Efficient third harmonic Generation in Photonic Nanowires

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In a photonic nanowire the strong optical confinement allows for the phase matching of nonlinear interactions that would not normally be phase matched, while the large longitundal component of the electric field serves to further enhance the effective nonlinearity. Thus such waveguides are good choices for studying nonlinear effects such as third harmonic generation. In this paper we analyse third harmonic generation analytically and present the criteria for optimal harmonic generation. In addition we analyse the inverse process of 1/3 harmonic generation and show that efficient parametric amplifiers can be made which would be a high brightness source of entangled photons for producing GHZ states.

Third harmonic generation can be described by the normalised set of equations[1,2]:

$$\frac{dv}{d\tau} = -2v\sqrt{v(1-v)}\sin\theta \tag{1}$$

$$\frac{d\theta}{d\tau} = a + 2bv + (4v-3)\sqrt{\frac{v}{1-v}}\cos\theta \tag{2}$$

where v is the normalised power in the fundamental mode and is θ the relative phase of both fields. Here we have assumed that there is a lossless medium and the two parameters a and b depend on both the geometry of the fibre and the total input power. The parameter τ measures the propagation distance normalised by the input power. Importantly these equations can be derived from a Hamiltonian H which is independent of z and so is a conserved quantity. Using this conserved quantity allows us to solve the equations analytically in terms of elliptic integrals. However in most cases contour plots of H reveal the important dynamics. This can be seen in Fig. 1 which shows the case when $a = -0.02$ and $b = 0.2$. Importantly the dynamics are determined by the position of the stationary points which splits the plane up into distinct regions bounded by separatrix trajectories. Of particular interest is case where initially all of the power is in the third harmonic and we are looking to generate a strong beam at the fundamental. Such a situation would be useful to create mid -IR sources from 3 to 6 microns using fibre lasers (either Yb. doped or Thulium). More-over by manipulating the position of the stationary points we can create highly nonlinear amplifiers which would be useful for coherent communication systems since they could amplify light in one quadrature but not in others. An example of this is shown in Fig. 2 which shows that by varying the input power slightly the amplifier gain can vary by more than 30dB.

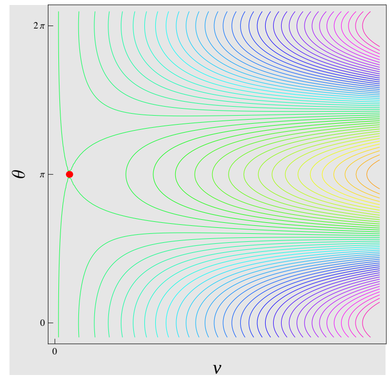

Fig. 1. Contour plot of the Hamiltonian when $a = -0.02$ and $b = 0.2$

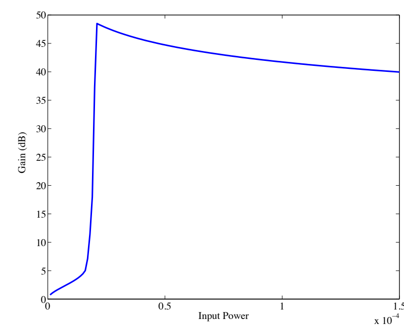

Fig. 2. Maximum parametric gain for various input powers when $a = -0.02$ and $b = 0.2$ for a $0 < v < 1.5\times10^{-4}$.

A practical problem with using photonic nanowires for phase-matched interactions is that the tolerances on the diameter are extremely tight. So for example while tapering standard fibres down to sub-micron diameters phase-matched third harmonic generation can be seen over a 100nm bandwidth with each wavelength being generated at a specific point along the fibre. Thus generating long interaction lengths is difficult in a standard configuration. One way around this is to put the tapered fibre into a resonator allowing the 3rd harmonic efficiency to improve dramatically at the expense of the bandwidth. We have started modeling this theoretically and results of this will be presented at the conference.

1. J. Armstrong, *et al.*, Phys. Rev. 127, 1918 (1962).
2. V. Grubsky *et al.*, Opt. Exp. 13, 6798 (2005).