Demonstration of Monolithically-Integrated InP Widely-Tunable Laser and SOA-MZI Wavelength Converter

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Abstract

The first monolithically integrated widely tunable wavelength converter, consisting of a Sampled-Grating Distributed-Bragg-Reflector laser and a semiconductor optical amplifier-based Mach-Zehnder interferometer, is reported. Static extinction ratios better than 19dB and 13 dB using electrical and optical control, respectively, were measured over a 22nm laser wavelength range.

I. Introduction

The monolithic integration of tunable lasers and all-optical wavelength converters is a critical step towards solving one of the last obstacles for all-optical switching to have the functionality and flexibility needed to be a serious candidate to replace electronic switches. These structures allow data to be imprinted from an input wavelength to a tunable output wavelength without passing the signal through electronics. The semiconductor optical amplifier Mach-Zehnder interferometer (SOA-MZI) wavelength converter is an important class of integrated wavelength converters that also implements the significant feature of digital signal regeneration. InP integration of SOA-MZIs has been reported (1,2,3), however, to the best of our knowledge, a tunable laser integrated with a wavelength converter has never been reported. Previously, an SOA-MZI was integrated with a non-tunable DFB laser, but there were severe tradeoffs due to reflections from the MZI back to the laser (4). Nonetheless, despite the fact that minimization of reflections has to be considered carefully, this level of integration also reduces the coupling loss between laser and converter as well as improves the converter noise figure, conversion efficiency and size/complexity/cost of the entire component. For wide wavelength tunability, the sampled grating distributed Bragg reflector (SGDBR) laser is well suited for integration with other components due to its lithographically defined mirrors that enable lasing without a facet reflection. Integration of tunable lasers with other elements has been reported, for example the SGDBR laser with an SOA (6) and Mach-Zehnder modulator (7).

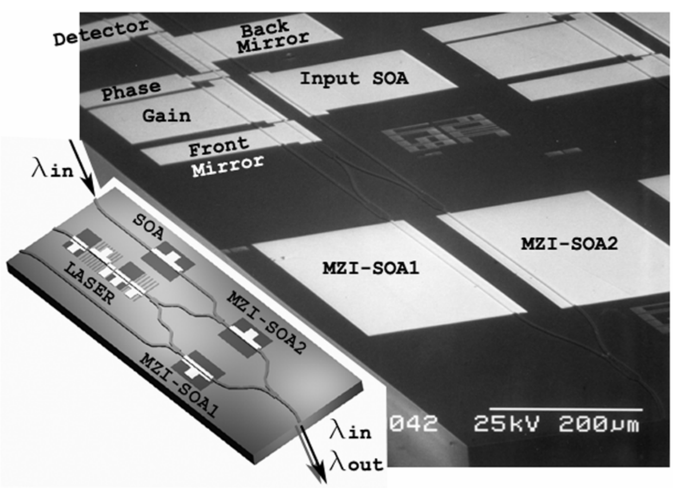

Fig. 1. SEM image and a schematic of the device

II. SGDBR/SOA-MZI Design and Fabrication

The device consists of an InP SGDBR laser integrated with a SOA-MZI (Fig. 1). The laser is 1.5mm long and has five sections: front mirror, gain section, phase section, back mirror and back facet detector. The front and back mirrors of the laser consist of periodically sampled DBR gratings to form a comb-like reflectivity spectrum (5). Since the sampling periods of the mirrors differ, they have different peak reflectivity spacing, so that only one set of mirror reflectivity peaks is aligned within the desired tuning range. By differentially tuning the front and back mirrors a small amount, adjacent reflectivity peaks can be aligned, and the laser will operate at this new wavelength (5).

The interferometer branches are defined by two S-bends and 1mm long SOAs (Fig. 1). The total waveguide separation in the interferometer is 70 μm. The laser and the interferometer are connected via a multimode interference (MMI) splitter.

The input signal is coupled onto the chip through a tapered, angled input waveguide, and then amplified by a 800 μm long input semiconductor optical amplifier. The same MMI splitter/combiner design is used to connect the data input waveguide with one of the interferometer's SOAs, as well as to combine the light from the two branches at the interferometer output. Waveguides in Mach-Zehnder branches are of the same width and length, hence, with no external stimuli the signal traversing the two interferometer arms will experience no phase change, compared to each other, and thereby add constructively at the output. The total device length is 4.8mm.

