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Double Wavelength Conversion with Multi-Resonant Saturable Absorber-Based Vertical-Cavity Semiconductor Gate

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Abstract—**We report simultaneous wavelength conversion at two different wavelengths using a multi-resonant, all-optical vertical-cavity semiconductor gate. The device is compact, passive, polarization independent and ensures wavelength conversion with high extinction ratio and low OSNR penalty.**

Cost-effective and easy to implement solutions enabling wavelength conversions are thought to be key elements for increasing flexibility, throughput, and transparency. For such purposes, semiconductor devices seem to be the most promising candidates; their main advantages are compactness, low power operation, and relatively fast response times. In recent years, beside implementation based on the popular semiconductor optical amplifiers (SOAs), wavelength conversion with passive nonlinear gates exploiting saturation of absorption in semiconductor multiple-quantum-wells (MQWs) has attracted increased attention [1]–[3]. In particular, in [3] we have demonstrated that a vertical-cavity semiconductor gate (VCSG) comprising MQWs embedded in a resonant asymmetric Fabry–Pérot (FP) cavity can be highly effective in converting external input data to a wavelength close to one cavity resonance. Good quality for the wavelength converted data over a relative broad range of input signal wavelengths was demonstrated. In this work, we extend the same principle to a multi-resonant (MR) FP VCSG to simultaneously convert the input data pattern into two output wavelengths. The operation could in principle be extended to a higher number of wavelengths. Our demonstration shows the potential of this technology for effective all-optical broadcasting with a passive device. In our experiment we have used a VCSG grown by solid-source molecular beam epitaxy on n-type InP (100) substrate. The sample consisted of Burstein–Moss shifted distributed Bragg reflector (DBR) with 19.5 pairs of n+-$Ga_{0.47}In_{0.53}As$/InP [4], a 480-nm InP spacer layer, an active region, and a ~11.1-µm InP cap layer. The active region was comprised of four groups of seven $Ga_{0.47}In_{0.53}As$ QWs with a thickness of 9 nm and 10 nm thick InP barriers. The QWs have been centred at the antinodes of the FP cavity defined between the DBR and top surface of the gate. The DBR reflectivity was over 96 % in the wavelength range from 1525 to 1610 nm. The DBR reflectivity and the low-intensity reflectivity spectrum of the gate are depicted in Fig. 1, where the presence of several resonances with a free spectral range of ~25 nm can be seen.

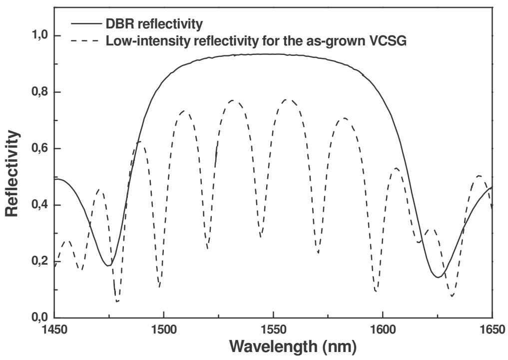

Fig. 1: Low-intensity reflectivity spectrum for the MR-VCSG (dotted line) and DBR reflectivity spectrum (solid line).

To increase the nonlinear effects, a ~63 % reflective dielectric mirror was deposited on the top of the device [5]. The experimental set-up we adopted for demonstrating double wavelength conversion using the MR-VCSG is shown in Fig. 2. Two external-cavity semiconductor tunable laser sources (TLSs) delivered the probe CW signals at λ_1 and λ_2, matching the cavity resonances of 1541 nm and 1566 nm, respectively. Another TLS was used to deliver the pump field at λ_p = 1553 nm. This beam was modulated by a 2^{31}-1 PRBS data stream using a lithium-niobate intensity modulator. The repetition rate for the input data was set to 100 Mb/s to avoid undesirable effects related to the slow response time of the saturable absorption. However, the repetition rate could attain multi-Gb range if ion-irradiated VCSG with a fast absorption recovery time were used [1], [6]. The pump signal was amplified by means of an Erbium Doped Fiber Amplifier (EDFA). An optical filter (OF) was used to remove the out-band noise after the EDFA. The probes and the pump fields were combined and butt-coupled to the MR-VCSG. The pump power at VCSG input was ~13 dBm, while the power for the two probe beams was ~2 dBm. The light at the gate output was collected trough an optical circulator and split into different paths, each comprising an EDFA and OFs centred at the probes wavelengths. However, the number of amplifiers and OFs in the output path could be minimized by using a notch filter centred at the pump wavelength.

