Phase sensitive amplification based on cascaded SHG/DFG process in a periodically poled lithium niobate waveguide

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Phase-sensitive amplifiers (PSAs) have long been known to offer the possibility of amplification with a noise figure below the 3 dB quantum limit of phase insensitive amplifiers (PIA) [1]. Other advantages of the PSAs are the potential for optical signal processing, including all optical phase regeneration of phase encoded signals, dispersion compensation and coherent wavelength exchange. PSAs are usually demonstrated using highly nonlinear fibres as the nonlinear element. However, the use of cascaded sum- and difference-frequency generation (cSFG/DFG) of second-order nonlinearities in periodically poled lithium niobate (PPLN) waveguides [3] offers a number of attractive features relative to corresponding fibre based PSA implementations including the prospect of compact devices, large operational bandwidths and importantly a far greater immunity to the effects of Stimulated Brillouin Scattering (SBS) of the pump beams which imposes performance limitations and adds complexity to silica fibre based PSA devices. Herein, we propose and demonstrate both theoretically and experimentally a new scheme for frequency non-degenerate PSA based on the cSHG/DFG process in a single PPLN waveguide. A theoretical model is developed for the quadratic cascading interaction and the corresponding calculated signal phase sensitive (PS) gain is plotted in Fig. 1(a) as a function of the relative phase amongst the three waves (pump power of 33dBm). The results show that the maximum signal gain is 19.0dB and 30.1dB for the crystal lengths (L) of 30 mm and 50 mm, respectively. These correspond to peak-to-peak gain differences of 41.3dB and 48.4dB, respectively. The results also clearly show that the gain increases as the crystal length increases due to the longer interaction length (maximum gain is proportional to the fourth-power of the crystal length). The validity and practicality of the approach are then confirmed in a proof-of-principle experiment using a 3-cm waveguide device operating at wavelengths around 1550 nm. Fig.1 (c) shows the measured and simulated gain profile as a function of the relative phase of the signals for a pump peak power of ~20dBm, confirming excellent agreement between them. While the maximum gain achievable was 0.65dB only (peak-to-peak signal gain variation of 3.4dB), the gain profile clearly indicates the phase-sensitive behaviour with a π-period as opposite to the PIA gain behaviour. Finally we investigate the broadband PSA operation, see Fig.1 (d). The measured PS gains are almost constant across the whole 16 nm wavelength range and the theoretically predicted device bandwidth of 88 nm can be obtained if the operating wavelength range of the tunable CW source used for the signal can be further increased.

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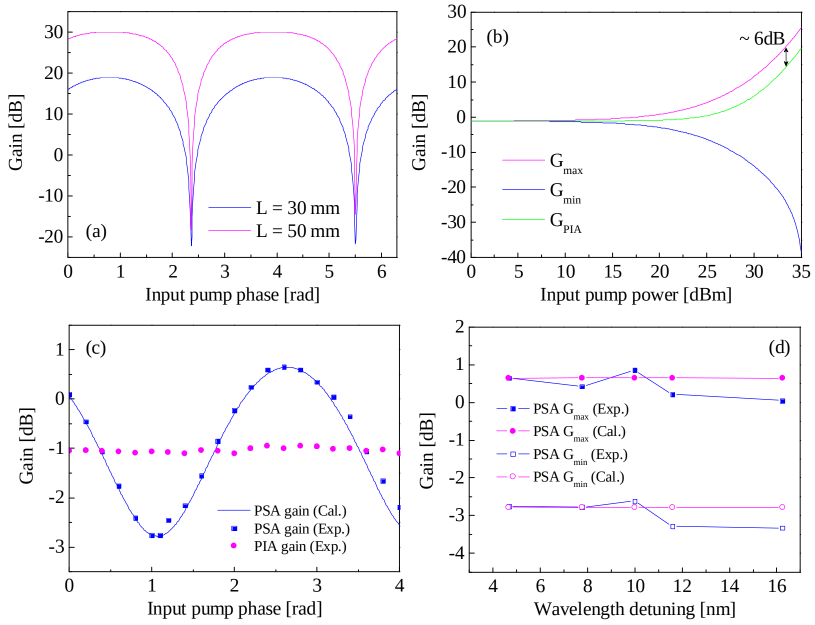

Fig. 1. (a) Calculated signal gain plotted as a function of the initial relative phase. (b) Variation of maximum, minimum PSA gain and PIA gain as a function of the input pump power for a crystal length of 30 mm. (c) Measured and calculated PS gain plotted as a function of initial relative phase for PIA and PSA. (d) Maximum and minimum PS gain as a function of wavelength.

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