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Broadband and Efficient Dual-Pump Four-Wave-Mixing in AlGaAs-On-Insulator Nano-Waveguides

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Abstract: We characterize dual-pump four-wave-mixing in AlGaAs-on-insulator nano-waveguides and demonstrate an output conversion efficiency as high as -8.5 dB at 155-mW pump power. The idler optical signal-to-noise ratio is above 25 dB over a 26-nm bandwidth.

OCIS codes: 190.4380 Nonlinear optics, four-wave mixing, 190.4390 Nonlinear optics, integrated optics, 230.4320 Nonlinear optical devices.

1. Introduction

Historically nonlinear optics for optical communication has mainly been demonstrated using highly nonlinear fibers (HNLFs). Integrated platforms, however, allow using more compact devices as well as overcoming some of the challenges of HNLFs such as stimulated Brillouin scattering. Along such direction a significant effort has been dedicated to investigate silicon with numerous promising results being reported [1]. The benefit of strong Kerr nonlinearity in silicon is however hindered by the presence of two-photon absorption (TPA) and free-carrier absorption (FCA) at telecom wavelengths and even though techniques to tackle such effects have been reported [1, 2], other materials may provide a more suitable solution. AlGaAs is one such material as it combines high intrinsic nonlinearities with the ability to tailor the material bandgap and thus avoid TPA at 1550 nm enabling efficient four-wave mixing (FWM) [3–5].

Here, we extend the investigation of AlGaAs-on-insulator (AlGaAsOI) nano-waveguides of [5] by characterizing the conversion efficiency (CE) for different waveguide lengths and pump powers using a dual-pump FWM scheme. A constant output CE of -8.5 ± 0.5 dB is demonstrated over a broad 26-nm bandwidth, i.e. most of the telecommunication C-band. Such high CE enables producing high-quality idlers with optical signal-to-noise ratios (OSNRs) above 35 dB over 20 nm, proving the potential of the AlGaAsOI platform for high-performance nonlinear signal processing.

2. Experimental setup

The experimental setup is sketched in Fig. 1. Two continuous-wave (CW) pumps at 1535 nm and 1565 nm are amplified in erbium doped fiber amplifiers (EDFAs), narrow band filtered with 0.8-nm wide optical bandpass filters (OBPFs) and coupled into the AlGaAsOI nano-waveguide together with a CW signal. Their states-of-polarization were aligned to the TE mode of the waveguide using polarization controllers (PCs) and the output optical spectrum was monitored with an optical spectrum analyzer (OSA).

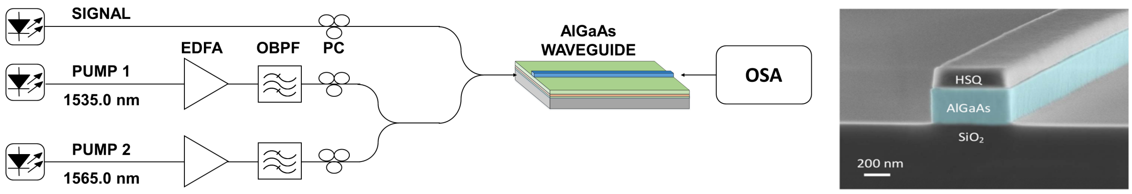

Fig. 1: Experimental setup for FWM characterization of the AlGaAs waveguides. Inset: SEM image of the waveguide.

The AlGaAsOI wafer was prepared by wafer growth, wafer bonding and substrate removal. The AlGaAsOI platform provides a larger index contrast between the AlGaAs core (n$\sim$ 3.3) and the insulator cladding (n$\sim$ 1.5) enhancing the field confinement in the waveguide and thus the nonlinear effects. The waveguides were defined by electron-beam lithography and dry etching using hydrogen silsesquioxane (HSQ) as hard mask. The inset in Fig. 1 shows an SEM image of the fabricated waveguide just after the dry-etching process. The waveguide cross-section is 290×630 nm^2 and several lengths have been considered ranging from 3 mm to 9 mm in 2-mm steps. Inverse tapers [6] are used at both facets to increase the coupling efficiency leading to a coupling loss of 2.1 dB/facet. The propagation loss and zero dispersion wavelength are estimated to 1.5 dB/cm and 1500 nm for the TE mode.

