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FABRICATION OF AN INTEGRATED DYNAMIC CHANNEL EQUALIZER BY SELECTIVE AREA MOVPE

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ABSTRACT

We integrated an InP-based demultiplexer with quantum-well phase modulators in a Mach-Zehnder interferometer scheme. Selective area MOVPE growth with an arrayed mask was used to realize active and passive regions in a single growth step. Simultaneous control of wavelength-multiplexed channels is possible.

1. INTRODUCTION

The Reconfigurable optical networks need photonic integrated circuits that provide control over each channel wavelength multiplexed (WDM) signal. An arrayed waveguide (AWG) demultiplexer together with variable optical attenuator in each channel can provide for such dynamic channel equalizer [1]. Such equalizers can compensate for uneven gain profile of the Erbium-doped fiber amplifier (EDFA), and are known to prevent channel degradation in case of sudden change of power.

However so far these devices have been fabricated on silica-material due to its low propagation loss. But the chip was large and the response time was of ms order. InP-based equalizer is desirable due to inherently fast response time and possibility of integration with optical amplifiers. An InP-based prototype was fabricated by a multiple etch and regrowth process, but this process has its difficulties and poor yield [2]. Quantum well intermixing (QWI) is another method for active-passive integration by single epitaxial growth [3], but it is difficult to have more than 2 bandgaps simultaneously. Selective area metal organic vapor phase epitaxy (SA-MOVPE) [4] can give us tailored layout of different bandgaps with a single growth on patterned substrate, and our group demonstrated integrated all-optical switch in this method. In this work we have used the SA-MOVPE method further to integrate and array of phase modulators with a pair of passive AWG demultiplexers to work as a dynamic channel equalizer.

2. OPERATION OF INTEGRATED DYNAMIC CHANNEL EQUALIZER

The dynamic channel equalizer consists of a pair of AWG demultiplexers for dividing and combining the incoming and equalized channels, respectively (Figure 1). Each channel is equipped with a Mach-Zehnder interferometer-based variable attenuator. An array of phase modulators are employed, with are driven by a programmable driving unit. Incoming channels with unequal power is divided into two branches by multi-mode interference (MMI) couplers.

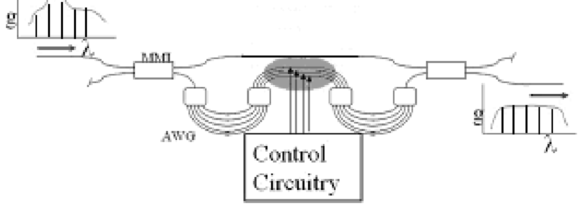

Fig. 1 Scheme of an integrated dynamic channel equalizer. The control circuits equalize uneven channel power.

3. SA-MOVPE

Figure 2 shows the principle of integrating different bandgaps by a single growth step. An InP substrate is covered with a dielectric mask; typically thin silica (200nm). No epi-layer grows on areas that are covered by silica. Growth takes place in the open area surface, lowering concentration of the reactants in comparison to where there is mask. The reactants diffuse in the vapor phase as well as over the surface of mask, but usually in areas a few μm-s away from the mask the vapor phase diffusion become the dominant factor. Gas phase diffusion caused in the vicinity of the masks an enhancement in the growth rate and In-enrichment compared to Ga. A red-shift occurs due to In-enrichment. When applied to quantum well, growth rate enhancement causes a further red-shift because thicker wells lower the quantum states as well as the effective bandgap energy. Due to In-enrichment there is a compressive strain, which is contained within the critical limit by using an opposite (tensile) strain in the passive region.

