Raman-induced limits to efficient squeezing in optical fibres

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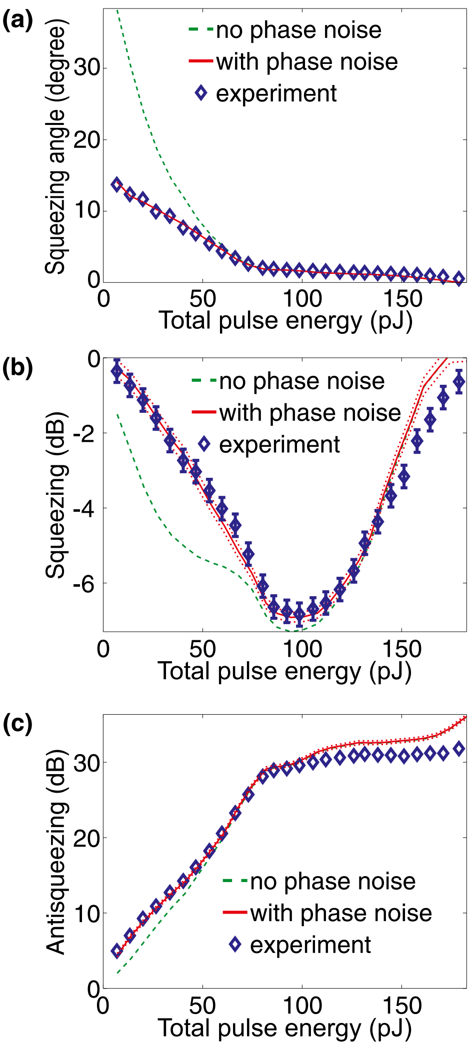
We report new experimental measurements and quantum simulations of polarization squeezing using ultrashort (FWHM 140 fs) photonic pulses in a single pass of a birefringent fiber. We measure what is to our knowledge a record squeezing of -6.8 $\pm$ 0.3 dB in optical fibres, which when corrected for linear losses is -10.4 $\pm$ 0.8 dB. The measured polarization squeezing as a function of optical pulse energy, spanning a wide range from 3.5-178.8 pJ, shows very good agreement with the quantum simulations. Furthermore, the experiments confirm the theoretical prediction that Raman effects limit and reduce squeezing at high pulse energy [1].



Experimental and simulation results for the (a) squeezing angle, (b) squeezing and (c) antisqueezing for a 13.2m fibre are plotted in the figure as functions of the pulse energy. Error bars on the squeezing data indicate the uncertainty in the noise measurement; for the antisqueezing, the error bars were too small to be plotted. Dotted lines indicate the sampling error in the simulation results.

The quantum dynamics of radiation propagating in a single-mode optical fibre were simulated using a truncated Wigner phase-space method[2]. The simulations included the effects of dispersion up to the third order and the $\chi^{(3)}$ nonlinearity as well as the Raman coupling to thermal phonons. The Raman fraction of the nonlinearity is estimated as 15% and the photon number ($2\bar{n}$) in a fundamental soliton pulse as 4.5 $\times$ 10^8. The excess phase noise, such as depolarizing guided acoustic wave Brillouin scattering (GAWBS)[3], is estimated by fitting the simulated squeezing angles to the experimentally measured squeezing angles as shown by red solid line in Fig. (a). After taking the 13% linear loss into account, the theoretical results for squeezing and antisqueezing which are given in the Fig. (b) and (c) by red solid lines achieve a very good match with the experimental results. The effect of the GAWBS is seen to be a reduction in squeezing for lower pulse energies.

As the optical energy goes beyond 98.6 pJ, the squeezing is reduced, eventually reaching the shot noise limit (SNL), and the increment of antisqueezing slows down to a plateau area. Above the soliton energy ($\approx$120 pJ), the deterioration of squeezing is attributed to the Raman effects since this deterioration does not appear in simulations with only electronic nonlinearity and dispersive effects; in addition, the third-order dispersion (TOD) has a noticeable effect on the squeezing at high energies.

References

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