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Reconfigurable Monolithic Wavelength Filter Using Gated Amplifying Mach-Zehnders

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Abstract- A programmable filter is realized using an active Mach-Zehnder interferometer filter and broadband optical gating elements. Coarse- and fine-spectral-tuning over 3.2nm free spectral range is achieved with an extinction ratio exceeding 25dB.

I. INTRODUCTION

Fast-reconfigurable integrated filters are of increasing interest to next generation multi-rate and gridless networks [1], and optical microwave signalling [2]. However many of the circuit architectures so far proposed have required complex electro-optic control and calibration. Micro-ring networks may be engineered to allow the tuning of poles and zeros to construct arbitrary transmission spectra [3], but many designs can be sensitive to strict fabrication tolerances [4]. Combinations of ring resonators and Mach-Zehnder interferometers have been integrated to electronically tune the pass-bandwidth and centre wavelength [5], but with potentially complex control and the possibility of on-chip oscillation. In this work we propose a wavelength selective Mach-Zehnder switch interleaved between broadband semiconductor optical amplifier gates. Coarse wavelength-selection functionality is demonstrated using the integrated SOA gates which are either operated in a zero or high current state. Fine wavelength tuning is shown by means of current tuning in the active Mach-Zehnder filter element with a near linear dependence of peak wavelength with current.

II. DEVICE DESIGN AND FABRICATION

A proof of concept reconfigurable filter is implemented with a broadband gate stage, a wavelength selective switch stage and a final broadband gate stage monolithically integrated on InP-InGaAsP. Fig 1 shows the mask layout for the waveguides and the control electrodes. The details at the Mach-Zehnder interferometer (MZI) are enlarged as an inset. The device is fabricated from a four quantum well active InGaAsP/InP epitaxy with a gain spectrum covering the range 1600-1620 nm. A three-step reactive ion etch is performed to define deep, shallow and electrically-isolated waveguides for the required operation. The MZI filter uses deep-etched waveguides to ensure tolerable loss in the 100 μm radius bends. The arrangement can be conveniently concatenated with arbitrary free spectral ranges at each filter stage by changing the differential length in the bends. In this study the

filter arm lengths are 500 μm and 272 μm , respectively, and designed to provide a free spectral range of 3.2 nm. The three stages occupy a total area of 1 mm $\times$ 4 mm, although this can be readily reduced using shorter amplifier gates. Multimode interference couplers are employed as splitters and combiners. Input and output waveguides are angled at 7° with respect to the facets to suppress reflection. Using a feed-forward filter as the Mach-Zehnder interferometer filter also increases the allowed gain before the occurrence of on-chip oscillation. Nonetheless, here operating currents are restricted to avoid oscillations from the facets, indicative of high levels of on-chip gain.

Fig.1. Mask details of the fabricated reconfigurable filter. Mach-Zehnder interferometer filter details are inset.

The gold shaded electrodes in Fig. 1 are wire bonded and electronically tuned to study spectral reconfigurability. The first broadband selector stage is operated by complementary biasing of SOA gate 1 and SOA gate 2. The wavelength selective Mach-Zehnder filter stage is operated by operating the inner short arm with a fixed bias near the transparency current (20mA), and by varying the outer electrode current. The final broadband switch stage is operated by complementary biasing of SOA gates 3 and 4. The scheme is readily scaled through concatenation.

III. COARSE WAVELENGTH SELECTION

The coarse waveband tuning functionality of the fabricated device is characterized in the optical domain. Coarse wavelength selection is achieved by injecting four wavelengths at $\lambda_1=1600.9$ nm, $\lambda_2=1602.5$ nm, $\lambda_3=1604.1$ nm and $\lambda_4=1605.7$ nm. An off-chip filter directs the shorter wavelengths to SOA 1, and the longer wavelengths to SOA 2. Lensed fibers are

employed to couple light in and out of the chip. Polarization controllers are employed at the inputs to the device. The SOA₁, SOA₂, SOA₃ and SOA₄ gates are operated either in a high or zero current state. Complementary operation is considered for the two broadcast stages. The optical spectra for the four combinations are measured at the chip output and shown in Fig. 2. The minimum cross-talk is 16.5 dB, the maximum is 20 dB. The optical signal to noise ratio exceeds 25 dB. This mode of operation has been recently exploited for routing 10Gb/s data signals [6].

Fig. 2. Output optical signal displayed as a function of gates state for four input wavelengths showing selected wavelength and out of band signal extinction over one free spectral range.

IV. FINE WAVELENGTH TUNING

Fine wavelength tuning is demonstrated by scanning a tunable laser over the range from 1600 nm to 1607 nm for a signal launched at SOA1. An optical spectrum analyzer (OSA) measures the optical transmission through the filter device for a range of bias conditions at the longest MZI arm. Wavelength is tuned by scanning current from 40.0 to 100.0 mA in Fig. 3a. The wavelength is changed in the range from 1604.57 to 1606.97 nm covering the overall free spectral range. DC currents of 4.1 mA and 22.8 mA are applied to the two MMI splitters. The shortest MZI arm is biased with a 46.7 mA DC current. SOA1 and SOA3 DC currents are set to 99.4 and 103.1 mA, respectively. The output SOA current is fixed at 46.5 mA and the second last SOA current is 24.5 mA. Fig. 3a shows the current tuning of high contrast nulls. The extinction ratio increases with the current, and this may be enhanced through the amplified filters themselves. The extinction ratio exceeds 25 dB for 1605.57 wavelength case when increasing the bias current of the long MZI arm from 66.0 to 97.0 mA, but is ultimately limited by oscillation due to residual facet reflections.

Fig. 3b shows the continuously programmable fine wavelength tuning: the peak wavelength shifts of 1 nm almost every 10 mA tuning. In this case the DC current for the shorter arms is fixed at 33.6 mA. SOA1, SOA3 and SOA4 DC currents are changed into 118.3, 72.6 and 96.7 mA, respectively.

Fig. 3. (a) Output optical signal as a function of the current at the long MZI arm for four input wavelengths covering one free spectral range. (b) Contour map of optical transmission showing the fine wavelength tuning.

V. CONCLUSIONS

We demonstrated a new compact active programmable filter, monolithically integrated in an InP platform using a MZI filter and a chain of SOA gates. Coarse wavelength tuning is obtained with a maximum crosstalk of 20 dB and fine continuous wavelength tuning with extinction ratio exceeding 25 dB at a tuning rate of 0.1 nm/mA.

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