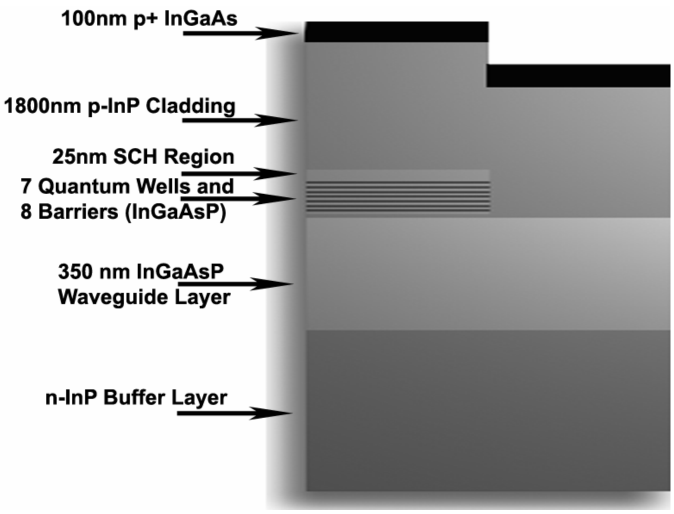

Fig. 2. Offset quantum well epitaxial structure - active-passive interface

This device is fabricated using an MOCVD grown offset quantum well integration platform (Fig. 2). The layer structure consists of a 350nm thick quarternary waveguide followed by a 7 quantum well active region and a thin InP cap. The first step of the process is to selectively etch off the quantum wells in the areas that are to become passive sections of the device. Subsequently, gratings are lithographically defined in the mirror sections using holography and then etched directly into the top of the waveguide layer using reactive ion etching (RIE). The surface of the sample is then regrown with a 1.8 μm thick p-doped InP upper cladding layer and a 100nm p^+-InGaAs contact layer(Fig. 2.). It is important to emphasize that this is the only regrowth step required in the entire process. All growth is performed using MOCVD crystal growth technology.

After the regrowth, ridges in InP are formed using a combination of RIE/wet chemical etching, followed by a proton implant to electrically isolate different electrodes. The surface of the sample is isolated with a dielectric film and the top metal contacts (Ti/Pt/Au) are evaporated using E-beam evaporation. After the sample has been thinned down, the back side (Ti/Pt/Au) contacts are evaporated and the sample is annealed. There are no additional major processing steps required to fabricate this device beyond the SGDBR fabrication process (6), which demonstrates the versatility of the integration platform used in this work.

III. Results

Electrical and static optical control and operation of the wavelength converter were demonstrated and characterized. For this purpose, the device was placed on a gold-plated copper stage and cooled to 17°C using a thermo-electric cooler. The electrical current was provided through direct probing of the electrodes and the light was coupled to and out of the device using conical-tipped lensed-fibers mounted on piezo-controlled translational stages.

The integrated tunable laser had a tuning range of about 22nm, which can be seen from its overlapped spectra, shown in Fig. 3. These spectra were recorded through the back facet of the device.

The output of the interferometer can be turned off by adjusting the bias of the SOA in one branch of the interferometer in order to achieve π relative phase shift between the two branches. The optical and electrical transfer characteristics depend on the laser output power, the bias currents of the SOAs in the branches of the interferometer, as well as the length of the SOAs. Typical electrical transfer functions for low SOA bias currents are shown as inserts of

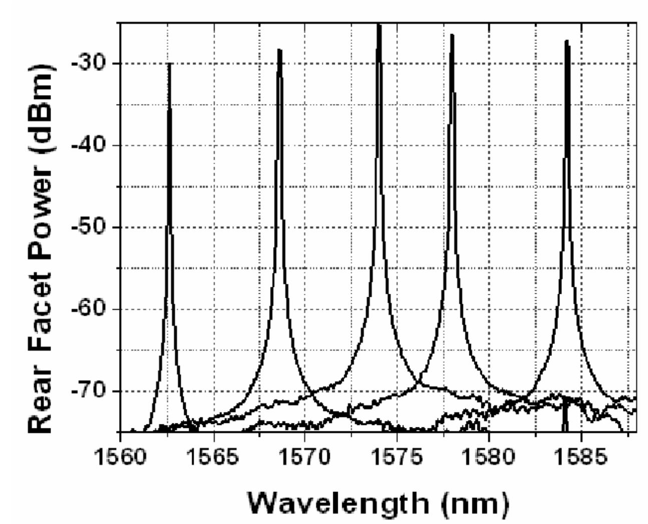

Fig. 3. Overlapped optical spectra of the on-chip tunable laser

Figures 4(a,b) for two different input wavelengths converted to two different output wavelengths (set by the SGDBR). The output extinction measured was better than 19 dB over the entire tuning range.

Representative optical conversion results for low SOA bias currents are shown in Fig. 4(a,b), for SGDBR operating wavelength of 1566 nm and 1573nm. Each characteristic is plotted for two different input signal wavelengths (1562nm and 1557nm respectively). The operating point of the wavelength converter for these cases is at the notch of the electrical transfer function (63mA in Figure 4(a,b)) in order to achieve optical modulation in the non-inverting regime. Optical extinction ratios for this biasing scheme were measured to be better than 13 dB over the entire SGDBR operating range.