3. Results

Fig. 2(a) shows the output CE, defined as the ratio between idler and signal power at the waveguide output, as a function of the total power coupled into the waveguide and the waveguide length for a signal at 1549 nm. At the waveguide input the two pumps were equalized in power and the signal-to-pump power ratio was kept below -30 dB. The power levels reported in the following refer to the total power coupled into the waveguide.

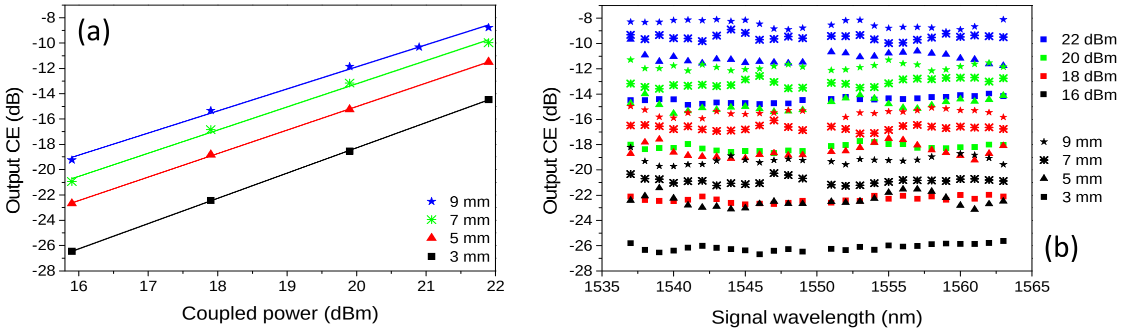

Fig. 2: (a) Output CE as a function of the coupled power for different waveguide lengths for a signal at 1549 nm and (b) CE bandwidth for various waveguide lengths and power levels.

The CE increases quadratically with the pump power showing no signs of saturation. The power was limited to 21.95 dBm (155 mW) due to power handling limitation of the inverse taper. The full CE bandwidths, i.e. sweeping the signal wavelength between 1537 nm and 1563 nm, for different power levels and waveguide lengths are shown in Fig. 2(b). For the whole wavelength range, the CE variations are below 1.5 dB and the CE follows the trends highlighted in Fig. 2(a). Fig. 3(a) shows the optical spectra at the output of a 9-mm long waveguide for a total pump power of 155 mW. An average CE of -8.5 ± 0.5 dB could be achieved over the whole 26-nm band. The idlers optical signal-to-noise ratio (OSNR) is above 25 dB over 26 nm and above 35 dB over 20 nm as shown in Fig. 3(b). High quality idlers are therefore produced over most of the telecommunication C-band. Additionally, we expect that the OSNR could be further increased with higher input signal power and improved amplified spontaneous emission (ASE) noise filtering after the amplification of the pumps.

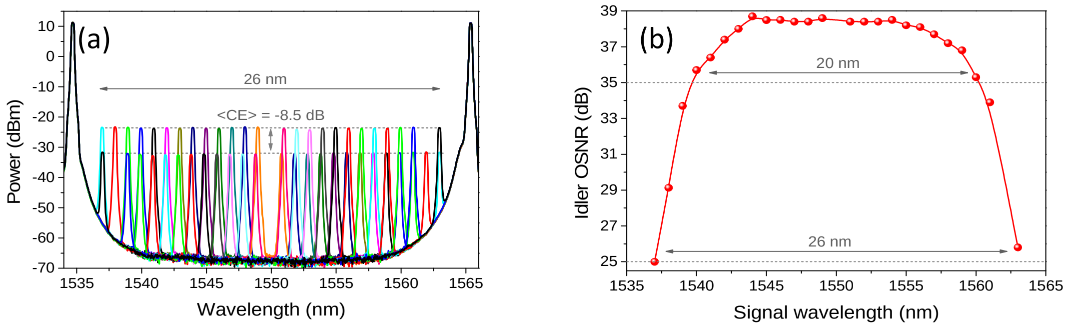

Fig. 3: Optical spectra at the 9-nm waveguide output ($P = 155\ mW$) (a) and idler OSNR as a function of the signal waveguide (b).

4. Conclusions

A dual-pump FWM scheme based on AlGaAsOI waveguides is characterized. Output CE values as high as -8.5 dB over 26 nm (pump power of 155 mW) generate high-quality idlers (OSNR$\geqslant$25 dB). Improvements in the power handling are expected to enable even higher CE, and thus idler OSNR values, as no signs of saturation are detected.

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