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Supercontinuum light source with adjustable spectral width by inducing mechanical stresses in photonic crystal fiber

Fuente de luz supercontinua con ancho espectral ajustable mediante la inducción de tensiones mecánicas en fibra de cristal fotónico

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ABSTRACT:

In this paper we show experimental results based on the study of a supercontinuum light source whose spectral width can be tuned in a range from ~748 nm to over 1420 nm while it maintains a good flatness. The proposed configuration for the supercontinuum source was developed using a relatively short piece of photonic crystal fiber (PCF) as the nonlinear medium pumped by a microchip Q-switched laser at 1064 nm. We demonstrated experimentally that the spectral width control on the supercontinuum source is made possible through the stress applied to the PCF used in the experimental setup, which induces birefringence and causes changes of polarization along the fiber. These phenomena are made possible by the application of bending and twist to the PCF in conjuntion with retarder plates inserted into the optical arrangement, which allows selecting the bandwidth of the white light source. Finally, a description of important features of the measured output spectrum is provided, and potential applications are proposed.

Key words: Fiber Optics, Nonlinear Optics, Laser Diodes.

RESUMEN:

En este artículo se muestran los resultados experimentales basados en el estudio de una fuente de luz supercontinua cuyo ancho espectral puede ser seleccionado en un rango entre los 748 nm a más de 1420 nm manteniendo un espectro con una buena planicidad. La configuración propuesta para la fuente de luz supercontinua se desarrolló usando una longitud corta de fibra de cristal fotónico (PCF) como medio no lineal bombeado por un láser tipo microchip operando a 1064 nm. Se demostró experimentalmente que el control sobre el ancho espectral de la fuente supercontinua es posible a través de la aplicación del estrés aplicado a la PCF, induciendo birrefringencia y cambios de polarización a lo largo de la fibra. Estos fenómenos fueron posibles debido a la aplicación de curvatura y torsión en la PCF en conjunto a las placas retardadoras insertadas dentro del arreglo óptico permitiendo seleccionar el ancho espectral deseado de la fuente supercontinua. Finalmente, se menciona una descripción de importantes características medidas a la salida del espectro, así como posibles aplicaciones.

Palabras clave: Fibras Ópticas, No Linealidades Ópticas, Diodos láser.

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1. Introduction

The control of supercontinuum spectral characteristics is crucial for many scientific and technological applications. For this reason, actually new methods are being developed based on laser techniques that have succeeded in temporarily narrow pulses [1,2] allowing the supercontinuum (SC) generation have a remarkable progress. The features provided by new pumping sources, such as a large spectral width and a high power level can be found in a microchip laser [3]. Several authors are working with different designs of supercontinuum sources, taking advantage of the very fast development of special fibers and pump sources capable of emitting ultrashort pulses with durations in the order of picoseconds and femtoseconds.

Stimulated Raman scattering (SRS), self phase modulation (SPM), four wave mixing (FWM), soliton effects, cross phase modulation (XPM) and modulation instability (MI) are nonlinear phenomena involved in SC formation [4,5]. A supercontinuum source with controllable spectral width is of great interest for different potential applications. This work seeks to improve the experimental results obtained previously by using pulses with a duration of 700 picoseconds in a piece of PCF. We demonstrated experimentally that the spectral width control on the supercontinuum light source, which may extends over a bandwidth of more than 672 nm, is possible through the application of bending and twisting in the PCF in conjunction with a half-wave retarder (HWR) and quarter-wave retarder (QWR) inserted into the optical arrangement.

2. Experimental setup

In the experimental setup shown in Fig. 1, a pump source based on a microchip Q-switched laser operating at 9 kHz repetition rate was used. The pulses were characterized by a peak power of 10 kW, an energy of 7 μJ and a duration of 700 ps at 1064 nm. The proposed optical design consists in the use of pulses with high energy and wide-spectrum facilitating the spectral broadening. The laser beam is coupled into a piece of 2 m of PCF using an arrangement of two mirrors, a 10X microscope objective and an XYZ stage. A half-wave retarder and a quarter-wave retarder inserted in the experimental setup allowed to select a circular, linear or elliptical polarization at the fiber input.

