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Wavelength conversion techniques and devices

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Introduction: The wavelength converter is expected to become a key component in future photonic WDM networks. The converters will enable, e.g., efficient WDM cross-connects with low wavelength blocking [1,2]. This feature together with relaxed requirements to the management [3] has motivated research projects world wide to consider the use of wavelength converters. The great interest has led to several suggestions for realising the conversion device. Apart from the straight forward opto-electrical converter [4] several all-optical techniques such as four-wave-mixing in fibres [5] and semiconductor optical amplifiers (SOAs) [6], cross-gain (XGM) or cross-phase (XPM) modulation in lasers [7], XGM in SOAs [8] and conversion by difference frequency generation [9] have been proposed. Still, the most promising technique seems to rely on XPM in SOAs placed in interferometric structures [10]. Due to the limited space we consider only the XPM converters in the following while our presentation will be broader in scope.

Interferometric wavelength converters: The interferometric wavelength converters can be realised by both passive-active integration [11,12] of SOAs in to the Michelson (MI) and Mach-Zehnder (MZI) interferometer or by integrating an all-active waveguide (see Fig. 1) [13]. For all four combinations shown in Fig. 1 the conversion principle is essentially the same: The signal at λ_{in} depletes carriers in one SOA and thus changes the phase difference between the two interferometer arms. Simultanously, a CW light at the desired output wavelength, λ_{conv}, is injected. This CW light experiences the phase modulation which at the output leads to an intensity modulation that follows the digital information on the incoming data signal.

Performance: The interferometric converters can be made polarisation insensitive [11] and the chirp of the converted signals can be controlled to support transmission on standard fiber [14]. Additionally, the output extinction ratio can be higher than the input extinction ratio which can be utilised for regeneration [15]. Moreover, the technique is nearly wavelength independent and can operate at bit rates up to at least 40 Gbit/s [16]. This is illustrated in Fig. 2 that gives the extinction ratio for the converted signal versus the output wavelength at 40 Gbit/s. Apart from a high extinction ratio the signal-to-ASE ratio for the converted signals is higher than 25 dB (1 nm

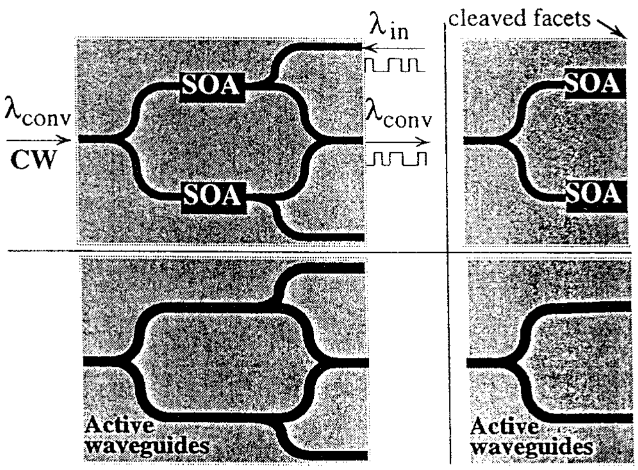

Fig. 1: *Left:* Interferometric Mach-Zehnder wavelength converters realised by active-passive (top) or all-active (bottom) integration. *Right:* Interferometric Michelson wavelength converters with cleaved right factes (R=36 %) realised by active-passive (top) or all-active (bottom) integration.

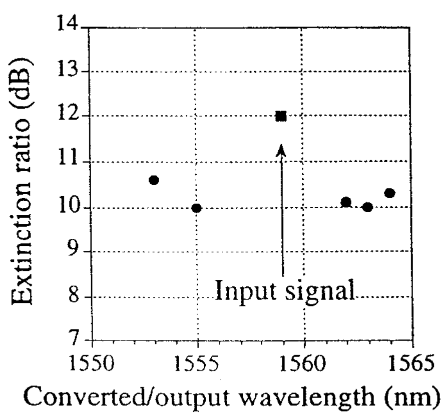

Fig. 2: Converted extinction ratio versus output wavelength for conversion at 40 Gbit/s using an all-active Michelson converter.

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bandwidth) which is of importance when wavelength converters need to be cascaded.

The features listed above underline the high quality of the interferometric converters. The draw-back, however, is their fairly limited input power dynamic range measured to be 3-4 dB at 10 Gbit/s. The limitations are is caused by a small required gain modulation (4-5 dB to change the phase in the SOA by π, i.e. from contructive to destructive interference) that give rise to strict requirements for the input power levels. To increase the dynamic range, a fast control mechanism that can compensate for power fluctuations at ~1 nsec level has been proposed [17]. The scheme is illustrated in Fig 3.a and utilises gain-control of an SOA: If the input power is low the gain in the SOA is adjusted to be high and vice verca. Thereby, the output power of the SOA is constant and thus the operation of the wavelength converter is not affected by power variations. The efficiency of the control scheme is demonstrated in Fig. 3.b. that shows a measured IPDR of ~25 dB at 10 Gbit/s.

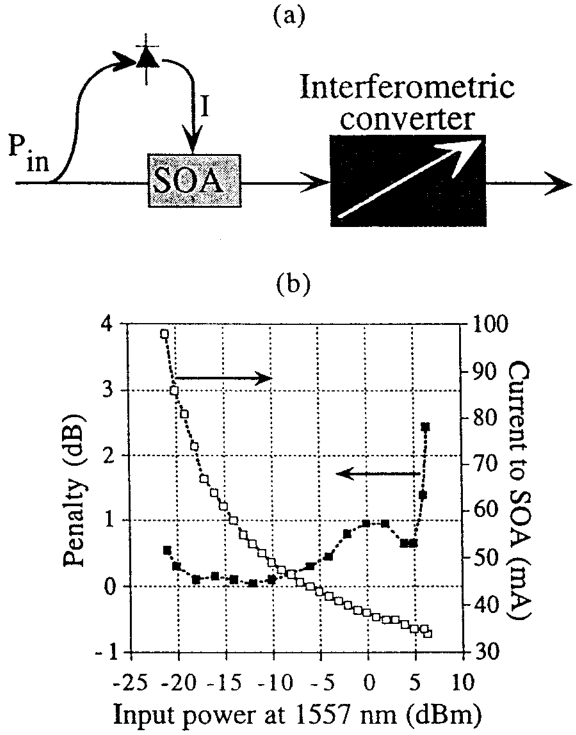

Fig. 3: (a) Fast control scheme of input power to the interferometric wavelength converter using gain/output power control in an SOA. (b) Result of control scheme at 10 Gbit/s for conversion from 1557 to 1560 nm using an all-active integrated Michelson converter. CW input power: ~9 dBm.

Summary: Taking into account the requirements to the converters e.g., bit rate transparency (at least up to 10 Gbit/s), polarisation independence, wavelength independence, moderate input power levels, high signal-to-noise ratio and high extinction ratio the interferometric wavelength converters are very interesting. However, the perfect converter has probably not yet been fabricated and new techniques such as conversion relying on cross-absorption modulation in electro-absorption modulators [18] might also be considered in pursue of effective conversion devices.

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