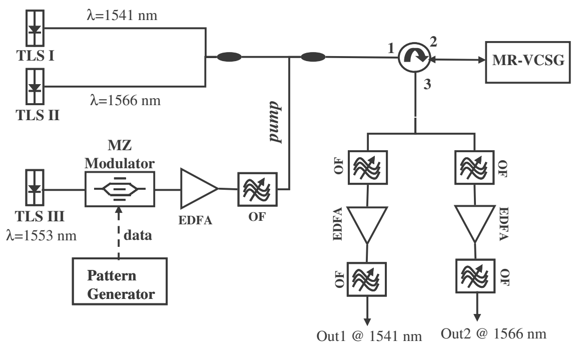

Fig. 2: The set-up for the double wavelength conversion experiment.

Fig. 3 shows the optical spectra at MR-VCSG output with and without the pump data signal applied. It can be seen that in the absence of pump signal the probe fields were strongly attenuated. When pump was applied, the absorption in the MQWs was further saturated and the reflectivity experienced by the probe fields was increased. The measurements revealed an average reflectivity change of ~18 dB for both probe beams.

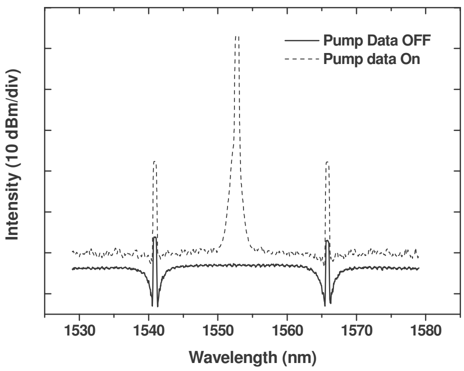

Fig. 3: Optical spectra at the output of the MR-VCSG with pump Off (solid line) and On (dashed line).

After being amplified and filtered, the two probe signals at the MR-VCSG output were sent to a 125 MHz photoreceiver and monitored on a sampling oscilloscope. The oscilloscope traces, showing the input and the converted eye diagrams, are shown in Figure 4. An extinction ratio larger than 10 dB was measured at both converted wavelengths. Finally, a BER vs. OSNR measurement was performed for the input and converted data. The OSNR could be varied by means of a local ASE source and was measured on an OSA within a 0.1 nm bandwidth. The results, shown in Fig. 4, indicated an OSNR penalty (at BER=10^{-9}) of 1.9 dB and 2.7 dB for the 1541 nm and 1566 nm signals, respectively. The difference in the OSNR penalty is ascribed to the different EDFA related noise figures for the two output wavelengths.

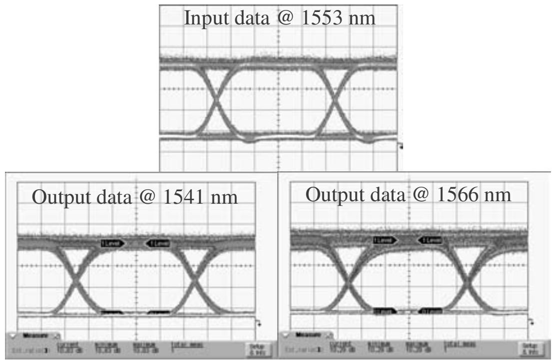

Fig. 3: Eye diagrams for the input and converted output data. Amplitude scale: 100 mV/div, time scale: 2 ns/div.

These results show the potential of MR-VCSG to perform effective multiple wavelength conversion with passive, polarization independent, cost-effective vertical-cavity technology for all-optical networking and broadcasting applications. Advanced designs will be implemented to reduce the spacing between adjacent channels and to increase the operation speed.

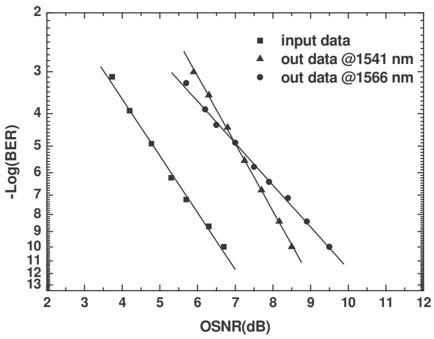

Fig. 4: BER vs. OSNR for the input and output converted data.

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