WDM compatible 2R regeneration device based on eight-channel saturable absorber module


The first pigtailed saturable absorber chip has been implemented with eight independent fibres using a simple coupling technique. This device provides full WDM regeneration compatibility, which has been experimentally demonstrated at 42.6 Gbit/s.

Introduction: An all-optical regenerator could be one of the key devices for future optical networks as it allows reduction of transmission impairments and thus enhancement of transmission distance. To qualify as a viable alternative to the state-of-the-art optoelectronic regenerators, an all-optical regenerator must be easily scalable with the number of wavelength-division-multiplexing (WDM) channels. The saturable absorber (SA), which is a vertical semiconductor-based quantum-well microcavity, is of great interest for all-optical regeneration thanks to its capacity and performance. First, the SA provides an efficient and completely passive solution for noise reduction and extinction ratio enhancement at bit rates as high as 160 Gbit/s [1]; secondly, simultaneous regeneration of several WDM channels has been shown with spatial demultiplexing [2]. Moreover, some WDM compatible solutions have been developed that fully reshape the signal at 10 Gbit/s [3].

In this Letter, we assess the first pigtailed SA device with eight independent fibres. Component homogeneity and spectral functionality are evaluated through switching contrast measurements. Cascadability and wavelength tunability are experimentally studied at 42.6 Gbit/s in a recirculating loop.

Module fabrication: The saturable absorber chip contains seven MOCVD-grown InGaAs/InP quantum wells embedded in a microresonator. Quantum wells are located at the antinodes of intracavity intensity. The bottom mirror is a broadband high-reflectivity metallic-based mirror (Ag) and the top mirror is a multilayer dielectric mirror (2 × [TiO2/ SiO2]). A heavy-ion-irradiation shortens the absorption recovery time down to 5 ps. The device operates in a reflective mode, the reflectivity being small at low signal level, and high at high signal level. More details on the device fabrication can be found in [4, 5]. A special fibre array has been developed by Yenista Optics for efficiently interfacing the saturable absorber chip to eight standard singlemode fibres with 250 μm spacing. The fibre array is fixed to the mirror with an adhesive so that all the eight outcoming beams typically have a mode field diameter (MFD) of 4.5 μm on the surface of the mirror. Focusing the beams onto the mirror reduces the input power threshold required for the nonlinear effect of the mirror. This compact and low-cost technique does not need any coupling optimisation.

As complete 2R regeneration with limitation on ‘mark’ fluctuation is not ensured by the SA alone, the regeneration requires another nonlinear function [6]. In this Letter, a fibre-based solution is used. The passive 2R regenerator consists of two stages: the first pulse compression stage comprising a nonlinear fibre (NLF) followed by an optical filter for equalisation of ‘mark’ levels [7], and the second stage made of the SA module for attenuation of the ‘space’ level. The nonlinear fibre in the pulse compression stage consists of a 1 km span of DSF (dispersion 0.1 ps nm⁻¹ km⁻¹) and a 1 km span of standard NZ-DSF (dispersion 4.5 ps nm⁻¹ km⁻¹). This stage requires an EDFA to ensure a high enough power (typically 18 dBm in our case) to emulate significant nonlinear effects. An optical circulator allows injecting and recovering a data signal in the SA module.

First, the impact of the 2R regeneration was studied at a signal wavelength of 1546.6 nm. Fig. 3a shows the bit error rate (BER) evolution against distance with and without the regenerator (full triangles) for a launched power of 5 dBm corresponding to the optimal propagation length. After insertion of the 2R regenerator in the loop, we observe a significant improvement of the transmission distance for each channel of the SA module. At least 4000 km are covered with a BER of 10⁻⁴ for the worst channel. We have also investigated the regeneration behaviour with respect to the signal wavelength for channel 5 (Fig. 3b). We measured the distance improvement ratio (DIR) corresponding to the BER of the covered distance with and without the regenerator (full triangles) for a launched power of 5 dBm corresponding to the optimal propagation length. Results show that the DIR is better than 3 over more than 13 nm (from 1541 to 1554 nm), demonstrating experimentally the wideband behaviour of the device.

These experiments confirm the good homogeneity of the component and its functionality over a wide spectrum. In the context of a WDM configuration, it is possible to process simultaneously eight channels spaced at 100 GHz with this compact module. For the moment, the technique for ‘mark’ level equalisation (fibre followed by optical filter) is limited for WDM application owing to inter-channel nonlinearity. Recently, it was reported that it was possible to reduce the...
inter-channel-nonlinearity-suppressing dispersion map enabled by period group-delay devices [8]. Moreover, a new design of the same type of nonlinear microcavity device should make it possible to reduce ‘mark’ level fluctuations on several channels simultaneously without the fibre compression stage [9].

**Fig. 3** BER evolution against distance without and with SA module DIR (at BER \(10^{-4}\)) evolution against signal wavelength for channel 5

- **a** BER evolution against distance
- **b** BER evolution against signal wavelength

**Conclusions:** We have reported for the first time the WDM compatibility of a simple, compact and completely passive eight-channel 2R regenerator module based on a saturable absorber. SA module average switching contrast is 5.5 dB on all channels and a switching contrast higher than 3 dB is attainable over 18 nm. We have also shown a distance improvement ratio (at BER of \(10^{-4}\)) of at least 3.3 in a 100 km regeneration span in a recirculating loop. Finally, we have demonstrated a distance improvement ratio greater than 3 over 13 nm. This module is fully compatible with photonic integration, which would allow for a compact and low-cost WDM 2R regeneration.

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