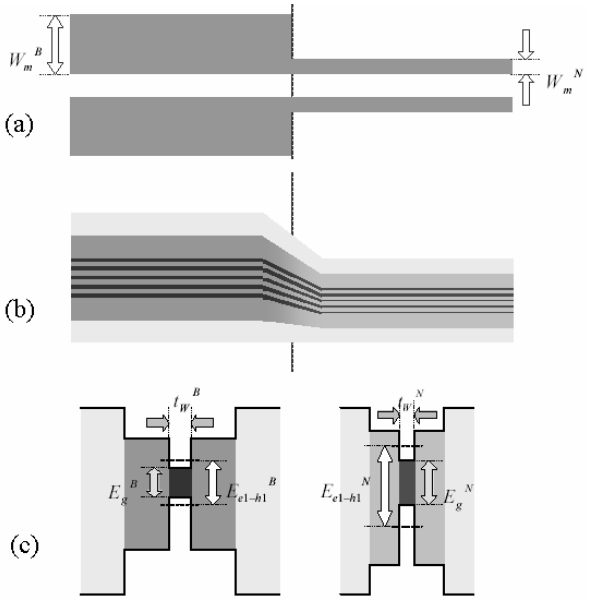

Fig. 2 Bandgap variation by SA-MOVPE. (a) mask pattern (top view), (b) side view quantum wells grown by SA-MOVPE, (c) band diagram of quantum wells. Wider masks give a smaller bandgap.

Two critical parts of the optimization are adjustment of the bandgap in the active region to modulate light in the 1.55μm wavelength region and shifting the bandgap of the passive region as far as possible towards shorter wavelength region in order to have minimal absorption loss at 1.55μm. The optimum mask parameters (width, spacing) were experimentally obtained.

We fixed the active area width between two silica masks at 20μm and varied the mask width (Wmask) as well as the distance between a pair of masks. It anticipated that increasing the Wmask from 20 to 50μm would lead to smaller bandgaps (red-shift), and decreasing the mask-to-mask distance (from 100 to 20μm) would have the effect of enhancing the red shift. However the effect of mask applies to a distance of about 100μm from mask, so additional dummy masks were placed in the both extreme sides of the array. Figure 3 shows spatially resolved photoluminescence (μ-PL) peaks from the middle of the arrays. The PL peak at the passive region was at 1390nm. When the mask width was 30μm, the bandgap corresponded to about 1490nm. Due to some blue-shift observed during the device fabrication, we chose this wavelength for use as phase modulators.

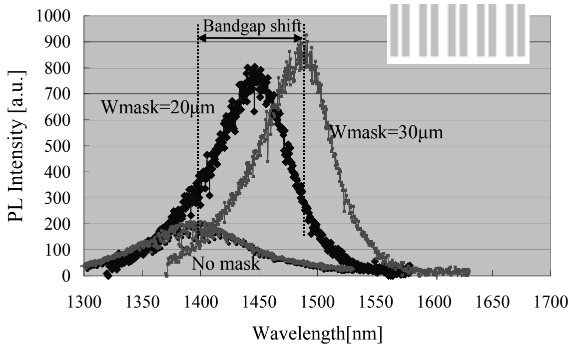

Fig. 3 Spatially resolved photoluminscence spectra of InGaAsP quantum wells showing bandgap shifts for arrayed mask of width 20μm and 30μm and the region far from mask. Inset shows arrayed mask.

4. DESIGN OF DYNAMIC CHANNEL EQUALIZER

The region without mask had a bandgap corresponding to 1390nm, which is almost sufficient to reduce the band-to-band absorption loss of light at 1.55μm. Subsequently high index contrast waveguides were employed to design a compact 8channel AWG demultiplexer with 400GHz (3.2nm) channel spacing. Figure 3 shows the mask pattern for the integrated AWG with Mach-Zehnder interferometer structure. A mirror-transformed pattern was employed to save chip area. The active area employed an array of 30μm wide mask with 20μm mask-to-mask distance for optimum bandgap shift. The minimum bending radii was 500μm and the chip was contained within 8x3mm^2 area (Figure 4).

5. FABRICATION

Our layer structure resembles that of a typical multi quantum well (MQW) separate confinement heterostructure (SCH) laser, since the performance of the phase modulator must be given more priority (large change of index with applied reverse bias). It contains on n+-InP substrate an n-InP buffer, InGaAsP lower separate confinement heterostructure (SCH) of bandgap 1.25μm (Q1.25) in the active region, 5 InGaAsP/Q1.25 quantum wells, upper SCH of Q1.25m p-InP cladding and p+-InGaAs contact layer.

