OTDR technique for the characterization of supercontinuum generation along optical fibers

G. Ravet[1], A. Mussot[2], M. Wuilpart[1], A. Kudlinski[2],
C. Caucheteur[1], and P. Mégret[1]

[1] Faculté Polytechnique de Mons, Service d'Electromagnétisme et de Télécommunications, Boulevard Dolez 31, 7000 Mons, Belgium
[2] Université de Lille 1, Laboratoires PhLAM et IRCICA, 59655 Villeneuve d'Ascq Cedex, France

We present a new technique that allows to characterize the supercontinuum generation process along an optical fiber. This non destructive method is based on a tunable and wavelength selective optical time domain reflectometry set-up It allows to examine the spectral balance between the different linear and non linear effects that take place when a high power pulse is launched in the fiber and give rise to the generation of the frequency continuum. This method can be used to optimize the pump power according to the length of the fiber and the desired supercontinuum shape..

Introduction

The supercontinuum generation (SCG) consists in a dramatic spectral broadening of the spectrum of an intense light travelling in a medium [1]. It arises from the interplay between several nonlinear optical effects, among others by self phase modulation, modulation instability (MI), four-wave mixing and/or Stimulated Raman scattering [2]. This phenomenon finds application in numerous domains such as spectroscopy, medicine or optical telecommunications for example. During the past decade, SCG has been extensively studied in the case of optical fibers since the light confinement in the core provides a high nonlinear efficiency. More particularly, the case of photonic crystal fibers was of great interest in the comprehension of SCG since the dispersion that plays an important role in the nonlinear interactions can be tailored adequately with respect to the wavelength of the light used as the initial source, called the pump [3].
Although it is easy to measure the spectrum at the end of the fiber, up until now the only means to have an insight of what is happening inside the fiber, was the cut-back method that leads to the destruction of the fiber. In this paper, we propose an innovative experimental method to measure the spectral evolution of the light along its length, based on the optical time domain reflectometry technique.

Experimental Set-Up

The experimental set-up that we developed in order to measure the spatial distribution of the supercontinuum generation along an optical fiber is derived from the one we proposed in [4] and is depicted in Figure 1. The principle relies on replacing the low power broadband LED of the OTDR by a high peak power monochromatic tunable source. For that purpose we modulate a tunable erbium doped fiber laser boosted by an optical amplifier (EFA1) with an acousto-optic modulator. The modulation scheme is the same as the one of the OTDR which is decoded by a photodiode toward which the OTDR pulses are directed through circulator 1. The modulated signal is then amplified again by EDFA2 to reach high peak power. The noise generated by the amplifier is removed with a tunable band pass filter (TBF1). The pulses are then launched into the fiber under test by circulator 2. The Rayleigh backscattered signal generated by the light inside the fiber is then directed toward the OTDR after passing through both circulators and being filter by TBF2 that allows the wavelength selection of the wave to be monitored.

