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Mid-infrared supercontinuum generation seeded by geometrical parametric instabilities amplified in TDFA

Geoffroy Granger[1], Yann Leventoux[1], Alessandro Tonello[1], Stefan Wabnitz[2], Vincent Couderc[1], and Sebastien Fevrier[1]

[1] *Université de Limoges, XLIM, UMR CNRS 7252, 123 Av. A. Thomas, 87060 Limoges, France*
[2] *Dipartimento di Ingegneria dell'Informazione, Elettronica e Telecomunicazioni, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy*

sebastien.fevrier@unilim.fr

Abstract: We demonstrate thulium-doped fiber amplification of sub-nanosecond pulses generated at 1870 nm by exploiting spatiotemporal nonlinear dynamics in graded-index multimode fibers. The microjoule pulses at 1870 nm trigger supercontinuum generation in InF_3 fiber.

1. Introduction

High-energy transform-limited pulses with tens to hundreds of picosecond duration in the near to mid-infrared are particularly interesting for many applications such as polymer or semi-conductor micro-processing, or to act as a pump for mid-infrared supercontinuum generation. However, these temporal characteristics are difficult to reach because of the Q-switching process, which limits the pulse generation in the nanosecond scale. Whereas mode-locking techniques deliver short pulses in the picosecond/femtosecond domains.

In this communication, we present a novel approach to generate high-energy sub-nanosecond pulses, by exploiting complex spatiotemporal nonlinear dynamics in graded index (GRIN) multimode fibers. Because of their particular core refractive index profile, the intermodal beating in GRIN fibers gives birth to a longitudinal modulation of the multimode field, producing a periodic self-imaging [1,2] of the Gaussian input beam. When combined with the Kerr nonlinearity, the self-imaging process leads to a periodic nonlinear refractive index modulation, which allows for quasi-phase-matching of parametric processes, both in the spatial and in the frequency domains. Thus, spatial self-cleaning and geometric parametric instability may be observed, and generate either a spatial beam reorganization [3] or a series of sidebands [4], which are detuned by more than 100 THz from the pump. It has also been demonstrated that this nonlinear frequency conversion regime is accompanied by a strong temporal shortening of pulses emerging from the sidebands, while keeping unchanged the initial repetition rate of the pump source. Moreover, the spectral detuning, which is determined by the optogeometrical characteristics of the fiber, can be easily matched to the spectral gain of several ions used for amplification in optical fibers [5].

Here, we describe how to optimize the refractive index profile of a GRIN fiber and the parameters of the pump laser, in order to drive the emission of sub-nanosecond pulses in the thulium-doped fiber amplifier (TDFA) emission band. Next we demonstrate the efficient pulse amplification of these spectral emissions in a core-pumped TDFA. We also illustrate the strong applicative potential of our amplified source, by generating a mid-infrared supercontinuum spanning from 1800 to 3500 nm in fluoride fiber.

2. Experimental results

In Fig. 1 we depict the experimental setup to produce sub-nanosecond pulses at 1870 nm from a GRIN multimode fiber, and to amplify the pulse energy to the microjoule level in a TDFA.

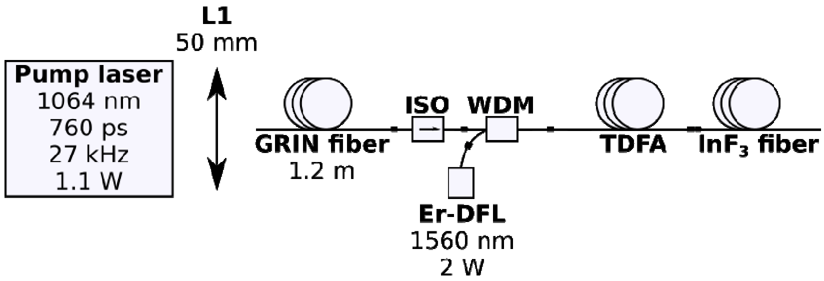

Fig. 1. Schematic of the laser setup

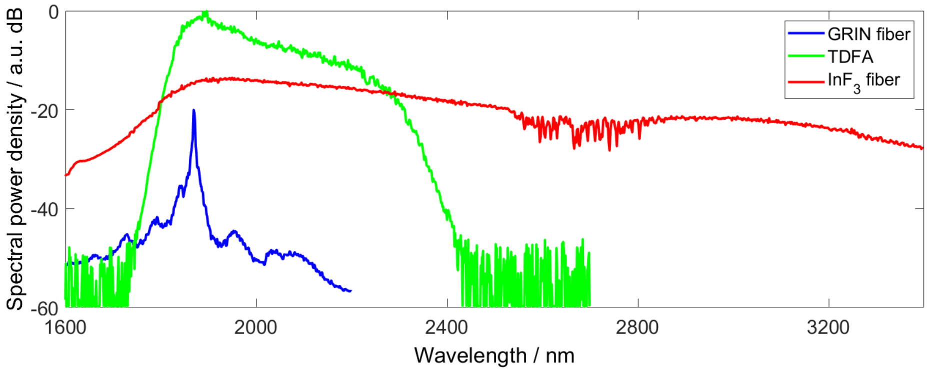

Fig. 2. Measured spectra.

We used an amplified microchip Nd:YAG laser, delivering pulses of 740 ps at 1064 nm (27 kHz), to pump two different GRIN multimode fibers with 52 µm and 62.5 µm core diameters, respectively. The pump beam triggers the generation of sidebands at 2070 nm in the 52 µm GRIN fiber, and at 1870 nm in the 62.5 µm GRIN fiber. In the following, we restrict our analysis to the generation of sidebands in 62.5 µm GRIN fiber, because the 1870 nm line is well-suited to seed a core-pumped TDFA. The amplifier is based on a single-mode, large core area TDF, pumped at 1560 nm by a cw Erbium-doped fiber laser delivering up to 2 W. The pump and seed beams are multiplexed through a 1560/1900 wavelength division multiplexer. Amplification of the generated sidebands at 1870 nm yields pulses with several microjoules of energy. Finally, we demonstrate the suitability of our new approach to mid-infrared supercontinuum generation, by launching the amplified pulses in an InF_3 fiber (Le Verre Fluoré). The spectrum spans up to 3400 nm, which is the limit of the optical spectrum analyser (Yokogawa).

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3. References

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