High resolution method for measuring Brillouin spectrum scattering in special optical fibers

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ABSTRACT

An experimental setup and a method to obtain the Brillouin scattering spectrum (BSS) out of optical fibers are proposed. The setup is described and experimentally validated by developing the measurement of the Brillouin spectral distribution of a birefringent microstructuted optical fiber. The setup here proposed is based on a Brillouin ring cavity that uses the fiber under test as the active medium. The measurements are obtained in base band by beating the Stokes wave with a reference wave that is taken from the optical pump. The data can be obtained with high resolution frequency.

Keywords: Brillouin scattering spectrum, stimulated Brillouin scattering, microstructured optical fibers, Birefringent fibers

1. INTRODUCTION

In the stimulated Brillouin scattering process, the probe signal is amplified provided the conditions of momentum conservation. Thus, the Brillouin gain can be used for amplifying a weak optical signal with a frequency that matches the Brillouin frequency of a pump wave. Following this idea, the Brillouin gain process in optical fibers can be used for making fiber resonators by placing the fiber inside a cavity. The two most significant configurations of fiber resonators are the Fabry-Perot and the ring geometry. The configuration of fiber ring cavity is used for reinforcing the backscattered signal and increasing the efficiency of the Stokes generation. The narrow linewidth (~30MHz) of the Brillouin gain offers the possibility to use the current fiber as an active medium, which can be useful for example to build cavities for lasers with a narrow bandwidth[1].

In this paper, a setup configuration and a method to obtain the Brillouin scattering spectrum (BSS) of optical fibers are proposed. The method is experimentally demonstrated by measuring the Brillouin spectral distribution of a microstructuted optical fiber. The method here described is based on a Brillouin ring resonator that uses the fiber under test as the active medium. The measurements are obtained in base band with high resolution.

2. CONCEPTS AND EXPERIMENTAL SETUP

The pump power threshold needed to induce the Brillouin scattering is a factor that mostly depends on the fiber and its characteristics. Hence, if a fiber has high transmission losses, the amount of threshold power should be drastically increased and the Brillouin scattering spectrum is hardly measured; such is the case of some special fibers. Typically, the power threshold of Brillouin scattering for standard optical fibers is given by: $P_{th} \approx K_1 \left(K A_{eff} / g_B L_{eff} \right)$, where g_B is the peak Brillouin gain of the fiber, A_{eff} is the effective area of the light propagation mode in the fiber, L_{eff} is the effective length, K_1 and K are numerical factors. K_1 may be approximate to 21 in the case of standard fibers[2]. An important advantage of Brillouin fiber resonators is the reduction of the threshold pump power required for the interaction process. Normally this threshold is considerably reduced when the factor 21 is replaced by a number in the range of 0.1 to 1. Then, the gain can be defined by[3]: $G = \exp\left(g_B L_{eff} \, P\eta / A_{eff} - \alpha L \right)$, where P is the pump power, η is the polarization factor and α is the transmission loss of the fiber.

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The ring configuration amplifies the spontaneous scattering signal because the light is auto reinforced into the fiber loop. If in addition to the spontaneous signal, the process is stimulated by an "external seed" signal launched in the ring cavity, the Brillouin shift modes can be stimulated and then measured. This seed signal is obtained from the pump light in order to preserve the coherence of the optical waves. Thus, in ring cavities the power efficiency becomes an advantage that helps to measure fibers with a short length, high transmission losses or fibers with high coupling losses. Besides, the amplification of the Brillouin modes as laser lines allows a high resolution in the Brillouin spectra determination.

The proposed configuration is presented in Figure 1. This proposal is based on the ring cavity resonator, but fed by a high resolution tunable laser line, which is the "external seed signal". In this configuration three signals are used, the pump, the reference and the seed which are obtained from the same continuous laser by using two couplers. 98% of the signal from the first coupler is equally divided; one branch is amplified through an Erbium doped fiber amplifier (EDFA) with an optical output up to 23dBm, which is used as the pump in the fiber ring cavity. The ring cavity is signaled by the red dash line in the figure, which is formed by an optical circulator used to get the Stokes signal out, two polarization controllers (PC), an optical isolator and the fiber under test (FUT). The pump is monitored with a power meter (PWM) and regulated with a variable optical attenuator (VOA). The seed signal is one of the first side bands in the frequency spectrum when the signal from branch 1 is modulated in intensity by an x-cut LiNbO3 modulator. The signal from branch 1 is a low level laser sample (about -20dBm). By sweeping the RF generator and measuring the frequency set in the seed, the Brillouin spectrum is tested. The spectral resolution can be of 1MHz or less depending on RF generator and the ESA properties. This seed signal can be used as probe line to stimulate the spontaneous Brillouin scattering and make sensible measurements of the scattering.

