Loss-Less Four-Channel Wavelength Selector Monolithically Integrated on InP

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Introduction

Wavelength selective filters are key components for WDM applications, and more specifically for high-speed optical packet switching [1]. Such a device can be composed of two phased-array wavelength demultiplexers and an array of semiconductor optical amplifiers (SOA's), as shown in figure 1, and works as follow: the WDM channels are separated by the first phased-array which outputs are connected to SOA's used as optical gates. The wavelength selection is done by opening the gates, i.e. by injecting current in the SOA's, and several channels can be selected simultaneously. Then the selected channels are multiplexed by the second phased-array back onto a single output port. The control of the selected channels is digital, which makes this device very convenient in a system environment. In addition, one key feature of the wavelength selector is its fast switching speed that is limited only by the rise- & fall times of the SOA's. Moreover, the SOA's can also provide loss-less operation if their gain compensates for the total losses of the passive sections of the device.

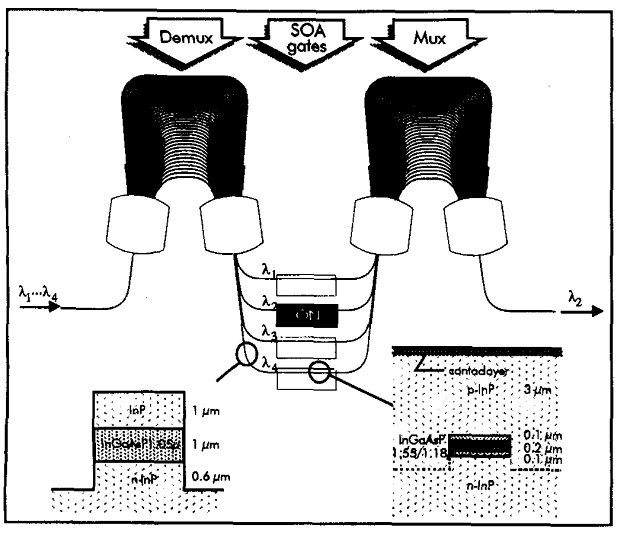

Fig. 1 *Principle of operation of the wavelength selector, with a schematic view of active and passive waveguides.*

A loss-less wavelength selector based on hybrid integration of silica phased-array wavelength demultiplexers and SOA's on a PLC platform with very good performance was reported [2]. However, monolithic integration of passive and active devices seems to be the most promising technique in order to meet constraints in terms of cost and functionality for the mass production of more complex devices. Wavelength selectors showing the potential of monolithic integration on InP have already been reported [3, 4]. Here we report on a 4-channel wavelength selector with zero fiber-to-fiber insertion loss. Bit error rate (BER) performance at 2.5 Gbit/s and 10 Gbit/s was also investigated.

Device fabrication and characteristics

The passive sections of our device consist of a deeply etched structure, that enables fabrication of high-performance phased-array wavelength demultiplexers [5], and the active sections consist of a separate confinement heterostructure with a low tensile-strained bulk active layer for high-gain polarization-independent SOA's [6]. Geometrical characteristics of the structures and composition of the layers are given in figure 1. All the layers were grown using gas-source molecular beam epitaxy, except the top layers of the SOA's which were grown using metal organic vapor phase epitaxy. In our integration process, the passive and active waveguides were butt-coupled to each other - the passive structure being grown first - and were patterned in a single lithographic step to ensure reproducible coupling loss between the active and passive sections. Moreover, the cladding InP layer on top of the guiding layer in the passive sections is undoped to keep propagation losses between 2 and 3 dB/cm (see [5]).

The array of each demultiplexer is composed of 30 waveguides with curvature radii of 50 μm. The free spectral range of the demultiplexers is 24 nm and the channel frequency spacing is 400 GHz. The spacing between the four SOA's is 150 μm and their total length is 550 μm. The total size of the device is only 2.4 mm x 1.2 mm. The operational wavelengths of the wavelength selector are 1551.4 nm, 1554.6 nm, 1557.8 nm and 1561.0 nm. Thanks to the small size of the device and also to the simple and reproducibly-processed deep ridge structure, the operational wavelengths of the two phased-array wavelength demultiplexers are perfectly matched.

Experimental results

The fiber-to-fiber insertion loss of the wavelength selector has been measured for the four channels at their operational wavelength as a function of the injected current in the corresponding SOA. The result is plotted in figure 2. We can see that loss-less operation was achieved for injected current of 50 mA for all the channels. In this experiment, input signals, from a tunable source, and output signals were coupled to the device through lensed fibers. Residual reflections in the device have been reduced since our previous report [3], so that the gain of the SOA's has been slightly increased. The total loss of the passive sections is estimated as 19 dB, 5 dB being due to coupling loss with the lensed fibers and 14 dB to the phased-array wavelength demultiplexers. Theoretical coupling loss between active and passive waveguides is 3 dB, leading to an estimation of the SOA internal gain of 22 dB.

From the wavelength selectivity point of view, the on/off ratio of the SOA's is higher than 50 dB as shown in figure 2, whereas the on/off ratio of the wavelength selector, taking into account the crosstalk of the cascaded phased-array wavelength demultiplexers, is 40 dB.

