Supercontinuum Generation in Standard Telecom Fiber Using Picoseconds Pulses

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ABSTRACT

We reported Supercontinuum (SC) generation in standard telecom fiber using picosecond pulses of microchip laser. The pulses width is 700 ps at 1064 nm, using 57 m long of standard fiber, and the spectra extend from 700 to above 1700 nm, some 100 nm further into the visible. The physical processes leading to the formation of the continuum spectrum were studied by monitoring the growth of the SC while increasing the input power. The coupling efficiency of ours experimental setup between the microchip laser and the telecom fiber helped us to obtain this wide spectrum.

1. INTRODUCTION

As it is known SC generation is experiencing a boom thanks to the discovery and production of a new type of optical fibers, photonic crystal fibers (PCF) or microstructured fibers. The production of these devices requires high-cost technology, as expensive laboratory equipment and material are necessary, and those are usually not easily accessible. Supercontinuum (SC) generation through a standard fiber is a topic that has not been analized in detail, however, the development of devices capable of providing the power required to induce nonlinear phenomena in telecom fibers allowed that research of SC generation in this kind of fiber again began to have a big boom.

Laser sources based on passive mode-locked technique [1], Nd:YAG lasers [2] and microchip lasers [3] are axamples of pump sources used in standard fibers in SC generation. SC generation study is of great importance in wavelength tunable sources [4], optical metrology [5] and low noise sources for the characterization of devices [6]. Input factors (pumping) that are associated with nonlinear effects that occur during SC genration in optical fibers are the pulse width, pump power and the dispersion parameter of the group velocity β_2 . Therefore, one can conclude that progress in the field of SG is due in large measure to the remarkable advancement in the features provided by new pumping sources can be found on the market, features such as: spectral width and the level of power supplied.

We know that SC generation involves a series of nonlinear phenomena, such as: the SRS effect, modulation instability (MI) and four wave mixing (FWM), self-phase and cross-phase modulation (SPM and XPM), as shown in various papers published about the topic [7-9]. When pumping with sub-ps pulses, the nonlinear mechanism that starts spectral broadening is SPM consequently amplified by SRS. This requires ultrashort pulses with duration ranging between ~10 and 100 fs with a very high peak power. The propagation media to generate SC spectra can be PCF, highly non-linear fiber (HNLF), zero dispersion fiber or standard fiber. If now pico- or nanosecond pulses, or even a CW signal is used as the pump, SC generation involves modulation instability which manifests itself spectrally by the appearance of two side lobes on either side of the pump, whereas in the time domain a bunch of ultrashort pulses is formed. In general, the phenomena described above are the result of the interaction between nonlinear and dispersive effects [10]. Once solitons are formed Raman SFS takes place, resulting in a widening of the input spectrum to longer wavelengths in the order of several tens or hundreds of nm.

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In this work we propose the use of pulses with duration of ~700 ps generated by microchip laser with a central wavelength of 1064 nm, to seed SC generation at shorter and longer wavelengths in a piece of telecom fiber. The final spectrum extend from 700 nm to above 1700 nm (~1000 nm of spectral width), the OSA upper bandwidth limit, assuming that the SC actually extends well beyond the range that can be measured by the OSA. We studied in detail the physical processes leading to the formation of the continuum spectrum by monitoring the growth of the SC while increasing the input power in the ~57 m of telecom fiber. The coupling efficiency of ours experimental setup between the microchip laser and the telecom fiber helped us to obtain this wide spectrum. Finally, we show that the SC spectrum obtained present a high flatness in a relatively very short length of conventional fiber, using low average pump power and with a low demand on the pumping wavelength, as we use the most common wavelength of optical communication (in the 1550 nm region), well into the anomalous dispersion region of the fiber.

