Fabrication of InGaAsP/InP Mach-Zehnder Interferometer Optical Amplifier Switches by Metalorganic Vapor Phase Selective Area Epitaxy

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Semiconductor optical switches are becoming of importance associated with photonic internetworking. In particular, Mach-Zehnder interferometer (MZI) optical switches incorporating semiconductor optical amplifiers (SOAs) into their arms are important since they can work not only as current-controlled optical switches but also as “all-optical” switches for ultra-fast optical signal processing. However, fabrication of such devices has not been simple because they require integration of active and passive components. In doing that, people often resort to low yield “etch and regrowth” technique or hybrid integration. On the other hand, the selective area growth (SAG) technique in metal-organic vapor phase epitaxy (MOVPE) has been known as another simpler technique for monolithic integration (where only one-step epitaxy is needed) although its applicability has been limited. In this paper we describe InGaAsP/InP integrated SOA MZI switches prepared completely by the single step MOVPE SAG for the first time.

Figure 1 shows a schematic of the SAG technique. The SAG region between SiO_2 masks grows faster than planar region, and its bandgap turns to be smaller. The bandgap energy or corresponding photoluminescence (PL) peak wavelength shifts towards lower energy (longer wavelength) side as the mask width W_m increases. Figure 2 shows this dependence in our sample where the core layer consisted of InGaAsP multiple quantum wells. The SiO_2 mask width was changed from 10 to 50μm whereas the width of SAG region, 20μm, was fixed. The maximum shift was as large as 140nm (from 1420nm to 1560nm). A cross-sectional micrograph of the 20μm-wide SAG region with W_m=50μm is shown in Fig. 3. A 2μm-wide waveguide is to be formed at around the center of the SAG mesa.

Figure 4 illustrates the multimode interference (MMI) 3dB splitter/coupler to be incorporated into the SOA MZI switches. Simulation and experimental results were found to agree well. Depicted in Fig. 5 are the designed circuit patterns of the SOA MZI switch together with SiO_2 mask patterns for SAG. The region sandwiched by two SiO_2 masks is to act as an SOA. Microscope photographs of fabricated switches of two different types are shown in Fig. 6. One type uses ridge waveguides formed by photolithography and wet chemical etching, while the other uses high mesa waveguides by electron beam lithography and dry etching. In the high mesa type, due to stronger optical confinement, the size of MMI 3dB coupler becomes smaller, i.e., 12μm wide and 205μm long (cf. 20μm and 1280μm, respectively, for the ridge waveguide). The radius of waveguide bends could also be reduced from 1000μm to 500μm.

Signal light of 1580nm was coupled into the input port of the fabricated switch with a tapered fiber, and then the output light was coupled into another tapered fiber and detected through a filter. Phase shift in SOA was given by current injection. The current I_1 to the upper SOA was set to 47mA whereas I_2 to the lower SOA was varied from 0 to 120mA. As shown in Fig. 7 there appeared 6 pairs of peaks and valleys, indicating that total phase shift of 11π occurred. The SOA prepared by the SAG has thus been proven to possess carrier-induced index change large enough for all-optical switching.

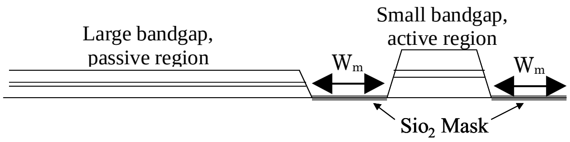

Fig.1 Schematic of the selective area growth.

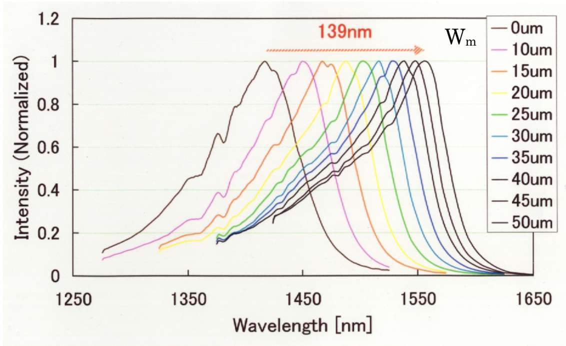

Fig.2 Photoluminescence from SAG regions with different mask widths. Maximum of 140nm shift from planar region (W_m=0) to SAG region was observed.