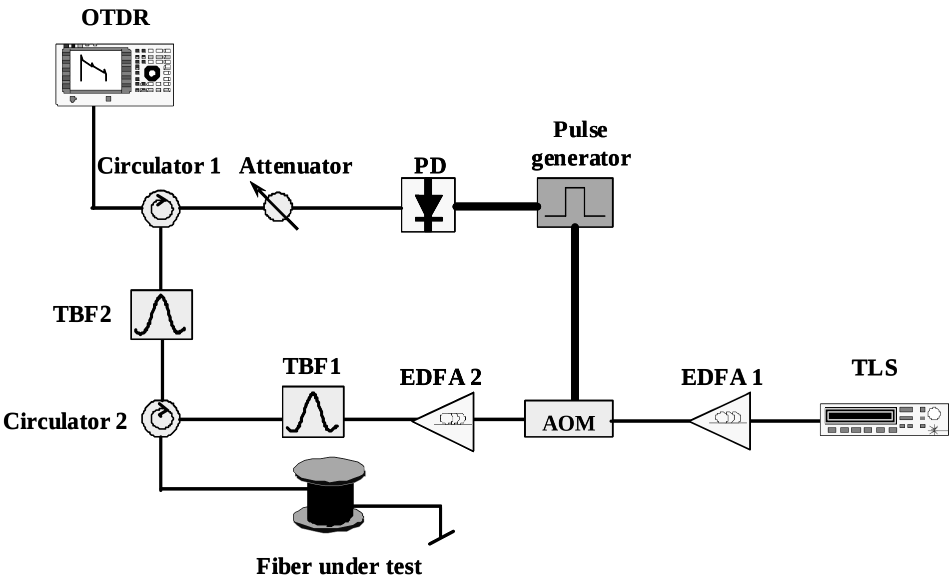

Figure 1: experimental set-up

Pulse width was set to 275 ns, giving a 27 m spatial resolution. Such a long duration allows us to consider that the regime is quasi-continuous. The average power was measured to be of the order of 100 mW. As the repetition rate is of the order of the kilohertz, this allows us to roughly estimate the peak power of the pulses to be around 1 W. The 500 m long highly nonlinear dispersion shifted fiber (HNLF) has an attenuation of 0.6 dB/km, a nonlinear coefficient of 20 /km/W and a zero dispersion wavelength of 1555 nm. The pump wavelength used in the experiments was 1566 nm, in the anomalous dispersion regime of the fiber.

Results and discussion

In order to measure the optical spectrum, the repetition rate was set to 20 kHz. The output spectrum is shown in Fig. 2

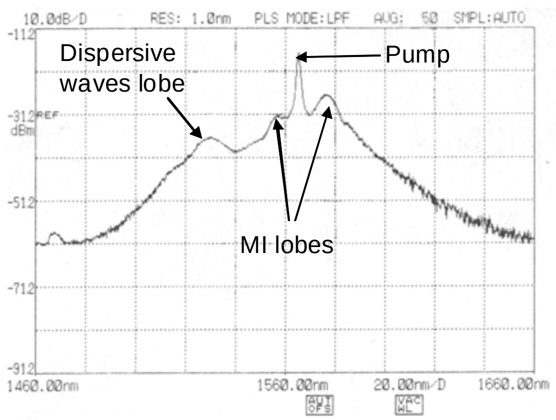

Figure 2: output spectrum of the SCG obtained with an optical spectrum analyzer

In Figure 3 we present the result of the distributed measurements of these particular wavelengths. On the three curves generated by the nonlinearities of the fiber, one can notice a plateau at the beginning of the fiber before that the power starts to grow. It is due to the backward spontaneous Raman scattering generated by the high peak power pulse.

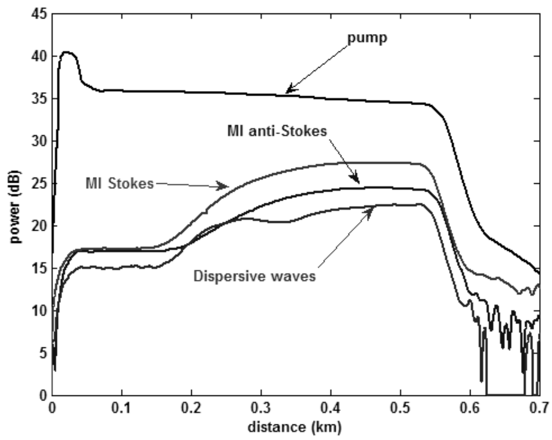

Figure 3: OTDR traces for the most noticeable feature in the spectrum

The pump power undergoes 1.5 dB losses instead of 0.3 dB. This is due to the depletion by the nonlinear effects generation.
The asymmetry between the two MI lobes is due to the effect of the dispersion slope.
With a systematic measurement of the power distribution by tuning the TBF2 with 1 nm step, we could draw a map of the supercontinuum generated between 1530 and 1600 nm. This map is shown in Fig. 4, where the first and last 50 m have been removed to have a better contrast y avoiding the fiber ends reflection peaks.