2. EXPERIMENTAL SETUP

A microchip laser emmiting pulses at 1064 nm with time duration of ~700 ps was used as the pump in the piece of standard fiber. Fig. 1 shows the experimental scheme used in this work, the use of an attenuator of variable density allowed obtaining an average power between 0 and ~3.8 mW at the fiber input. Adjusting the density of attenuator we measured with the OSA the output spectrum for different values of average power at the fiber input in order to study the physical processes leading to the formation of the SC spectrum by monitoring the growth of the SC while increasing the input power.

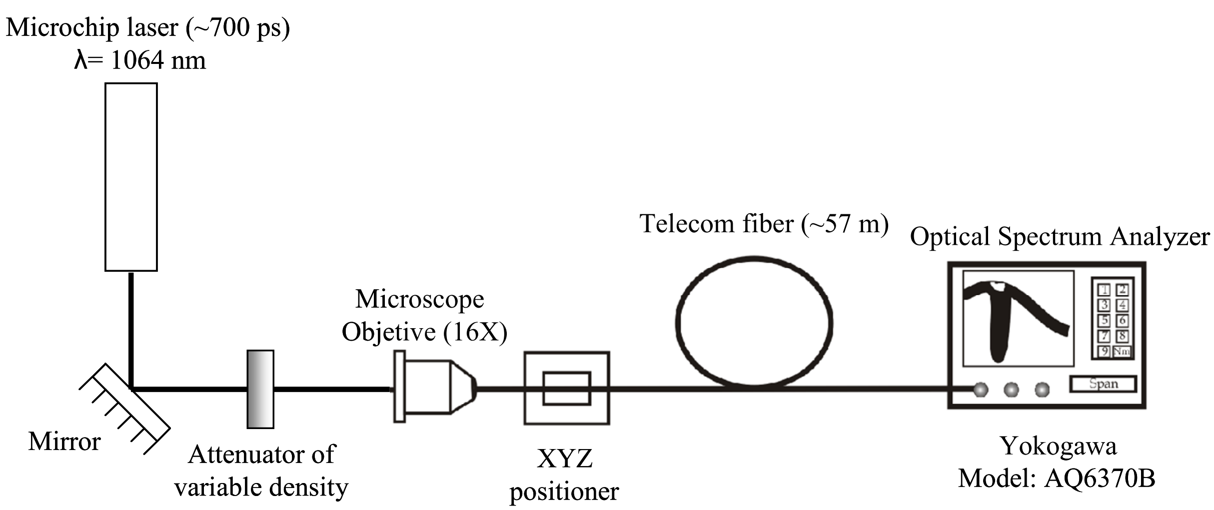

Figure 1. Experimental setup.

Experimental setup shown in Fig. 1 is composed also of a microscope objetive with a magnification of 10X and a XYZ positioner, both elements allow proper alingment between the laser beam and the fiber input. A piece of ~57 m of standard fiber was used in the scheme initially, then the section of optical fiber was reduced to smaller length in order to study the behavior of the spectra obtained at different lengths of fiber (shown in experimental results section). The spectra were measured by Optical Spectrum Analizer (OSA) for a range of 600 nm to 1700 nm obtaining the evolution of the SC spectrum for differents lengths of optical fibers to various input powers.

3. EXPERIMENTAL RESULTS AND DISCUSSION

SC generation consisted of the widening of an input pulse produced by microchiplaser. Fig. 2 shows the input spectrum and this is reference signal which will be used to observe the evolution of SC spectrum by increasing the input power into the optical fibers of varying lengths. The pulses generated by microchip laser have a time duration of ~700 ps, an energy of ~6 μJ, a repetition rate of ~8.6 kHz and a central wavelength of 1064 nm. With data providen and through of the experimental scheme we can be coupled to the output fiber to a maximal average power of ~3.8 mW.

