure of a proposed hybrid-type MZ-PS.

an input light such as wavelength and polarization. Therefore broadband and polarization-independent characteristics can be expected in high-mesa MMI couplers. Moreover, since precise etching control is not required, the high-mesa MMI coupler is easy to fabricate. Characteristics of the middle-mesa MMI coupler are very sensitive for etching depth. On the contrary, a middle-mesa waveguide is suitable for a phase-shifter. For polarization-independent operation, not only crosstalk but also switching current should be independent on polarizations of an input light. Therefore, the amount of effective phase shift for a certain value of current injection has to be the same value regardless of polarizations of an input light. From the perturbation theory, the amount of phase shift ($\Delta\phi$) and refractive index change (Δn) is related as $\Delta\phi \propto \Gamma\Delta n$. Here, Γ is an optical confinement factor of a phase-shifter waveguide under no modulation. From this relation, it is found that Γ has to be polarization-independent, which can be attained by controlling the etching depth during the formation of a phase-shifter. Moreover, two arm waveguides between two MMI 3dB couplers formed by middle-mesa structures are also effective to reduce crosstalk in switch-off state, which comes from the possible arm-waveguide asymmetry. Since a light less strongly confined in a waveguide tends to less suffer from change of its propagation constant by fluctuation of shapes and/or widths of the waveguide, the middle-mesa structure is more tolerant in fabrication than the high-mesa one. In addition, the middle-mesa structure is superior to high-mesa ones from view points of lower propagation loss, smaller surface leakage current and more efficient thermal diffusion.

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Experiment

The fabricated high-/middle-mesa hybrid-type MZ-PS is shown in Fig. 2. A clear boundary structure between high-mesa and middle-mesa is obtained. Fig. 3 displays static switching characteristics of a fabricated hybrid-type MZ-PS. The device size was 725μm long and ~8μm wide. The wavelength and power of an input light were 1571 nm and 0 dBm, respectively. Less than -20 dB crosstalk is confirmed for both TE- and TM-mode input lights. In switch-off state, any phase-adjustment method such as bias current is not operated. Extinction ratio (ER) of cross-port was about 25 dB regardless of polarizations of an input light. Since it was analytically found that realizing ER of more than 25 dB is difficult for the conventional middle-mesa MMI couplers[10], such a high ER is considered to be a result of the clear self-imaging effects in the high-mesa MMI couplers. Low switching currents of 5.25 and 4.75 mA were obtained for input lights of TE- and TM-modes, respectively, which are corresponding to low power consumptions of 5.3 and 4.7 mW, respectively. As PSs for OPS, the fabricated MZ-PS falls in the category of the lowest power consumption PSs. The still remained small polarization-dependence of the switching current is expected improved with more precise fabrication processes. Actually, the width of a phase-shifter broadened to ~2μm from the designed value of 1.5μm. Therefore, an optimal etching depth for polarization-independent switching current might have changed. Dynamic switching characteristics are also measured and the results are shown in Fig.4. High-speed switching time in about 3 ns is achieved. The result means that the fabricated MZ-PS can be adapted to OPS.

Conclusions

We fabricated the high-/middle-mesa hybrid-type MZ-PS with InAlGaAs/InAlAs material system. The fabricated device was rather compact of 725μm long and ~8μm wide and showed polarization-independent low-crosstalk operation of less than -20 dB. Switching current was very-low of about 5mA. And more, High-speed response with about 3 ns was also confirmed. The proposed and demonstrated compact, polarization-independent low-crosstalk, low-power consumption, and high-speed MZ-PS can contribute future highly-efficient and low power consumption optical switching system.

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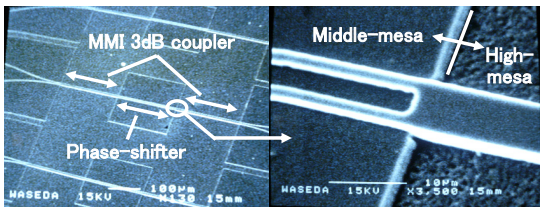

Fig. 2: SEM views of a fabricated hybrid structure.

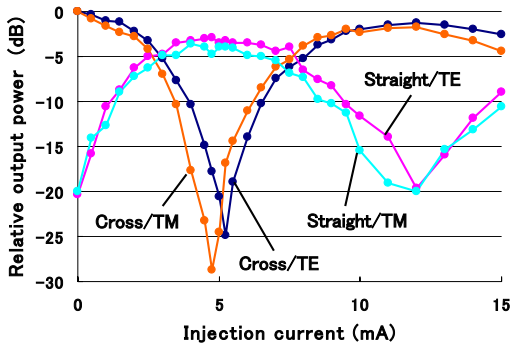

Fig. 3: Static switching characteristics of a fabricated hybrid-type MZ-PS for input lights of TE and TM modes. The wavelength of both input lights was 1571 nm, respectively.

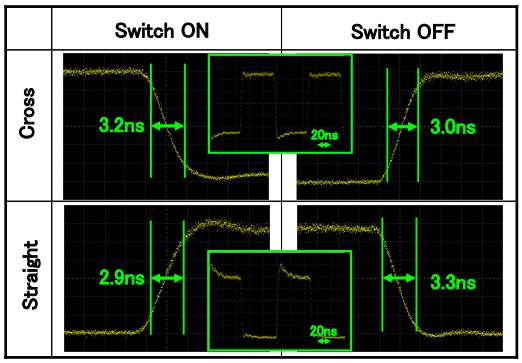

Fig. 4: Dynamic switching characteristics of a fabricated hybrid-type MZ-PS under 10 MHz modulation for input lights of 1550nm, TE-mode. Inset: Entire waveforms of each output port.