High-Gain Twin-Beam Generation in Waveguides: Experimental Characterization Using Cascaded Stimulated Emission

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Abstract: We introduce a new method for spectral characterization of twin-beam generation in waveguides, based on cascaded stimulated emission. We provide a complete and accurate experimental characterization of high-gain effects in a parametric down-conversion source.

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1. Introduction

The generation of twin-beams with up to tens of photon-pairs per pulse has been recently demonstrated using parametric down-conversion in waveguides [1], allowing for a new regime of quantum optics to be explored experimentally. In the high-gain regime, the description of twin-beam generation must consider the complex interplay of non-perturbative effects and parasitic nonlinear effects like self-phase modulation (SPM) of the pump, and cross-phase modulation (XPM) induced by the pump on the twin-beams. The spectral properties of twin-beam generation can be inferred by stimulated emission tomography (SET) [2], using the corresponding stimulated (seeded) process. In the case of parametric down-conversion, SET employs the difference frequency generation (DFG) signal. We note, however, that stimulated frequency generation also occurs in the same spatial mode as the seed field. In this work, we extend SET to include this same-mode emission. Our measurements of all stimulated emission processes allow us to experimentally explore high-gain effects in a waveguided ppKTP parametric down-conversion source, and characterize twin-beams with a mean number of photon-pairs up to 60 per pulse. The same-mode frequency generation can be interpreted as a cascaded stimulated emission, as illustrated in Figure 1, and its scaling with gain is different from that of the cross-mode process. Therefore, the ratio between same-mode and cross-mode intensity can be used to estimate twin-beam gain, in a way that is independent of experimental parameters such as efficiency and mode overlap. We show that we can accurately determine the effects of XPM and SPM using the information provided by the extended SET.

2. Results

Assuming negligible propagation loss, waveguided twin-beam generation is defined by a linear input-output transformation on creation and annihilation operators – s(i) stands for signal(idler) [3]:

$$a_{\mathrm{s}}^{(\mathrm{out})}(\omega) = \int d\omega'\, U^{\mathrm{s,s}}(\omega,\omega')\, a_{\mathrm{s}}^{(\mathrm{in})}(\omega') + \int d\omega'\, U^{\mathrm{s,i}}(\omega,\omega')\, a_{\mathrm{i}}^{\dagger(\mathrm{in})}(\omega'),$$
$$a_{\mathrm{i}}^{(\mathrm{out})}(\omega) = \int d\omega'\, U^{\mathrm{i,i}}(\omega,\omega')\, a_{\mathrm{i}}^{(\mathrm{in})}(\omega') + \int d\omega'\, U^{\mathrm{i,s}}(\omega,\omega')\, a_{\mathrm{s}}^{\dagger(\mathrm{in})}(\omega').$$

We scan a CW seed frequency and measure the stimulated emission spectral power, generating a 2D distribution for each pair of modes. Seeding mode x and measuring mode y, the result is proportional to the TF $U^{y,x}(\omega,\omega')$. The TFs can be computed by solving differential equations derived from Maxwell's equations [3]. The required physical parameters can be determined using cascaded stimulated emission, mostly in the low-gain regime [4]. In Figure 2, we show our measured stimulated emission spectral distributions, together with our calculated TFs. Our validated model indicates that SPM is the main source of degraded performance for our high-gain twin-beam source.

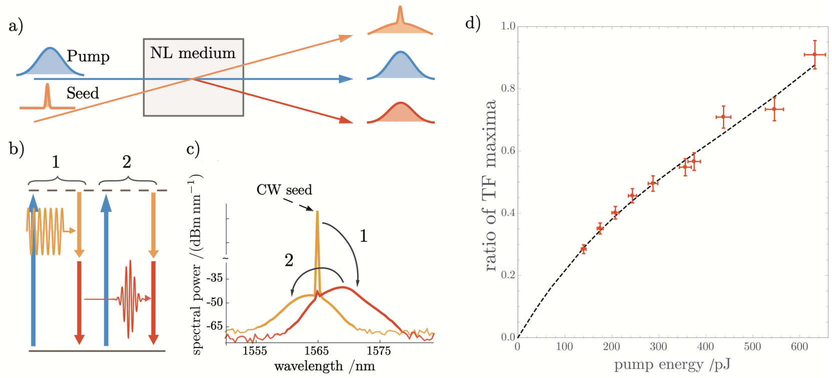

Fig. 1. a) Extended SET experiment. The spectral power of the pump and CW seed are shown as input. At the output, we have cross-mode frequency generation, as well as a broad-band 'pedestal' in the same mode as the seed field. b) The cascaded process that leads to same-mode frequency generation. In step 1, the pump and seed field generate stimulated emission in the cross-mode. In step 2, the pump and cross-mode emission generate stimulated emission in the same mode as the seed. c) Measured stimulated emission for our type II PDC source, with pumpe centered at 780 nm. Seeding at 1565 nm, we measured broadband signals in the opposite polarization (red) as well as in the same polarization as the seed (orange). d) Ratio of same- and cross- mode peak spectral power as a function of pump energy, showing that this ratio is a robust estimator of twin-beam gain.

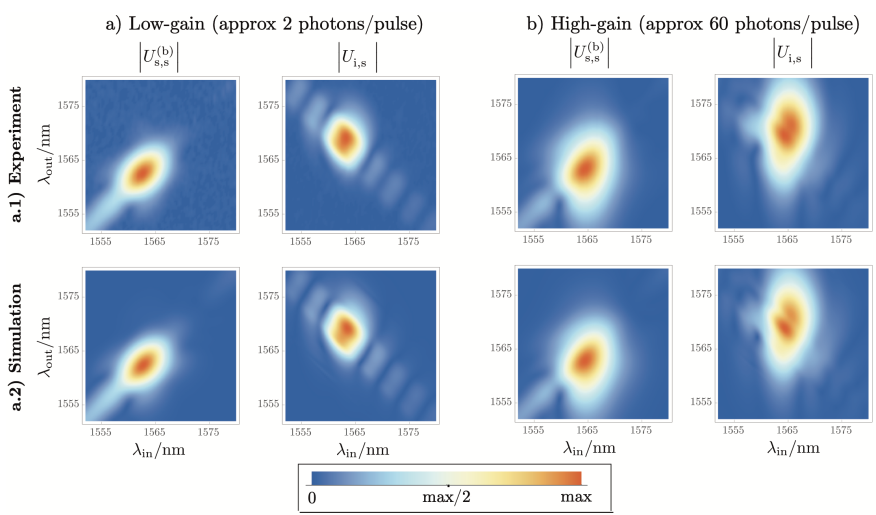

Fig. 2. TF absolute amplitudes. The high-gain distributions are broadened by non-parametric effects, shifted by XPM and distorted and broadened by SPM. The asymmetry of the same-mode TF is a signature of XPM.

References

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