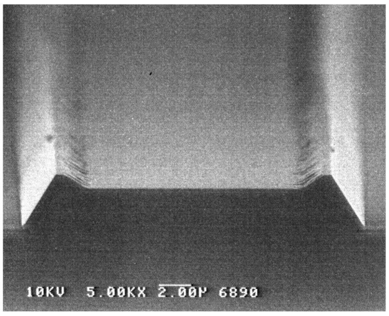

Fig.3 Scanning electron micrograph of SAG region cross section (W_m=50μm).

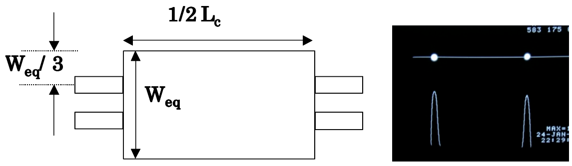

Fig.4 Fabricated MMI 3dB coupler with W_{eq}=21μm, L_c=1280μm (ridge waveguide) and output optical intensity image by IR camera (right figure).

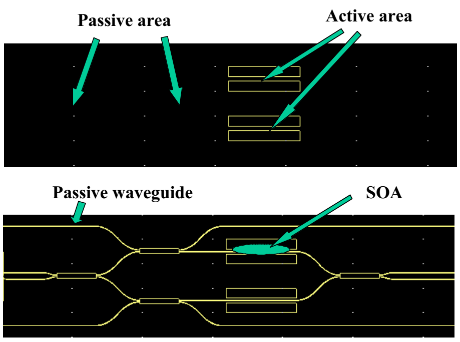

Fig.5 Designed circuit patterns: two sets of SiO_2 masks (upper figure) and MZI optical switch (lower figure). The waveguides between SiO_2 masks are to become SOAs.

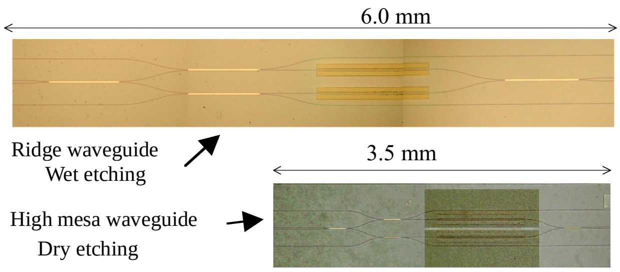

Fig.6 Two kinds of fabricated switches (top view). The reduction of the total size is attributed to the reduction of both the length of MMI and the radius of bends.

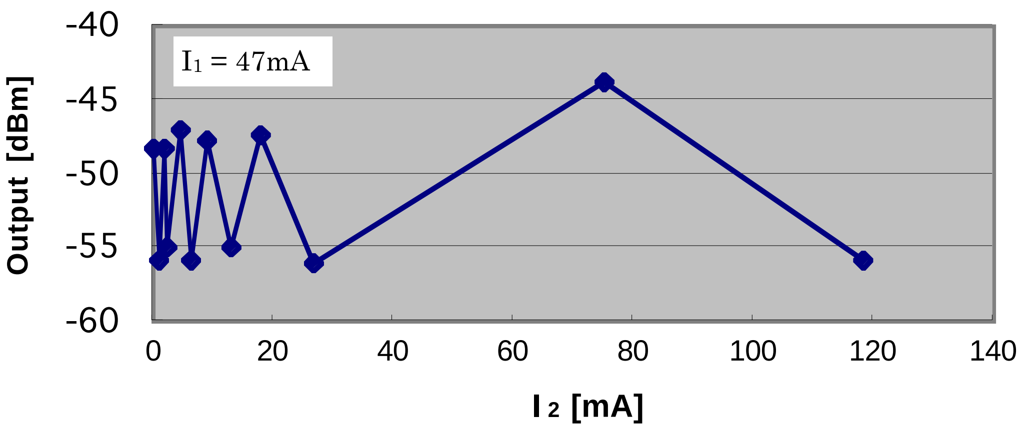

Fig.7 Optical switching observed by increasing injection current I_2 to the lower SOA. The injection current I_1 to the upper SOA was set to 47mA. The first phase shift of π occurred between I_2 = 0 and 0.8mA. Gain saturation retards the phase shift with the increase of I_2.