# Observation of Cladding Brillouin Scattering (CBS) modes using backscattering technique

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*Although cladding Brillouin scattering (CBS) modes propagate mostly in the same direction as the incident optical wave (co-directional propagation), contra-directional propagations have been observed using an electronic spectrum analyzer. Stimulated Brillouin scattering (SBS) studies rely on the interaction between an optical wave and the longitudinal acoustical mode in the fibre. Our approach is rather based on the interaction of the optical wave with the transverse acoustical modes also called guided acoustic-wave Brillouin scattering (GAWBS) modes. Theses modes are highly polarization dependent and their frequencies range from 20 MHz to 800 MHz. Such analysis opens a new and attractive way of detection in fiber-sensing applications. Spectra measured on various fibres are discussed and compared.*

## Introduction

For years, most studies in optical fibres concern stimulated Brillouin scattering (SBS), due to its large application in sensing domain [1, 2]. This electrostrictive effect comes from the nonlinear (inelastic) interaction between the optical incident wave and the backscattered Brillouin one. The frequency shift between both waves results from the modulation of the medium by the longitudinal acoustical wave. Due to its finite numerical aperture, a singlemode optical fibre behaves as a highly multimode acoustical waveguide. As a consequence, it follows an interaction of both longitudinal and transverse acoustical waves with the stimulating optical incident wave. This latter effect is called "guided acoustic-wave Brillouin scattering" (GAWBS) which is the most used term [3]. It is also called "forward Brillouin scattering" [4], "cladding Brillouin scattering" (CBS) [5] or "transverse stimulated Brillouin scattering" [6]. These transverse acoustical modes are guided along the fiber and propagate in the same direction with the incident optical wave while SBS mode is unique and propagates in the opposite direction. Contrary to SBS mode frequency that is about 10 GHz in fused silica singlemode fibre [7], GAWBS modes frequencies spread from 20 MHz to 800 MHz [3]. They depend only on the fibre structure and on the longitudinal and transverse waves velocities. GAWBS modes correspond to the radial ($R_{om}$) or torsional-radial ($TR_{2m}$) modes of the whole fibre. The first cause pure phase modulation whereas the others modulate the state of the polarization of the light. $TR_{2m}$ modes are also called "depolarized" GAWBS because of their polarization dependence. By converting the state of polarization modulation of the light into amplitude modulation, physical fibre parameters such as temperature [8], strain [9] or even fibre diameter [10] can be monitored. All these types of sensing applications used GAWBS in forward direction. As GAWBS process is a forward scattering, *Tanaka and al* in [11] proposed an interesting solution using SBS for GAWBS-based distributed sensors. With high power incident light, they observed GAWBS in backward direction. The present paper proposes an improved experimental set-up to observe GAWBS in backward direction. As in [10], one would expect that the strain and other inhomogeneities in the fibre (core and cladding) structure would perturb the GAWBS frequencies.

## Experimental set-up

The overlap between the acoustical and optical modes is poor and therefore GAWBS gain is comparable to stimulated Raman scattering (SRS) gain. Thus, one can estimate $g_{GAWBS} \equiv 10^{-2}\ g_{SBS}$ where $g_{GAWBS}$ and $g_{SBS}$ stand for GAWBS and SBS gains respectively. Taking into account this relative small $g_{GAWBS}$ value, the experimental setup shown in figure 1 is proposed.