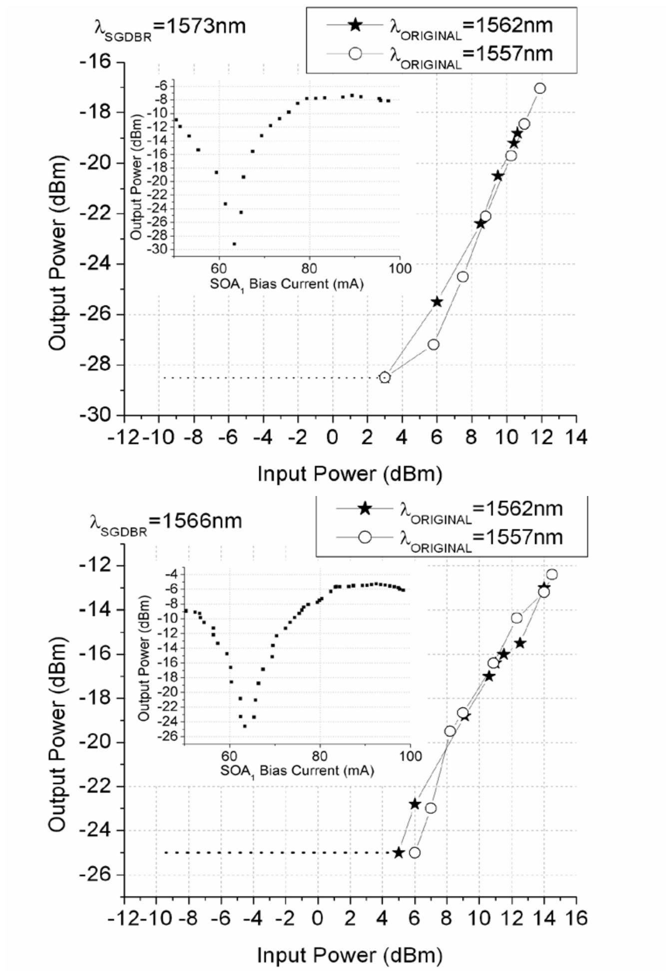

Fig. 4. Static electrical and optical control of the interferometer

Figure 5 shows an extinction map as a function of the currents applied to the SOAs in the interferometer arms. In the region of low bias currents (<120mA), for one SOA current set there clearly exists a combination of currents where the extinction ratio is greater than or equal to 20dB. However, with the increase in the SOA bias currents, the extinction ratio is reduced to as low as 10dB at 250mA on either of the SOAs. This can be explained by noting that the large difference in power levels emitted from the two branches of the interferometer when added, even with totally opposite phase, still yields significant power coming out of the interferometer. Hence, the performance of the device is presumed to be improved by running the SOAs in the interferometer in deeper saturation, i.e. by increasing the power of the incoming light.

IV. Conclusion

We have demonstrated monolithic integration of an InP widely-tunable SGDBR laser and an MZI wavelength converter. The device was fabricated using a simple offset quantum well technology with a single MOCVD epitaxial regrowth.

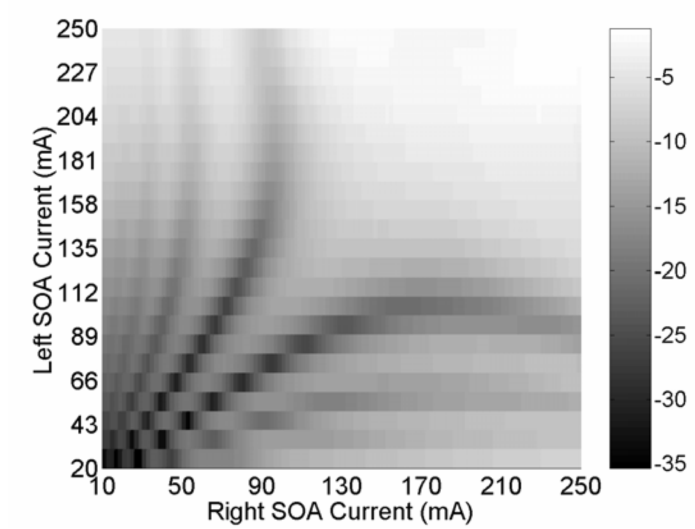

Fig. 5. Electrical extinction map for different SOA biases

The device has a measured static electrically controlled extinction ratio better than 19 dB over a 22 nm tuning range. The optically controlled extinction ratio was measured to be better than 13 dB over the same wavelength range. To the best of our knowledge, this is the first time a device of this kind has been demonstrated and reported.

V. Acknowledgments

We would like to acknowledge Laurent Isnard, Patrick Abraham and Nam Mach from Agility Communications for providing the epitaxial growth and facet coating services for this work. This work was funded by DARPA MTO – CS-WDM grant number N66001-02-C-8026.

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