Fabrication of Add-Drop Multiplexers in Fused Silica by Femtosecond Laser Direct Writing

Vítor A. AMORIM[1,2*], João M. MAIA[1,2], D. ALEXANDRE[1,3], P. V. S. MARQUES[1,2]
[1]Center for Applied Photonics, INESC TEC, Rua Dr. Roberto Frias, Porto, 4200-465, Portugal
[2]Department of Physics and Astronomy, University of Porto, Rua do Campo Alegre, Porto, 4169-007, Portugal
[3]Department of Physics, University of Trás-os-Montes e Alto Douro, Quinta de Prados, Vila Real, 5000-801, Portugal
* vitor.a.o.a@hotmail.com

Optical add-drop multiplexers (OADMs) [1] can be used in telecommunication networks for wavelength-division multiplexing (WDM). Fig. 1 (a) shows a schematic of a possible OADM configuration, which is based on a Mach-Zehnder interferometer and that has been investigated in this work.

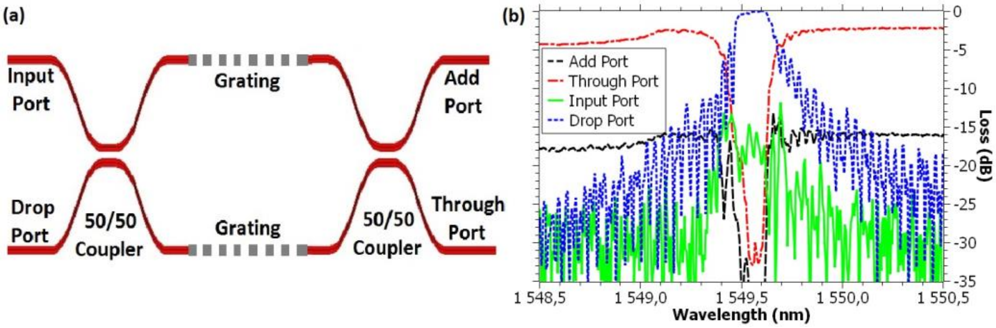

Fig. 1. (a) Schematic of the optical add-drop multiplexer configuration. (b) Measured reflection and transmission spectra of the input, drop, add, and through-port.

The input signal that is composed of several wavelength channels is split equally by the first directional coupler and then guided to two identical Bragg gratings where the resonant wavelength is reflected to the drop port to be read, while the remaining transmitted signals emerges at the through port. Similarly, new information at the resonant wavelength can be sent via the add port. In this configuration the Mach-Zehnder interferometer is responsible for the routing of the signals. In order to perform this routing correctly both arms must have an almost identical optical path length, within nanometer range differences.

Integrated OADMs based on this configuration can be fabricated using photolithographic techniques together with UV photoinscription of Bragg gratings and phase trimming because these allow the fabrication of devices with low insertion losses as well as low intra and inter-channel crosstalk. However, in this work, the more recent femtosecond (fs) laser direct writing technique [2] was used to fabricate, for the first time to our knowledge, this kind of device. For that a Satsuma HP fiber amplified fs-laser system, emitting a second harmonic beam at 515 nm with a pulse duration of 250 fs at 500 kHz, was used to induce the refractive index modification in homogeneous pure silica substrates. The laser beam was focused at a depth of 50 μm below the substrate surface using a 0.55 numerical aperture aspherical lens. The substrate was mounted on X-Y Aerotech stages (ABL10100-LN) and translated orthogonally to the incident laser beam. This technique enables 3D modification of the refractive index of the substrate with very high spatial resolution, allowing, for example, the fabrication of first order gratings.

To fabricate a complete monolithic OADM waveguides, first order Bragg grating waveguides (BGWs), and directional couplers were optimized and integrated in the Mach-Zehnder configuration represented in Fig. 1 (a). Optimal writing conditions were achieved for a 250 nJ pulse energy and 400 μm/s translation velocity at a depth of 50 μm, with a propagation loss of approximately 0.14 dB/cm and a coupling loss of 0.37 dB per facet being obtained for the implemented waveguides at 1550 nm. For the BGWs a propagation loss of 0.8 dB/cm was measured at 40 % modulation duty cycle in order to achieve a grating strength around 30 dB in a 20 mm long grating. The directional couplers showed a splitting ratio of 51/49 %, at wavelengths around 1550 nm, for a separation distance of 15 μm and an interaction length of 1.77 mm.

The results presented here show a device that had a good phase balance as written; real time phase trimming was not tested yet. The input, drop, add, and through-port spectra around the Bragg wavelength are shown in Fig. 1 (b) for horizontally polarized testing light. As can be seen, the reflected signal is emerging from the input and drop-port correctly, with an isolation of approximately 14 dB between ports, showing that the optical path difference between both arms is either very close to zero or a multiple of λ / $(2n_{eff})$ to allow constructive interference at the drop-port. It is also observable that the signal transmitted by the add and through-ports correspond roughly to the ideal behavior, with a deviation of approximately 14 dB. The transmission spectra exhibit, at the Bragg wavelength, an isolation better than -30 dB, enabling low intra-channel crosstalk. Regarding the reflection spectrum on the drop-port, it corresponds to the usual uniform Bragg grating spectrum with the undesired side lobes. The 3 dB bandwidth is 0.19 nm and a side lobe suppression of 20 dB is achieved for $\Delta\lambda=\pm0.75$ nm. A total insertion loss of 4.9 dB and 3.7 dB was measured for the through port and the drop port respectively.

Future improvement of this device is related to the fine tuning of the ports output by compensating phase errors with resourse to real time laser trimming. The same laser used to write the waveguides should be used to adjust the optical paths, first optimizing the drop port and after the through port. Also, the grating profile should be optimized in order to enhance, for example, channel crosstalk. This can be done through apodization [3].

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