Cascadability and wavelength tunability assessment of a 2R regeneration device based on a 8 channel saturable absorber module

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Abstract: We report on the first pigtailed chip saturable absorber which has been implemented with 8 independent fibers using a cost effective coupling technique. The cascadability and wavelength tunability assessment have been experimentally demonstrated at 42.6 Gbit/s.

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1. Introduction
All-optical regeneration has potential as a key technology for future optical networks as it allows the impact of transmission impairments to be reduced. In order to qualify itself as a viable alternative to the state-of-the-art electronic-domain regenerators, an all-optical regenerator must be easily scalable with the number of wavelength-division-multiplexing (WDM) channels.

A saturable absorber (SA) based on a vertical micro-cavity is of great interest for optical regeneration: Firstly the SA was shown to be efficient for noise reduction and extinction ratio enhancement at bit rates as high as 160 Gbit/s [1]; secondly, spatial demultiplexing [2] should enable simultaneous regeneration of several WDM channels. Moreover, some WDM compatible solutions have been developed to fully reshape the signal at 10 Gbit/s [3].

In this paper, we report on the 2R regeneration assessment of the first pigtailed chip SA with 8 independent fibers using a compact and low cost technique that does not need any coupling optimisation. We show measurements of signal extinction ratio enhancement on each channel, and experimentally demonstrate at 42.6 Gbit/s the cascadability and wavelength tunability of this 2R module in a recirculation loop.

2. Module fabrication
The saturable absorber chip contains 7 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.

A special fiber array has been developed by YENISTA OPTICS for efficiently interfacing the saturable absorber chip to 8 standard single mode fibers with 250 µm spacing. The fiber array is fixed to the mirror with an adhesive such that all the 8 out coming beams typically have a Mode Field Diameter (MFD) of 4.5µm on the surface of the mirror (Fig. 1).

![Fig. 1. Photograph of SA chip, Fiber array (top) and SA module (bottom)](image-url)
Focusing the beam on the mirror reduces the input power threshold required for the non-linear effect of the mirror.

3. Module characterisation

Fig. 2 shows the optical reflectivity spectra of each channel of the SA module. These curves were obtained with an Amplified Spontaneous Emission (ASE) source with low input power to the SA module. The spectral position of minimum reflectivity is 1546.6 nm on average on all channels with a standard deviation of 1 nm.

Fig. 3 and Fig. 4 are obtained with an experimental setup derived of classical pump-probe measurement [1]. The pump signal at 1535 nm is a RZ (33 %) signal modulated at 42.6 Gbit/s with sequence length of $2^{31}-1$ bit. For a high input pump signal power level, we obtain a crossed modulation of SA absorption on probe signal. The switching contrast is obtained from the measurement of the mark-space extinction ratio of the probe signal. For an input pump signal power of 12 dBm, the switching contrast is 5.5 dB on average on all channels with a standard deviation of 0.9 dB. Losses measured with this power are 9.5 dB on average, with a standard deviation of 0.5 dB. These figures are good enough to use the module in a 2R regeneration experiment.

4. System Characterisation

The 42.6 Gbit/s transmission experiment is carried out with a 100 km long recirculating loop (Fig. 5). Non-Zero Dispersion Shifted Fibre (NZDSF) is used and chromatic dispersion is partially compensated with a Dispersion Compensating Fibre (DCF). Losses are compensated essentially by Erbium amplification. The transmitter produces a RZ (33 %) signal modulated at 42.6 Gbit/s with a $2^{31}-1$ bit length sequence.
First the impact of the 2R regeneration was studied at a signal wavelength of 1546.6 nm. Figure 6 presents the Bit Error Rate (BER) evolution as a function of the distance without regenerator (full triangles) for inline 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 BER versus distance for each channel of the SA module. Table 1 summarizes the Distance Improvement Ratio (DIR) corresponding to the ratio of the distance obtained at a BER of $10^{-4}$ with and without the regenerator. Input power necessary for each channel is also shown.

<table>
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<th>Channel</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin (dBm)</td>
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<td>8</td>
<td>10</td>
<td>5.5</td>
<td>8</td>
<td>4</td>
<td>5.2</td>
<td>4.8</td>
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<td>DIR($10^{-4}$)</td>
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<td>3.8</td>
<td>3.7</td>
<td>3.6</td>
<td>3.8</td>
<td>3.5</td>
<td>3.3</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 1: Results of mean input power and Distance Improvement Ratio (at BER of $10^{-4}$) for each channel

We have also investigated the regeneration behaviour with respect to the signal wavelength for channel 1 (Fig. 7). Results show that the DIR is better than 3 over more than 13 nm (from 1541 to 1554 nm), demonstrating the wide-band behaviour of the device. In the context of a WDM configuration, it is possible to treat simultaneously 8 channels spaced of 100 GHz with this compact module. For the moment, the technique for ‘mark’ level equalisation (fiber followed by optical filter) is limiting for WDM application due to inter-channel non-linearity. Recently, it was reported that it was possible to reduce the inter-channel non-linearity suppressing dispersion map enabled by periodic group-delay devices [5]. Moreover, a new design of the same type of non-linear microcavity device should make it possible to reduce ‘mark level’ fluctuations on several channels simultaneously without the fiber compression stage [6].

5. Conclusion

We have reported for the first time the cascadability assessment of a simple and compact 8 channel 2R regenerator module based on a saturable absorber. SA module switching contrast is 5.5 dB on average on all channels. We have also shown a distance improvement ratio (at BER of $10^{-4}$) of at least 3.3 (for the worst case channel) in a 100 Km regeneration span in recirculation loop with all EDFA amplification. Finally, we have demonstrated a distance improvement ratio greater than 3 over 13 nm. This module is fully compatible with photonic integration, which could allow compact and low cost WDM 2R regeneration.

6. Reference