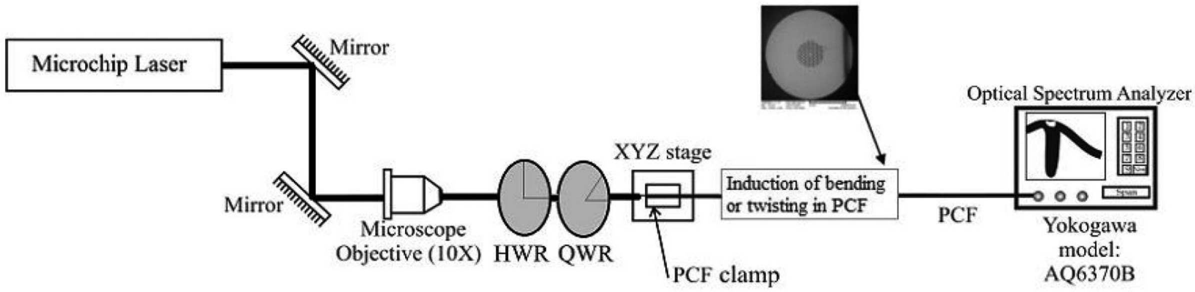

Fig. 1. Experimental scheme for studying the evolution of supercontinuum spectrum in PCF.

Mechanical effects are induced at the beginning of the PCF, in this case bending and twisting. The output spectra were recorded by an optical spectrum analyzer (OSA) model Yokogawa AQ6370B.

In a first case study the spectral evolution was obtained through different values in the number of turns per unit length (15 cm) on PCF and adjusting the angles of the retarder plates (HWR and QWR) to change the polarization state at the fiber input. The twist was imposed to the PCF by rigidly fixing one end of the fiber and mounting the other end in a rotation stage. In a second case, another important result was obtained by applying bending on the PCF using a mechanism capable of varying the bending diameter of a section of fiber. These curvatures were shown to change the spectral width because birefringence is induced in the fiber causing changes of the polarization state.

The PCF used in this work is a solid core fiber composed of silica as main element and the wavelength of zero dispersion was calculated on 1025 nm. The dispersion for PCF was estimated through empirical relations that only depend on two structural parameters, the air hole diameter and the pitch (distance among holes) [6]. Figure 2 shows the profile of the PCF used in the experimental scheme and the dispersion parameter as a function of wavelength, where the background index of silica is assumed to be 1.45. At the pumping wavelength ($\lambda = 1064$ nm), we find that $D = 7.67$ ps/nm·km, indicating that dispersion is slightly anomalous at that wavelength. In relation to the zero-dispersion wavelength ($\lambda_{ZD} = 1025$ nm), we have that $\lambda > \lambda_{ZD}$.

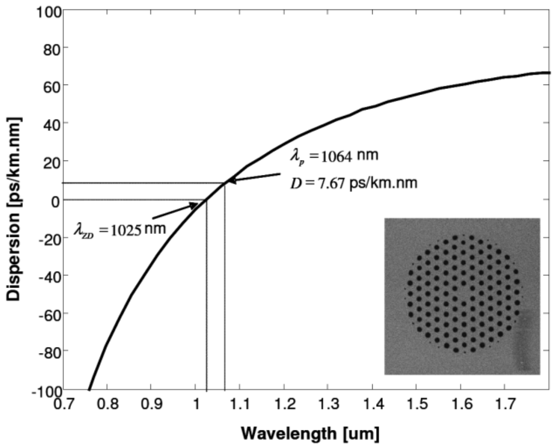

Fig. 2. Chromatic dispersion estimated for PCF as a function of wavelength.

3. Experimental results and discussion

We can appreciate in Fig. 3 the variations in the spectral width of the SC light source, in this case the spectral evolution was obtained adjusting the twist of the PCF in the experimental scheme. We also used different combination of angles for the retarder plates (HWR and QWR) in order to change the ellipticity of input pulses in the optical arrangement. In this figure we can appreciate the signal produced by microchip laser (pumping at 1064 nm) on the evolution of the SC spectrum for different adjustments of twist and ellipticity. The variations in the bandwidth of the supercontinuum source are due to changes in the polarization of light that affect the spectral width. We can observe in Fig. 3 that when the value of angles of HWR and QWR are adjusted to 240° and 160° respectively inducing twist of 2 turns in a section of 15 cm of the PCF, we obtained a SC with a bandwidth of

~565 nm. When we choose angles of 200° and 160° for HWR and QWR respectively with a 1 turns in a section of 15 cm, we observed that is possible to get a bandwidth of ~600 nm. The wider spectrum obtained was exemplified for 140° for HWR and 160° for QWR, 1 turns /15 cm obtaining a spectral width of ~672 nm. We observed that through the application of twist or changing the polarization state at the input of the PCF, we can control the spectral width of the supercontinuum source. It is interesting to have an easy and flexible control on the SC light source taking advantage of polarization effects in PCF.

