Spontaneous high efficiency third harmonic generation in optical fibres

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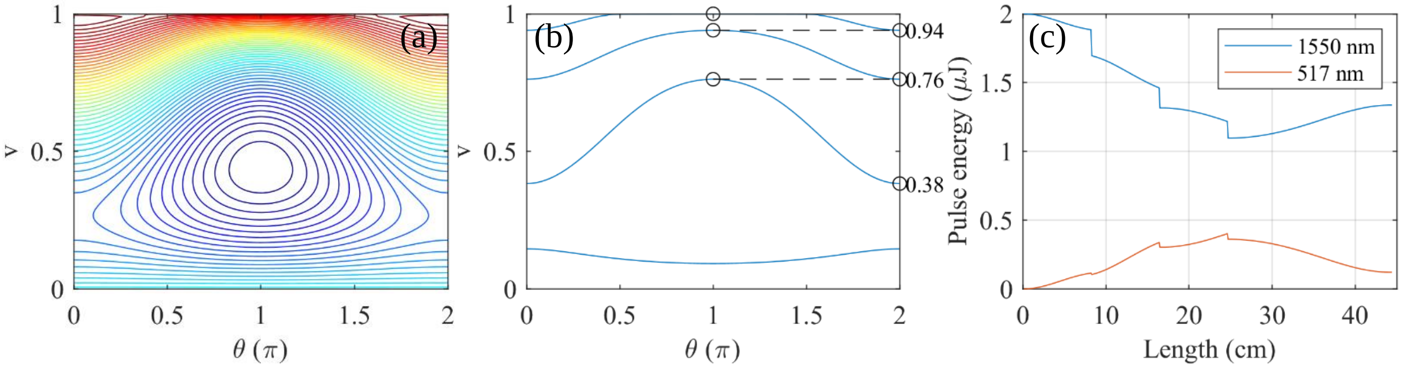
Unlike nonlinear second harmonic generation (SHG) and its reverse process (down conversion), which have found their way into many photonics and quantum optics applications, third and one-third (down conversion) harmonic generation (THG and OTHG respectively) have not been used in practice despite their potential unique applications in laser frequency translating and quantum optical devices [1]. THG and OTHG have not been demonstrated with practical efficiency in either bulk or guided geometries, mainly due to a demanding phase matching condition [2]. While it is possible to have phase matching between the fundamental and third harmonic wave in guided geometry, an engineered seed laser with a specific seed-pump phase locking condition is required to achieve high efficiency [3].



Here, we propose a scheme, based on which the efficiency of a spontaneously started THG process in an optical fibre can be significantly enhanced through a phase compensation stepladder process. The key concept of our approach is based on the Hamiltonian (the constant of the motion) of the THG and OTHG processes in optical fibres (Fig. a); for any initial value of $v_0 = P_1/(P_1 + P_3)$ and $\theta_0 = \phi_1 - \phi_3$, the pump and the third harmonic frequency laser follow a constant Hamiltonian contour as they propagate through the fibre [3]. The difference between the maximum and minimum values of v determine the highest efficiency for that contour. Starting with $v_0 = 1$, $\theta_0 = \pi$ on the contour associated with the spontaneous THG, top circle in Fig. b, we allow the laser beams to exit the fibre at $v = 0.94$ and acquire a π phase shift within a dispersive media (SiO2) before launching them into another fibre segment. With such a phase shift value, the THG/OTHG process follows the next contour which has a deeper trajectory in the v, θ plane and hence higher efficiency (Fig. b). This process can be repeated to achieve the highest THG/OTHG efficiency. In essence, we break the periodic behaviour of THG/OTHG power conversion by having a phase shift compensation between segments allowing us to achieve higher efficiencies every time. Fig. c shows THG efficiency of 45% of a 1 ns pulse at 1550 nm starting from a spontaneous process and after 3 fibre segments, including the propagation and coupling losses.

[1] C.W. Sandbo Chang et al., Phys. Rev. X 10, 011011 (2020).

[2] A. Cavanna et al., Optica, vol. 3, no. 9, pp. 952–955, Sep. 2016.

[3] S. Afshar V., M. A. Lohe, T. Lee, T. M. Monro, and N. G. R. Broderick, Opt. Lett., vol. 38, p. 329, 2013.