Noise suppression in monolithically integrated Michelson interferometer

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E. Moll, Y.J. Chai, K.A. Williams, R.V. Penty and I.H. White

A novel monolithically integrated Michelson interferometer using intersecting twin-contact semiconductor optical amplifiers is proposed and implemented whereby the two arms are gain imbalanced to give enhanced noise suppression. Experimental OSNR improvements of 8.4 dB for pulses with durations 8 ps and by default ER of 14 dB are demonstrated for low driving currents of between 25 and 30 mA. This is believed to be the smallest Michelson interferometer to date.

Introduction: Long-haul optical telecommunication systems require regularly-spaced repeaters to regenerate the transmission signal. To date these are typically based on optical-electrical-optical (OEO) regeneration. All-optical regeneration has the potential to surpass OEO in terms of bandwidth and reduced complexity of operation [1]. Interferometry may be used for regeneration by taking advantage of the inherent nonlinear transfer function. By mapping the input pulse onto the part of the transfer function where the slope is larger than 1, it is possible to achieve amplification only for the data part of the signal, thus relatively reducing the output signal noise. OSNR improvements have been achieved in integrated devices incorporating two SOAs and a *y*-branch coupler in conjunction with an erbium preamplifier to give noise suppression at 10 Gbit/s of 4.5 dB relative to a single SOA [2]; and 40 Gbit/s [3].

In this Letter we report a novel form of noise suppressing interferometric device. It is a monolithically integrated Michelson interferometer (MI) [2–4], consisting of two intersecting twin-contact semiconductor optical amplifiers (SOAs) in which a splitter/recombiner mirror is formed at the waveguide junction to provide Michelson functionality (Fig. 1). The use of twin-contacts in the Michelson arms allows the input power threshold to be tuned. Together with the integrated SOA splitter/preamplifier, it is found that the use of additional preamplifiers such as an EDFA is not required. The 50:50 splitter/recombiner junction is created by incorporating a mirror in the waveguide taper such that half the light passes through into one arm (e.g. the right direction in Fig. 1) while the other half is redirected to the other arm (e.g. downwards in Fig. 1). Cleaved facets provide reflection at the end of each arm. The length of each SOA contact is 250–300 µm creating an overall device dimension of 500 × 500 µm. The interferometer arms are terminated by cleaved facets while a Brewster angled facet is etched onto the input/output facet to provide antireflective access to the device. The device is based on a standard InGaAsP/InP ridge waveguide design with five quantum wells in the active region. Metal is patterned on the *p*-layer to provide local control of electrical current injection.

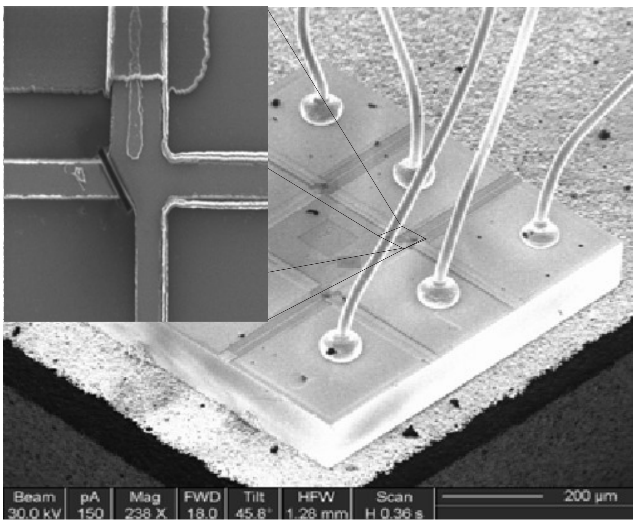

Fig. 1 *Electron microscope picture of monolithically integrated Michelson interferometer*

Inset: All-optical splitter/recombiner

Experimental setup: The experimental setup is shown in Fig. 2. The integrated Michelson device is mounted on a custom electronic board providing easy electrical access to each individual SOA. The current in each SOA is delivered from a laser diode controller providing good control of the injected current in each section. The currents are set at 29 mA in one arm for both SOAs and 29 and 25 mA in the other arm to achieve equal net path gain but imbalanced power maps. The transparency current levels for the operating device are estimated to be as low as 13 mA per SOA. The net gain in each arm is identical for optimum interferometer performance while the gain difference as a function of path length enables dissimilar pulse power distribution along the SOA and hence different nonlinear dependencies. This in turn leads to an enhanced nonlinear transfer function, as illustrated in Fig. 3. The device is operated at a controlled temperature of 20°C. The optical input is supplied from a 10 GHz frequency gain-switched source generating pulses with 8 ps FWHM duration and combined with an EDFA ASE source using a 2 × 2 power combiner. The wavelength of operation is set at 1535 nm to coincide with the material gain peak of the integrated the Michelson interferometer. The signal is coupled into the device through a circulator via a lensed fibre with a 1.6 um spot size. An EDFA is used to compensate the non-optimised fibre to chip coupling losses and the limits of the Brewster angle etch.

