Raman scattering and four-wave mixing

From fundamentals to fibre lasers

JOCHEN SCHRÖDER

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Supervisor:
Stéphane Coen

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Abstract

Raman scattering and four-wave mixing are two fundamental nonlinear phenomena present in optical fibres with important implications for applications in fields ranging from modern telecommunications networks to biophotonics.
This thesis investigates three situations when these two phenomena interact: Firstly we investigate the interplay of multiple four-wave mixing processes using coherent and incoherent pump waves in the presence of Raman scattering. We experimentally demonstrate that despite the requirements of phase-matching conditions it is possible to observe multiple phasematched and non-phasematched four-wave mixing processes. Furthermore we show that an incoherent light wave provided by amplified spontaneous emission noise can act as an effective pump wave for degenerate four-wave mixing.
The main part of the thesis is occupied by the investigation of a mode-locked Raman fibre laser. The use of dissipative four-wave mixing for the passive mode-locking technique in combination with Raman scattering as the gain mechanism offers the possibility of achieving ultra-high repetition rates at very high average output powers. We experimentally demonstrate the mode-locked operation of the laser at 500 GHz and achieve an average output power of almost 1 W. Additionally we examine the key limitation of the laser which is supermode noise caused by mode-locking the laser at very high harmonics of the cavity resonance frequency. In order to gain qualitative insight into the influence of supermode noise on the laser dynamics we create a laser model which takes account of supermode noise. Furthermore we design a scheme to reduce supermode noise using additional subcavities, and evaluate the scheme using a lower repetition rate laser. We show that by including the subcavities into the setup the amount of supermode noise can be reduced by at least a factor 100.
Lastly we introduce a novel method to measure the noise fluctuations of continuous wave lasers at timescales prohibiting the use of traditional noise measurement techniques. The noise is measured using a technique which transfers the fast noise from the continuous wave laser to a low repetition rate mode-locked laser which can be measured with traditional methods. We demonstrate that a continuous wave Raman fibre laser exhibits ultrafast, high contrast intensity fluctuations at timescales of tens of Gigahertz.
This work has led to three publications and six conference presentations.

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