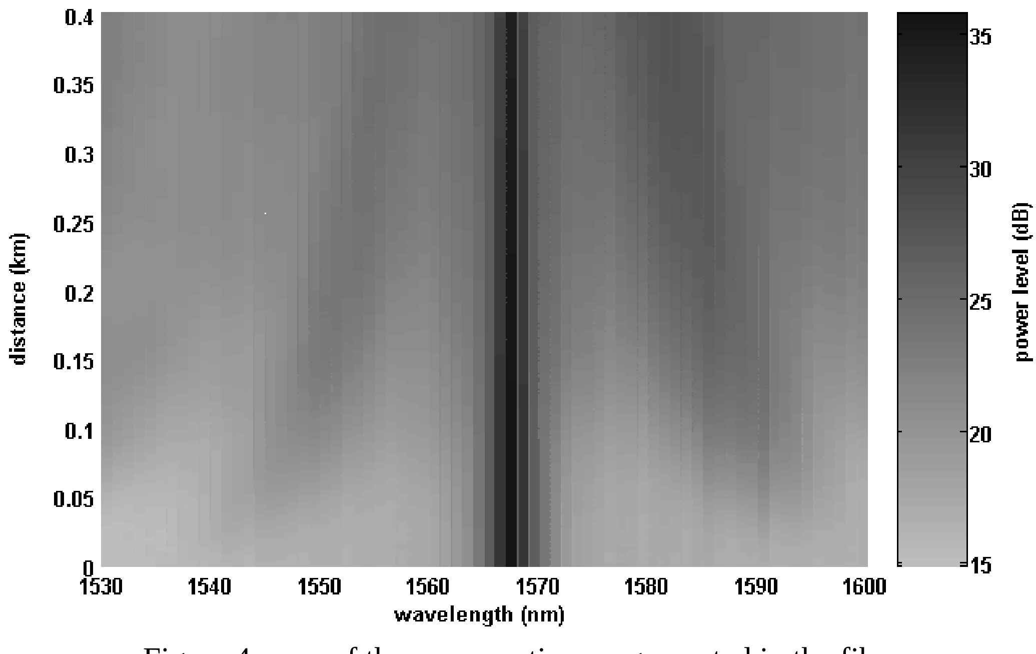

Figure 4: map of the supercontinuum generated in the fiber

One can notice that the modulation instability lobes central frequency difference with respect to the pump tends to decrease during the propagation.
In Figure 5, we show the output spectrum obtained with our technique. It is in good agreement when compared with the one obtained by a traditional method shown in Fig. 2, what validates our technique.

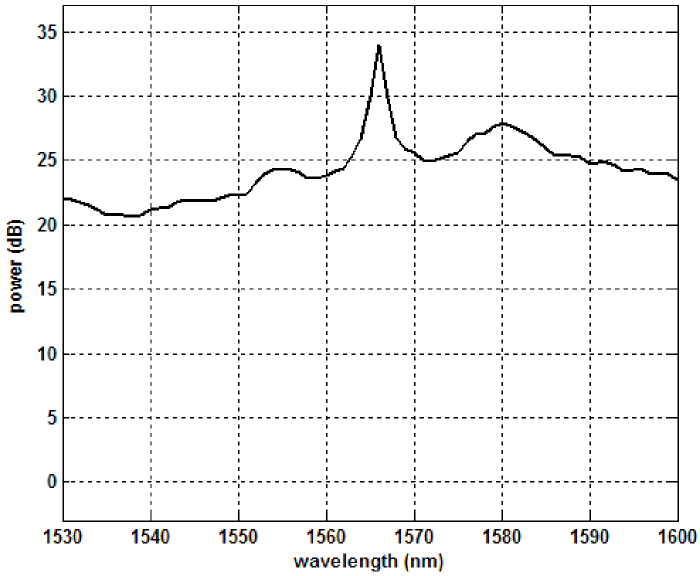

Figure 5: output spectrum of the supercontinuum obtained with the OTDR

Conclusions

In this paper, we have demonstrated a non destructive method for the characterization of the supercontinuum generation along optical fiber. We have shown a map of the SCG around 1566 nm in a highly nonlinear dispersion shifted fiber.

Acknowledgements

This research was supported by the Interuniversity Attraction Poles program of the Belgian Science Policy Office, under grant IAP P6-10 «photonics@be». The authors are grateful to Sumitomo Corporation for lending the fiber on which the tests were performed. The authors thank Olivier Aubry for technical support.

References

[1] Alfano, R.R. and S.L. Shapiro, “Emission in the region 4000 to 7000 Å via four-photon coupling in glass,” Phys. Rev. Lett. 24, pp. 584-587, 1970.

[2] G.P. Agrawal, Nonlinear Fiber Optics, Fourth Edition, Academic Press, 2006.

[3] J.M. Dudley, G. Genty, and S. Coen, “Supercontinuum Generation in Photonic Crystal Fiber,” Review of Modern Physics, vol. 78, pp. 1135-1176, 2006.

[4] G. Ravet et Al., “OTDR technique for the characterization of FWM processes in optical fibers”, IEEE Laser and Electro-Optics Society Symposium - Benelux Chapter, pp. 203-206, Bruxelles, Belgium, 17/12-18/12, 2007.