Distributed spectral measurement of supercontinuum generation along an optical nanofiber

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Abstract: this work presents preliminary experimental results concerning distributed measurements along an optical nanofiber of the generation of a supercontinuum in the visible range, for a spatial and spectral dynamics analysis.

1. Introduction

The generation of spectrally-broad single-mode supercontinuum (SC) light in optical fiber is well studied in the literature [1]. Indeed, SC has been the subject of various studies in a wide variety of nonlinear media, including solids, liquids and gases, and various types of waveguides, such as optical fibers in particular photonic crystal fibers (PCF) or sub-micrometric tapered fibers called nanofiber [1,2]. However, the spectral evolutions of the SC studies are mainly limited to the measurements at the waveguide output as a function of the injected power, and numerical simulations to predict the longitudinal propagation of the field along the fiber. Therefore, there is no experimental investigation of the SC generation along an optical nanofiber. For that purpose, we have recently developed a non-destructive and non-invasive experimental method in order to characterize spatially and spectrally the guided light along an optical waveguide [3]. By using this method, we present in this paper preliminary results of a distributed longitudinal measurement of SC generation along a nanofiber of millimeter length and sub-micrometric size.

2. Experimental setup and results

The experimental setup is based on the detection of far-field right-angle Rayleigh light scattering radiated out the waveguide using a micro-spectrometer [3] allowing a high spatial resolution given by the confocal microscope, and a high spectral resolution given by the spectrometer. Notch filters are used to remove the pump spectral components and to allow simultaneous Stokes and anti-Stokes measurements. The waveguide studied in this work corresponds to a nanofiber manufactured by heating and pulling a standard single mode fiber in visible wavelength range (SM450) until its diameter has reached a target value. After the tapering process, the nanofiber have a uniform waist of about 690 nm over 20 mm long accurately measured by Brillouin scattering method and SEM [3,4]. The nanofiber region is connected to the untapered fiber by taper transitions of 37 mm long each (Fig. 1(a)). After manufacturing process, the nanofiber is placed inside a closed transparent box in order to protect it from external air vibrations and to reduce any kind of contamination. The optical losses just after manufacturing were measured at 532 nm of wavelength and equal to 0.32 dB. This low level of losses ensures that the transitions are adiabatic at that wavelength. The waveguide is pumped at 532 nm frequency-doubled Nd:YAG laser source, with a repetition rate of 200 kHz, a 36 ps of pulse duration and a peak power of around 340 W. The laser beam is first injected in a small core fiber (SM600), connected to the SM450 fiber in order to control the injection preferentially in the fundamental mode of the non-stretched part of the SM450 fiber.

Fig.1(a) shows the locations of the different spectra performed along the waveguide either with the OSA (spectra 1 and 5) or with our technique (spectra 2 to 4), and Fig. 1(b) shows the corresponding spectra. First, due to the weak scattered intensity with a picosecond laser source, the exposure time for the spectrometer detector is typically 3 min for the two spectra 3 and 4, and 10 min for the spectrum 2. This difference of duration is explained by the fact that the standard fiber core presents a very low scattering level compared to the scattering at the nanofiber level [5]. It is important to note that the experimental data were recorded in the same experimental conditions with any normalization or correction of the intensity of the different spectrums. Therefore, the evolution of the scattered intensity represent the real evolution of the SC along the waveguide.

Figure 1(b) shows that the spectrum is developed in both Stokes and anti-Stokes regions between the end of the SM600 fiber and the input side of the non-stretched part of the taper (cyan and green spectra). This feature is due to the propagation of the high optical power of the guided mode along of about 1 m fiber with a small effective area (SM450), which increases the field intensity and therefore the nonlinearity. After propagation along the first transition, the recorded spectrum at the end of the transition 1 (spectrum 3) is well developed in the anti-Stokes region without any significant change for the spectral components in the Stokes region. This is due to the dispersion variation along the nanofiber with a zero dispersion wavelength decreasing from 1300 nm to 490 nm.

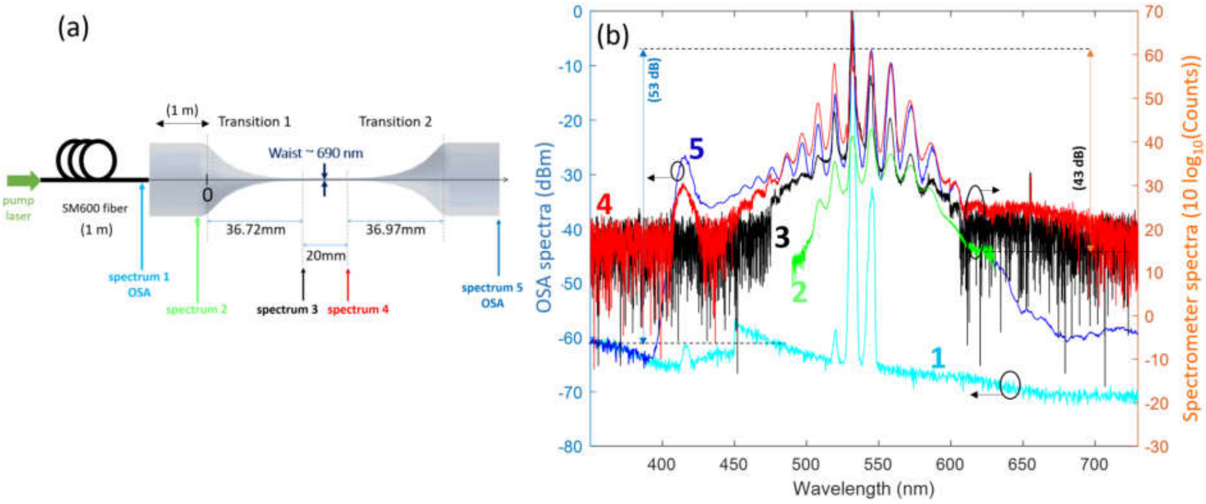

Fig 1. (a) geometrical data of the nanofiber, and (b) longitudinal evolution of the SC along the nanofiber.

This process seems to appear at the end of the transition 1 as a measurement in the middle of the transition 1 (not shown here) presents a spectrum quite similar to spectrum 3. After the propagation along the nanofiber, the spectrum 4 shows the presence of a dispersive wave located at a wavelength of about 415 nm. This dispersive wave can be predicted by analytical phase matching equation with the dispersion coefficients of the nanofiber. Moreover, the comparison between the spectrum 4 and the spectrum 5 shows that the whole features of the SC spectrum are already present at the end of the nanofiber region, a small difference is nevertheless observed in the anti-Stokes region certainly due to the difference of the dynamics of the measurements for our system (43 dB) in comparison to the dynamics obtained with the OSA (53 dB). This observation indicates that the influence of the second transition is weak or even negligible in the generation of the SC, and that, even with a small length of 20 millimeters, the large nonlinearity and the specific dispersion at the level of the nanofiber play a key role in the development of the whole SC features. In order to confirm these observations, we will perform numerical simulations based on the nonlinear Schrödinger equation, by including the two transitions and the nanofiber in order to take into account the continuous evolution of the linear and non linear parameters of the whole waveguide.

3. Conclusion

Primarily results provide for the first time to our knowledge distributed measurements for the evolution of a SC along a tapered fiber with a sub-micrometric diameter and millimetric length. This work shows the important role of the input transition and the nanofiber region on the SC generation due to the management of the dispersion and the large increase of the field intensity due to the strong confinement. It is noteworthy that the non-destructive and non-invasive experimental method can be used for other nonlinear optical waveguides working in nominal operation.

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4. References

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