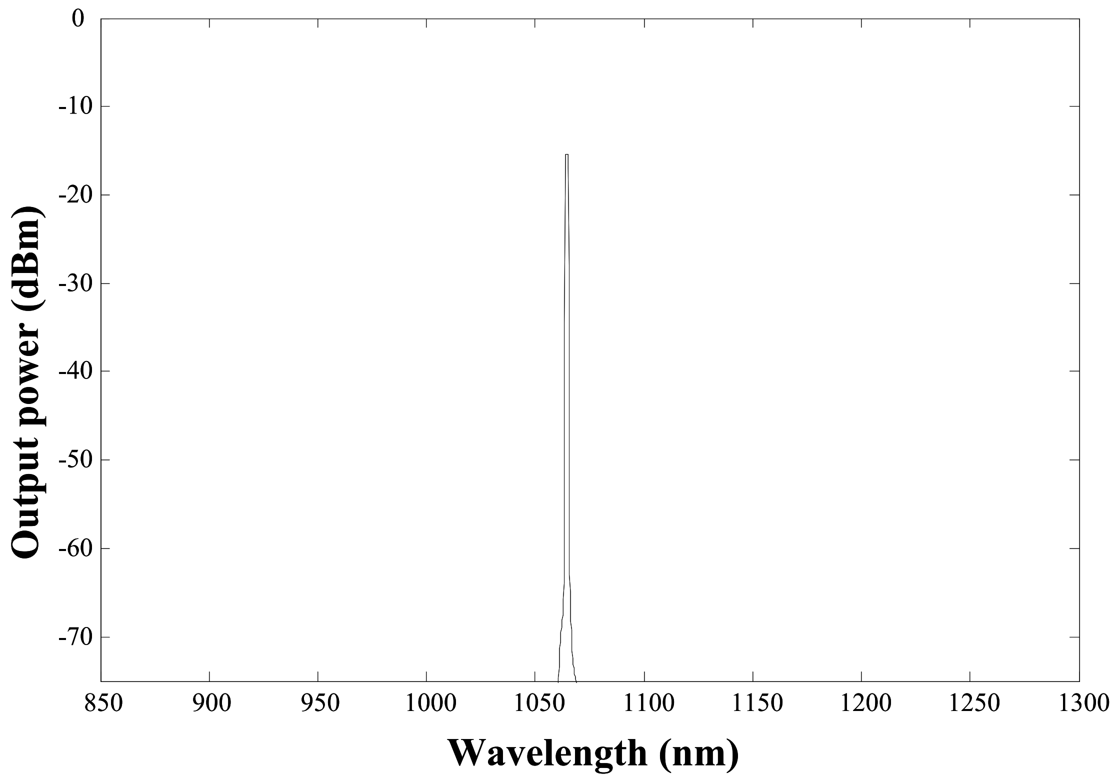

Figure 2**.** Spectrum of the microchip laser measured without the presence of nonlinear phenomena.

After selecting the length of the standard fiber to analyze, the attenuator of variable density (see Fig. 1) and we measured with the OSA the output spectrum for different values of average power at the fiber input. The Fig. 3 shows the evolution of SC generation for four differents lengths of optical fiber, in this case we have ~28 m, ~38 m, ~48 m and ~57 m. We observed that when the input power to the fiber spool is increased in the case of ~57 m, the spectrum of the pump pulses shifts to smaller and longer wavelengths, and that a broadband emission due to linear and nonlinear phenomena appears on the both side of the spectrum, extending up to the detection wavelength limit (1700 nm) for shorter frequiencies. The spectrum generated with the maximum length used is extremely uniform for three sections on the spectrum; one section is located on 775 nm to 860 nm (~85 nm), the second section is in a range of 868 nm to 1080 nm (~212 nm) and the last section is on 1280 nm to 1480 nm (~200 nm), in particular for output power in fiber with values of 2.93 mW and higher (see Fig. 3(d)).

By tuning the attenuator of variable density for each of the fiber lenghts selected we increased the power and measured at the output of the fiber performed a measurement for ~28 m of fiber lenght and 3.77 mW of maximum average power, obtaining in this case a comparison of SC spectrum evolution for four differents powers, in this case the spectrum extends between 1000 nm and 1540 nm approximately (yielding ~540 nm of spectral width, see Fig. 3(a)), we able to appreciate the appeareance of phenomena such as Stockes and a broadening towards longer wavelengths on the spectrum. The second measurement was performed for ~38 m of fiber lenght and a maximum output average power of 3.51 mW, in this case we have ~700 nm of spectral width, between 970 nm to 1670, the spectrum continues to present a most remarkable widening to longer wavelengths (see Fig. 3(b)).