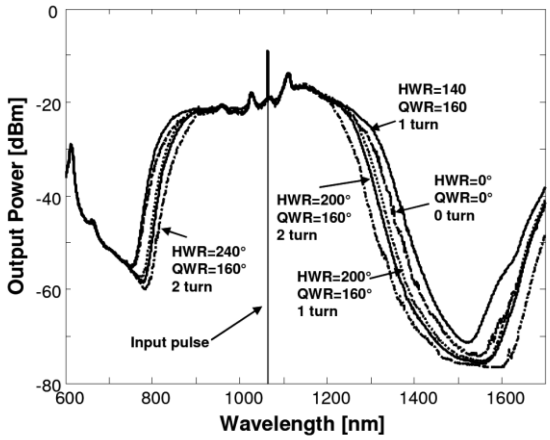

Fig. 3. Spectral evolution for different values of twisting in the PCF and varying the angles of retarder plates.

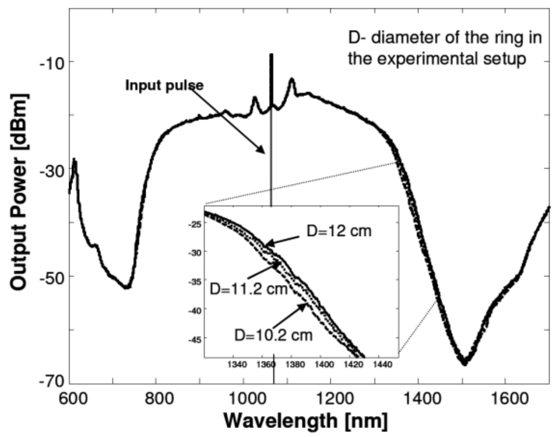

Fig. 4. Spectral evolution for different values of bending in the PCF.

Another interesting result is shown in Fig. 4, we obtained the spectral evolution applying bending to the PCF through an adjustment mechanism mounted on the arrangement in Fig. 1 allowing changing the bending diameter over a section of the PCF. In this case we fixed the value of the retarder plates angles. The curvatures change the spectral width because the fiber induces birefringence and hence the polarization state changes. In Fig. 4 we can appreciate the signal produced by microchip laser and the evolution on SC spectrum for some adjustment based on changing the diameter of curvature produced in the PCF. Through the analysis of the experimental results, we observe that the most notable change occurred in the case of twist adjustments obtaining a control over the spectral width of more than 50 nm. In the case of bending, the spectral width can only be adjusted over a few nanometers, however in this process a finer tuning in the spectral evolution is obtained.

Spectral width variations on supercontinuum source are due to the induction of losses, birefringence, changes in the dispersion and the polarization state. Through the analysis of the experimental results, we observe that the most notable change occurred in the case of twist adjustments obtaining a control over the spectral width of more than 120 nm. The twist in the PCF allows greater control over losses, scattering and changes in polarization states, for this reason, the spectral changes are more remarkable. In the case of bending, the spectral width can only be adjusted over a few tens of nanometers, however in this process a finer tuning in the spectral evolution is obtained. The explanation for such small variations in the case of applying bending to the fiber is related to the properties of the PCF, mainly its low sensitivity to bending losses even for high mode areas, however, some works show that a low effective area has a positive effect on the bending losses [7], while some studies shows that the twist generated more intense changes in the spectrum of PCF [8].

Finally, an important point to discuss is the different potential applications of a controllable supercontinuum source. Actually, the control of supercontinuum spectral characteristics is crucial for many scientific and technological applications, for example, in gas sensing since the SC sources cover a broad region where some gasses absorb. In some applications it can be useful to select in a simple way the spectral width of the broadband source. For instance in gas sensing usually it is necessary to isolate a spectral region in order to minimize background effects and absorptions from different gasses. This is typically carried out by band pass filters which can be relatively expensive. Therefore a broadband source, which spectral width can be easily selectable, can be interesting for several applications.

4. Conclusions

We demonstrated experimentally the possibility to get a spectral width control on supercontinuum light sources based in the stresses applied in the fiber. The control is possible through the induction of birefringence and changes of polarization by the application of bending and twisting in the PCF in conjunction with a retarder plate inserted into the optical arrangement. Finally, we can have different potential applications due that the controllable supercontinuum source proposed result an easy and flexible way for selecting the spectral width required, which is capable of increase or decrease the spectral width having a maximum selectable spectral bandwidth above 672 nm.

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