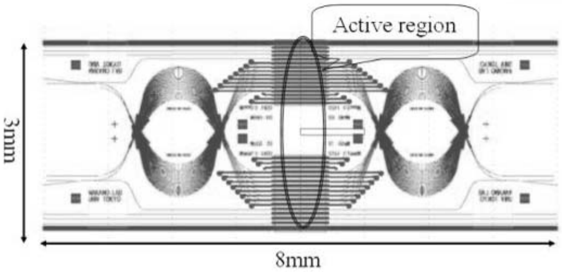

Fig. 4 Mask layout of integrated dynamic channel equalizer. The array of phase modulators is located in the middle of two AWG demultiplexers.

After the selective area growth of layer stacks, conventional photolithography and dry etching was applied to form waveguide patterns (Figure 5). Cl_2/Ar-based plasma in an inductively coupled plasma reactive ion etching (ICP-RIE) was used to form deep etched waveguides in the passive region and shallow etched phase modulators in the active region. In this way smaller bending radii were realized while avoiding rough sidewalls in the active layer. We optimized the lithography process in order to minimize the propagation loss. Subsequently electrical contact and pads were formed on the phase modulators by self-aligned patterning and a Au/Ti lift-off process. Although it was necessary for avoiding unwanted reflections, we did not apply anti-reflection coating on the cleaved facets.

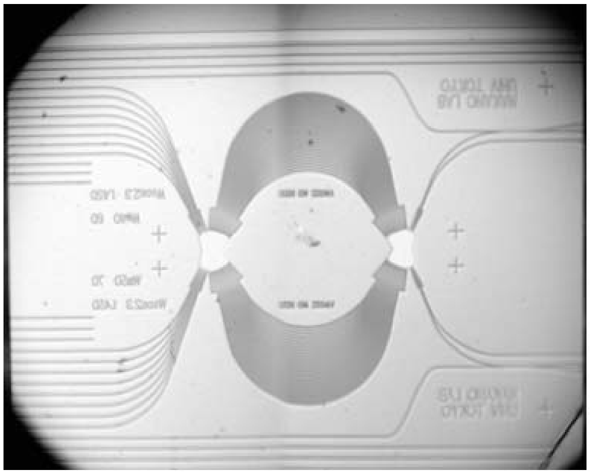

Fig. 5 AWG portion of the fabricated circuit after dry-etching.

6. MEASUREMENT

We characterized the passive demultiplexer and phase modulators separately. After measuring the optical loss of passive waveguides by Fabry-Perot method, a large propagation loss was found (typically 20 to 30dB/cm). This could be explained by relatively high free-carrier absorption loss in the p-InP clad layer. We achieved demultiplexing characteristics in a test AWG (Figure 5) based on bulk InGaAsP-core high refractive index contrast waveguides. The complete characterization of the combined circuit is under way.

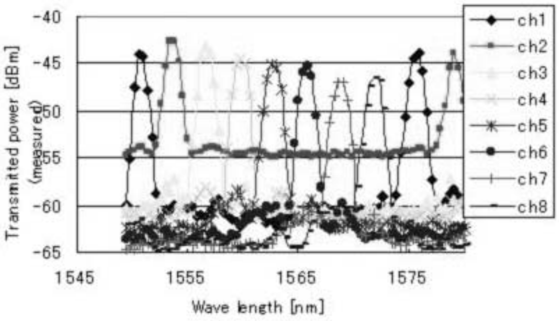

Fig. 6 Measured transmission characteristic of an 8channel 400GHz AWG demultiplexer in InP.

7. SUMMARY

We present the fabrication and characterization of a monolithically integrated dynamic channel equalizer based on the integration of semiconductor phase modulator with an arrayed waveguide grating demultiplexer. Our process uses a single selective area growth step, potentially increasing the yield and reducing cost. This scheme has the possibility of being used for fast gating of WDM signals or in dynamically reconfigurable WDM networks as channel power equalizers.

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