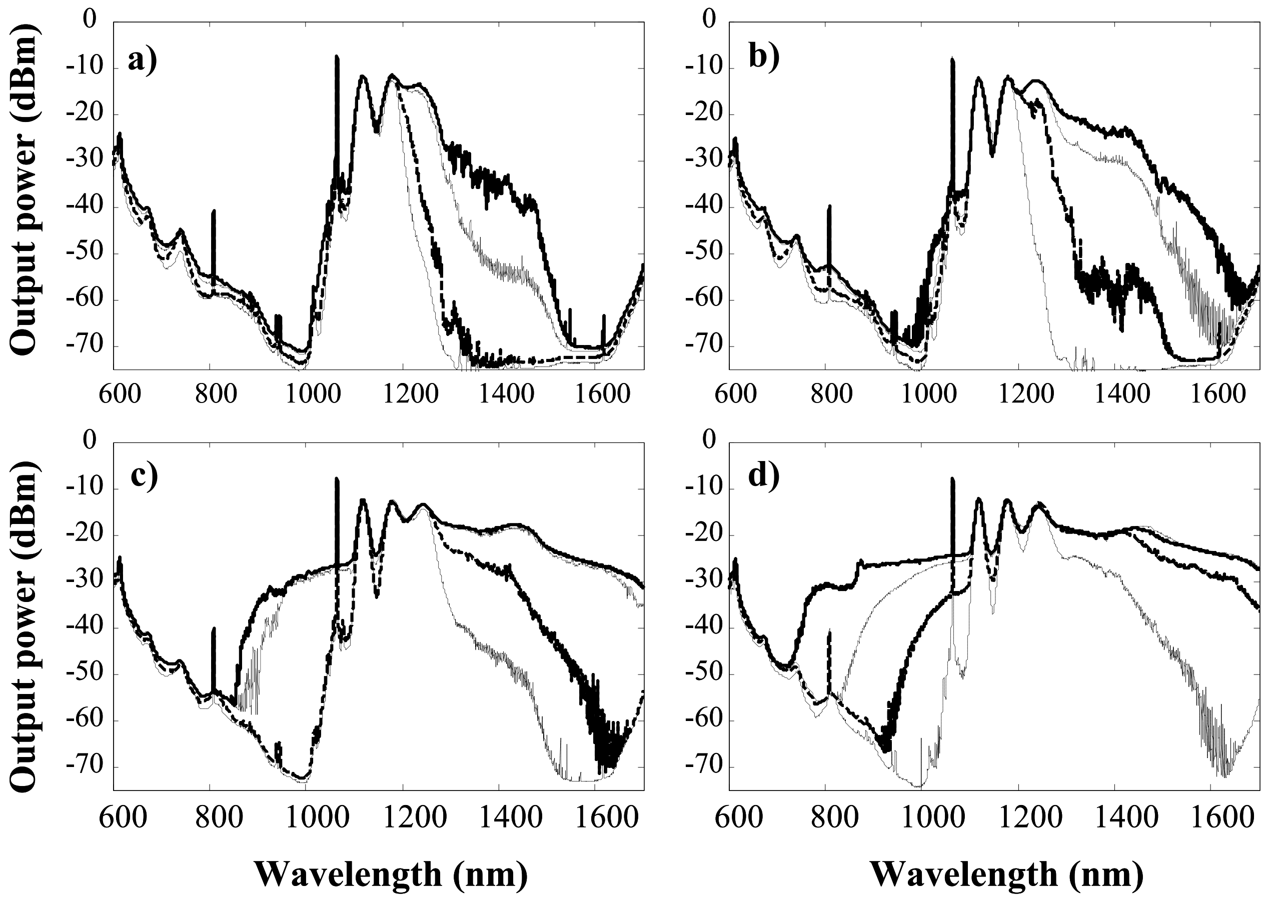

Figure 3. Evolution of SC spectrum for a) 28 m, b) 38 m, c) 48 m and d) 57 m of standar fiber pumped by microchip laser.