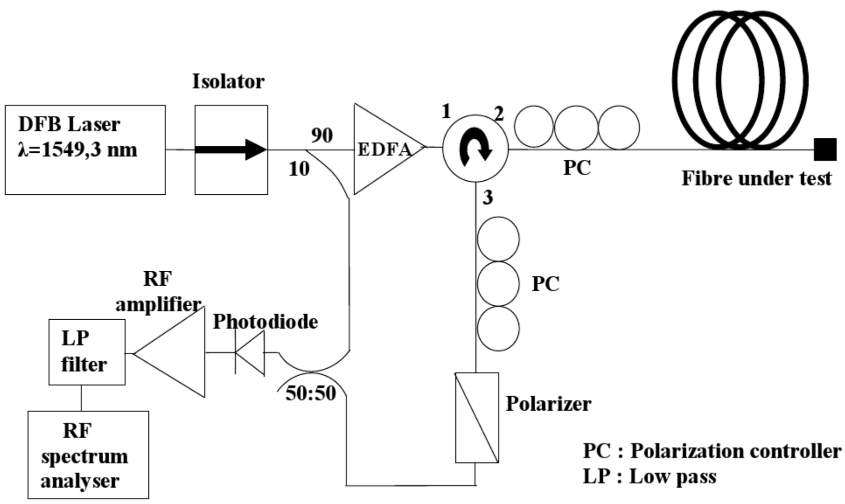


Figure 1: Experimental set-up

The pump is a distributed-feedback (DFB) laser operating at 1549,3 nm. Its linewidth is 1 MHz. The light source is amplified by an erbium-doped fibre amplifier (EDFA). A circulator is used to collect the backscattered wave out of port 3. To optimize intensity modulation, polarization controllers are tuned. The intensity modulation passes through a polarizer and the beat signal corresponding to depolarized GAWBS modes is detected. Given the weakness of the backscattered optical signal, a local optical oscillator signal is coupled using a 50:50 coupler. As polarization controllers, the optical oscillator use is relevant to observe backscattered weak GAWBS modes. The scattered signal is then detected with a photodetector and the GAWBS spectra is recorded by a radio-frequency (RF) spectrum analyser. A low pass filter is used to cut off SBS modes.

## Experimental results

The measurements are performed on three different fibres : a 2.2km-singlemode fibre, a 500m-dispersion- shifted fibre (DSF) and 500m-photonic crystal fiber (PCF). The electron micrograph scan (SEM) of the PCF is shown in figure 2.

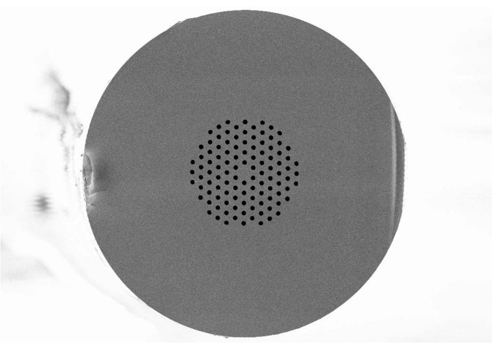

Figure 2: SEM photograph of the PCF

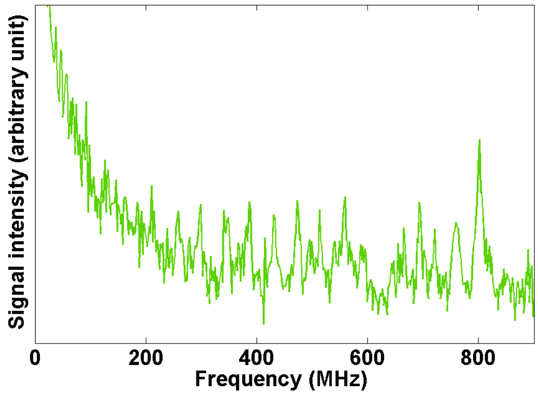


Figure 3: 500m-PCF GAWBS modes

The corresponding GAWBS spectra are shown in figures 3, 4 and 5.

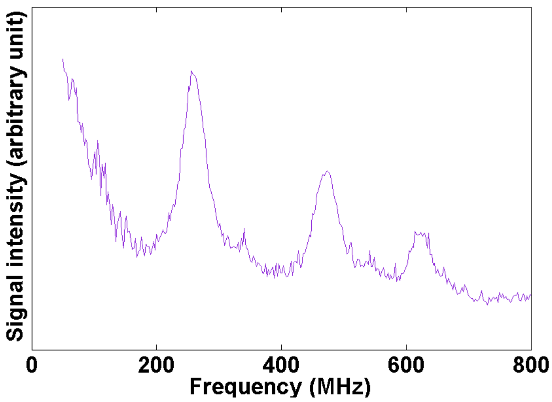


Figure 4: 500m-DSF GAWBS modes

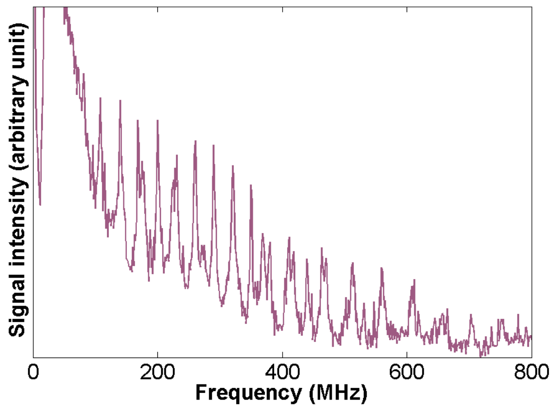


Figure 5: 2.2km-SMF GAWBS modes

We can observe that these fibres are multimode waveguides for GAWBS modes. The frequencies observed range from 100 MHz to 800 MHz. The signal intensity decreases as the mode frequency increases. GAWBS spectra are characteristic for the fiber geometry. By monitoring these modes along a fibre as in Brillouin optical time domain reflectometry (BOTDR) process, the inhomogeneity of the fibre structure can be analysed.

## Conclusion

The advantage of the proposed method lies in the simplicity of the experimental set-up necessary to observe GAWBS in backward direction. GAWBS spectra of three different FUT (FibreUnder Test) have been measured using the ?improved? set-up described supra.

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