Finally, BER experiments was done at 2.5 Gbit/s and 10 Gbit/s on the first channel of the wavelength selector, for an input power of –6 dBm and loss-less operation. A sensitivity penalty of 0.6 dB was measured at 2.5 Gbit/s for 10^{-9} BER, with a dynamic range of 13 dB for an excess sensitivity penalty of 1 dB. A penalty of 1.5 dB was obtained at 10 Gbit/s for 10^{-9} BER compared to back-to-back transmission, as shown in Figure 3. When the input power is changed by ±2 dB, the penalty increases by 1 dB. Figure 4 shows the eye diagram in back-to-back configuration and after insertion of the wavelength selector.

Conclusion

A 4-channel compact wavelength selector with 400 GHz channel spacing has been fabricated by monolithic integration on InP. Loss-less operation has been achieved for all channels around 1.55 μm for an injected current of 50 mA. BER performance at 2.5 Gbit/s and 10 Gbit/s has also been investigated showing respectively 0.6 dB and 1.5 dB penalty compared to back-to-back transmission.

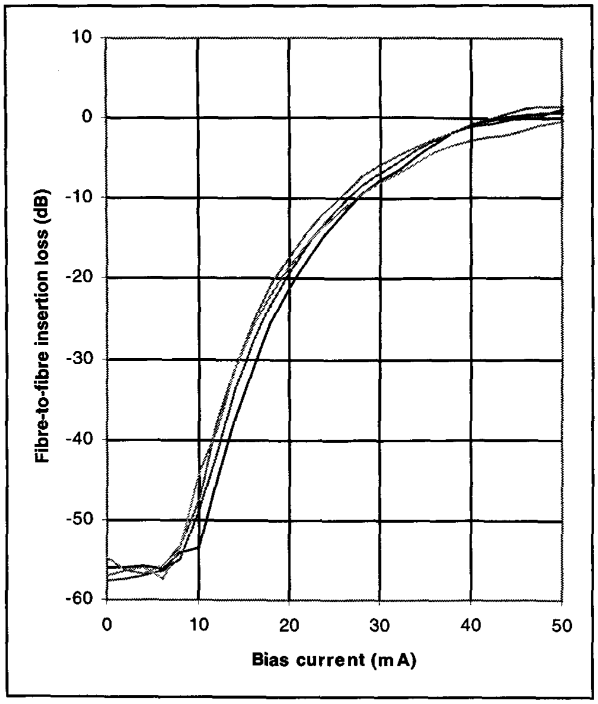

Fig. 2 *Fibre-to-fibre gain of the four channels of the wavelength selector.*

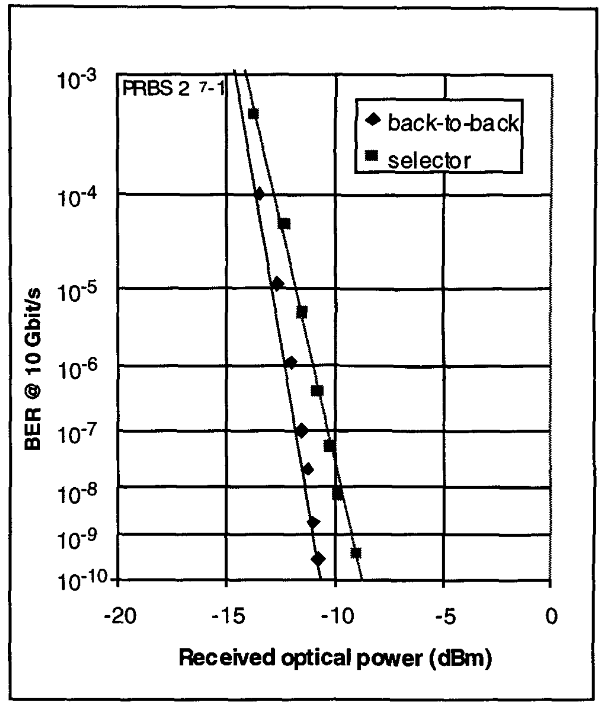

Fig. 3 *BER performance of the wavelength selector at 10 Gbit/s.*

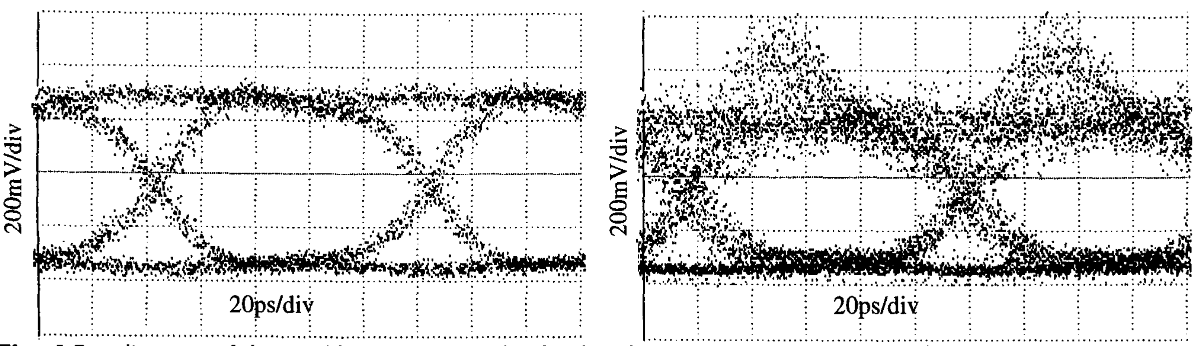

Fig. 4 *Eye diagram of the 10 Gbit/s NRZ signal in back-to back and after insertion of the wavelength selector*

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