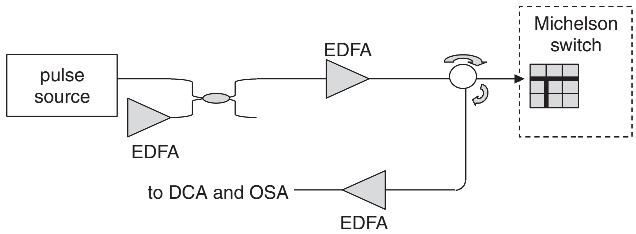

Fig. 2 *Experimental setup for Michelson interferometer regeneration experiment*

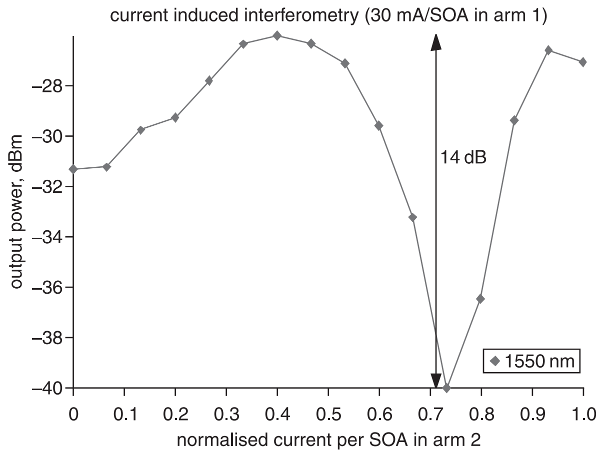

Fig. 3 *Optical transfer function showing 14 dB electrically-induced interferometric interference*

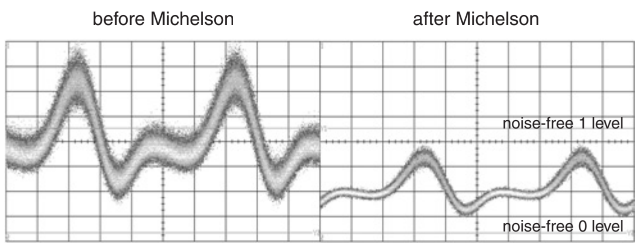

Fig. 4 *ASE plots comparing input and output of Michelson interferometer showing reduction in noise levels compared to respective 0 and 1 level noise-free noise levels*

Results: Fig. 3 shows the transfer function of the Michelson interferometer measured for the peak gain wavelength illustrating the high (14 dB) extinction ratios obtainable with different gains. By comparing the noisy signal before and after passing through the Michelson interferometer to their respective noise-free 0 level and 1 level in Fig. 4 (illustrated by lines on the plots), we can appreciate the noise suppression capabilities of the interferometer. The input with added noise has an increased zero level noise level and is degraded by the ASE of the source EDFA. Subsequent to the Michelson, one can see a suppression of the zero level noise level as well as a reduction in the overall signal noise level. Fig. 5 shows the associated spectrum before and after the Michelson. The typical gain spectrum associated with the EDFA is recognisable (i.e. gain peak at 1530 nm). The plots are normalised to the maximum output point to emphasise the increase in OSNR (from 5.4 dB for the input to 13.8 dB for the output). Some spectral filtering is also evident for shorter wavelengths. The ripples in the output spectrum arise from the Fabry-Perot resonances associated with residual reflection at the input of the Michelson. Improved antireflection coating of the I/O facet would help remove these cavity effects and thus further improve the measured OSNR.

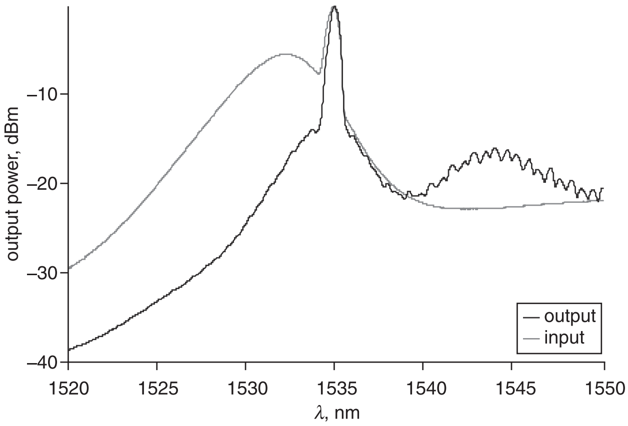

Fig. 5 *Optical spectra showing 8.4 dB OSNR improvement*

Conclusions: Noise suppression in a monolithically integrated Michelson interferometer with OSNR improvement of 8.4 dB has been demonstrated. The dimensions of the Michelson interferometer (500 × 500 μm) allows these regenerative features to be achieved for low driving currents (25 and 29 mA per SOA) and hence very low power consumption. The use of twin-contact SOAs in each arm of the Michelson interferometer allows for control of the gain imbalance leading to transfer functions exhibiting high extinction ratio features (14 dB extinction ration has been demonstrated electrically). It is further hoped that improved antireflective coating will allow much better results and higher operating speeds.

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