For ~48 m and a maximum output average power of 3.29 mW the spectral width at half height extends between 835 nm up to 1700 nm (we obtained more of ~865 nm of spectral width, see Fig. 3(c)). An important aspect to note in this case is the appearance of higher frequencies carrying substantially more energy compared to previous spectra and the spectrum present a high flatness with increasing input power or increasing the lenght of telecom fiber. Finally, for a fiber length of ~57 m and a maximum ouput average power of 1.21 we obtained a SC spectrum extending from 700 nm to more than 1700 nm (~1000 nm of spectral width). It is important to note that the SC spectrum obtained extends up to at least 1700 nm maintaining itself at a high level (a high percentage of peak pumping in Fig. 3(d)). Remarkably, in Fig. 3(d) the level of the newly generated frequencies form plateaus with very good flatness.

The chromatic dispersion of the fundamental mode plays an important role in the GS because this determines the extent to which different spectral components of a pulse propagate at different phase velocities in the optical fiber [11]. However, when there is interaction with other linear and nonlinear effects, a wide variety of processes involved in the broadening of the pulse propagated by the standar fiber. The factors that determine linear effects involved in the SG involve parameters such as, which is the parameter of the dispersion of the group velocity (GVD, Group Velocity Dispersion) and is the governing dispersion. The dispersion GVD can be normal, or abnormal, if, which directly depends on the wavelength of the pump beam, another linear factor lies with the inherent loss optical fiber and linear refractive index. Factors that determine the pumping pulse nonlinearities in the fiber are the input pulse width, peak power of the input pulse, the nonlinearity of the fiber. In general, the generation of a broad spectrum is the result of the interaction of multiple nonlinear effects such as stimulated Raman scattering, four-wave mixing, self-modulation and cross-phase modulation, soliton formation of higher-order instability modulacional and parametric mixing [12]. The results show that the optical spectrum at the fiber output exhibits features such as a smooth spectral width with a wide extension, and a very good flatness. This study demonstrated that using a telecom fiber with pulses generated by a microchip laser as the pump, we can generate a very wide spectrum in a relatively short length of conventional SMF-28 fiber (~57 m). This represents a good result in comparison with other works where special fibers were used (HNLF, fiber grating, microstructured fibers) [13-15], or in which several kilometers of SMF-28 fiber were required, as well as high values of input pump peak power (in the order of hundreds of kW) [7].

4. CONCLUSIONS

We studied experimentally the generation of a SC spectrum induced in a piece of standard single-mode fiber (telecom fiber) using pulses from a microchip laser as the pump. For ~57 m of fiber length, we obtained various sections with high flatness in the spectrum in the visble and IR region, the OSA upper bandwidth limit the measurement of the spectra broadening, however, we will work on a numerical study of the results obatined in this work. The possibility to generate a SC spectrum with a high flatness and spectral width of more of ~1000 nm in relatively short lengths (0.057 km) of conventional single-mode fiber, using as the pump pulses with no more than a few kW peak power at a non-zero-dispersion wavelength, is attributed to the peculiar properties of the pulses generated of the microchip laser (in ps regime). The spectra shown in this work are very interesting, particularly for lengths ~40m from when we get a relatively flat spectrum and is broadens toward shorter and higher wavelengths. We understand no longer appear nonlinear effects in the last third of the fiber of ~57 m. The dispersion and must have greatly reduced the peak power in this part. We think that the SC spectra of standard fiber present in others works are not uniforms, which implies that there is an original result due to the widening and uniformity of the spectrum obtained.This work shows the interest of considering the use of telecom fibers for SC generation due to the economy, and good results obtained, which is of great importance for applications like optical metrology, optical coherence tomography and low noise sources for the characterization of devices.

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