Phase-locked parametric-down conversion inside soliton waveguides in LNOI films

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Abstract. We have observed for the first time a parametric down conversion process within a solitonic waveguide. This feature ensures an optimal mode-overlapping between the interacting waves. Moreover, the excited photorefractive nonlinearity enables a phase-locking regime that allows the temporal overlapping of the interacting pulses too. A broadband PDC is then possible within a waveguide without special needs for phase-matching and temporal sinchronisation.

1 Introduction

Parametric down-conversion (PDC) is a fundamental nonlinear optical process widely used for generating entangled photon pairs, a crucial resource for quantum technologies. Typically, efficient PDC requires phase matching, a condition that ensures momentum conservation and maximises conversion efficiency. However, recent advancements have demonstrated the possibility of using the phase-locking phenomenon in parametric processes [1-4], i.e. without strict phase-matching conditions, significantly broadening the design flexibility of integrated photonic systems. However, as much as we know, phase-locking was never observed in PDC before. Waveguide-based PDC offers a highly advantageous platform for both classical and quantum applications. The tight optical confinement in a waveguide enhances nonlinear interactions, both in terms of high intensity and mode-overlapping, allowing for higher conversion efficiencies even in the absence of traditional phase-matching constraints. Moreover, integrated photonics enables scalable, stable, and low-loss architectures, which are essential for practical implementations in quantum communication, quantum computing, and metrology. Beyond the traditional waveguides, soliton ones ensure optimal mode overlap and nonlinear self-alignment, especially in the femto-second pulse-duration regimes where the electro-optic nonlinearity may play a fundamental role in the phase-locking process. The ability to achieve efficient photon generation in compact, chip-scale devices represents a significant step towards fully integrated optical circuits, bridging the gap between fundamental research and real-world applications. Here, we performed a PDC process within a solitonic waveguides in a Lithium Niobate On Insulator (LNOI) film [5].

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2 Experiment and Results

An 8µm-thick film of LNOI was placed on a Peltier heater to generate a static pyroelectric bias in order to excite the photorefractive nonlinearity necessary to get spatial solitons. A high rep-rate train of femtosecond pulses at 400nm were focused onto the input face of the LNOI film and coupled inside. The nonlinearity compensates the linear diffraction inducing a transversal self-confined beam, with an associated photorefractive waveguide. Within the waveguide was coupled also a CW laser seed at 785 nm. At the output an Optical Spectrum Analyzer revealed the presence of 3 main frequencies, at 400nm, at 785 nm (amplified) and at 815 nm (generated), as shown in fig.1. The process is very far from the perfect phase-matching.

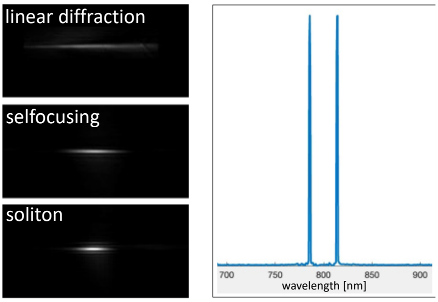

Fig. 1. left: soliton formation; right: IR spectrum outside the soliton waveguides showing the amplified seed at 785nm and the generated idler at 815nm.

3 Conclusions

We experimentally and numerically investigate the parametric down-conversion within a solitonic waveguide in LNOI film. The PDC process exploits a phase-locking between the pump and the generated pulses, enhancing the conversion efficiency and ensuring a process that requires neither temporal overlapping of femtosecond pulses nor perfect-phase matching which means easy to be realized with a broad band efficiency.

References

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