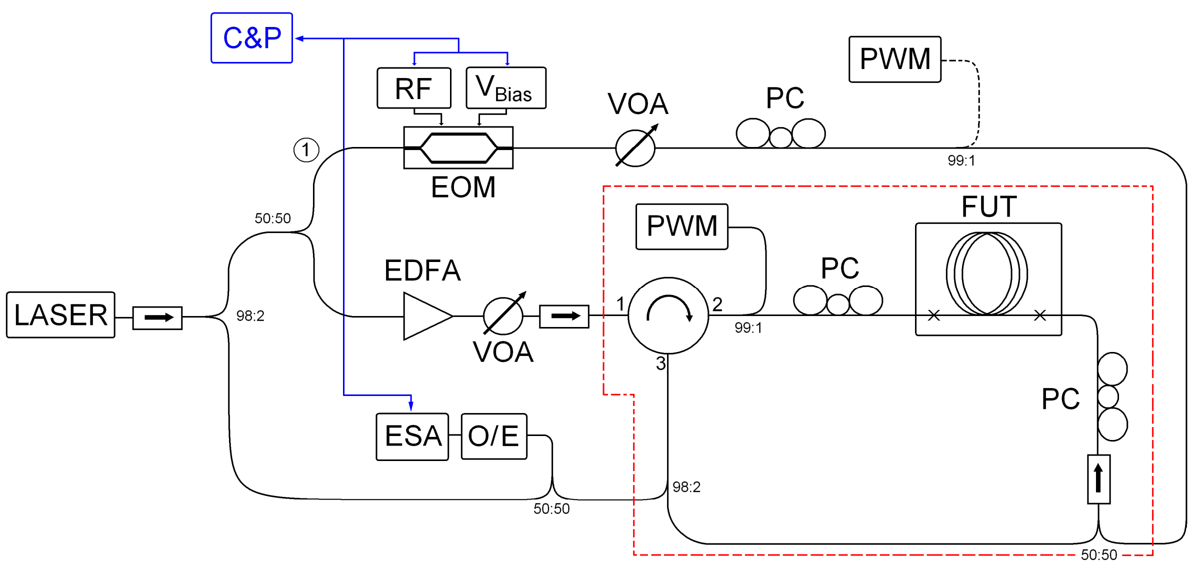

Figure 1. Experimental setup for Brillouin ring configuration. Setup composed by a variable optical attenuator (VOA), control and processing (C&P), optical to electrical converter (O/E), optical power meter (PWM) and polarization controller (PC).

3. BSS OF A MICRISTRUCTURED FIBER

The increment in the efficiency combined with the seed given by the probe makes this configuration attractive to better characterize the Brillouin spectrum of a special fiber. In order to check the method and measure BSS in a microstructured fiber (or photonic crystal fiber PCF), 20m of a polarization maintaining PCF is used in this experiment. As it is shown in Figure 2, the fiber has a solid silica core surrounded by air holes arranged in an hexagonal lattice. The microstructure also presents two larger holes adjacent to the fiber core that induce high birefringence. The diameters of the smaller and larger air holes are 1.7 and 3 µm, while the pitch is 3.75 µm.

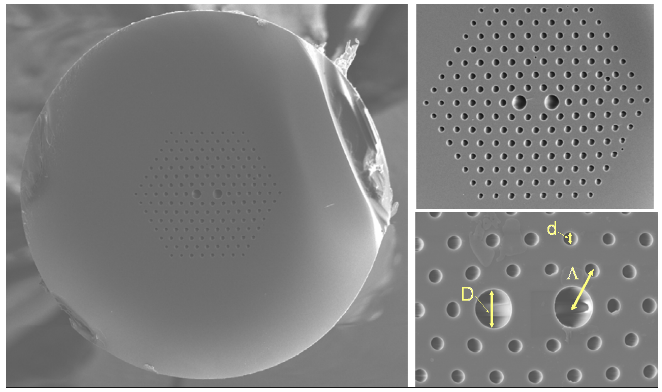

Figure 2. Polarization maintaining photonic crystal fiber. D=3μm, d=1.7μm and Λ=3.75μm.

Figure 3 displays data obtained by using the ring configuration (blue-line) and the experimental data from the standard pump-probe configuration[4] (red-line). The experimental measurements correspond to the x-polarization and shows two Brillouin peaks for this PCF separated ~100MHz. It has to be pointed out the good correlation between the numerical results[5] and the data obtained using the proposed technique. Besides, it is important to notice that in a previous paper only the first peak of the Brillouin spectrum is reported when the measurements were made with a similar fiber[5]. Such kind of Brillouin spectra that present more than a peak is common in fibers with non conventional structures and relative small core. This dual peak presence is related to the acoustics modes given by the lattice.

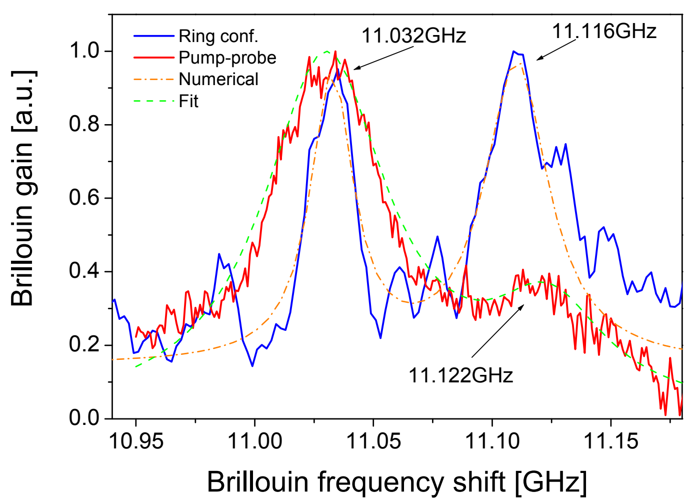

Figure 3. Brillouin spectra along the PCF shown in Figure 2 in the X-axis of polarization. The figure displays (Blue line) data from the ring cavity and (red line) data from the standard probe-pump configuration. It also shows the numerical (dotted-dashed line) Brillouin coupling coefficient and the fitting data.

4. CONCLUSIONS

A system configuration and a method for sensing the Brillouin scattering spectrum of an optical fiber are proposed and experimentally validated. The method is based on fiber ring cavities. The dual Brillouin peak present in the spectral distribution of a photonic crystal fiber is successfully measured by means of the ring configuration. This Brillouin configuration makes the Stokes and the probe enter in a resonance cavity, which increases the output efficiency of the backscattered signal and helps to improve the Brillouin detection and characterization.

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