

## Theoretical study of Stimulated Brillouin Scattering (SBS) in polymer optical fibres

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*We present the modelling of stimulated Brillouin scattering (SBS) in graded index polymer fibres made with fluoropolymer CYTOP<sup>®</sup> (Cyclic Transparent Optical Polymer). Comparison of SBS in silica and polymer optical fibres is presented. What emerges is that polymer-based fibre sensors require, compared to silica-fibres sensors, higher power sources (in the order of Watts). The innovative aspect of this work is first the "polymer" characteristics of the material.*

### Introduction

A light wave that is propagated in a dielectrical transparent material i.e. the optical fibre core, compresses the material when its intensity is above a certain threshold [1, 2]. The thermal phonons created, make an acoustic Bragg grating which moves in the same direction as the passing optical wave in the material. This inelastic interaction between the incident wave and the diffracted network in movement, gives rise to a light wave known as **Stokes wave** also called scattered Brillouin wave. The frequency shift between both waves, called *Brillouin shift*, comes from the Doppler effect introduced by the moving Bragg network. Contrary to stimulated Raman scattering (SRS), SBS is observed at lower power levels so a few mW are sufficient to create stimulated Brillouin effect in unimode fibres with a length of about ten km [3].

In this process, an important part of the light optical power crossing the fibre is converted into scattered power. Brillouin frequency shift is sensitive to temperature and constraints variations to which the fibre is subjected [4].

Polymer optical fibre (POF) already offers an alternative to Glass optical fibre (GOF) in Local Area Network (LAN), due to its large bandwidth and low installation and connection cost [5, 6]. POF could also become a preferred component in manufacturing distributed fibre sensors [7], due to its low elasticity modulus (Young's modulus) and its higher thermal expansion coefficient.

### Model

Characterizing SBS in polymer optical fibres requires the measurement of Brillouin frequency shift ( $\Delta f_B$ ), threshold power ( $P^{cr}$ ) and Brillouin gain factor ( $g_B$ ). It can be done using two configurations. One is a simple configuration i.e. using only a laser; while

the other is referred to as pump-probe configuration which needs two lasers. In the latter case, the first laser is used as a pump laser and the second, the probe, emits a light wave from the fibre end; its wavelength and its power are chosen to obtain an SBS at a lower power level. In the first case, Stokes wave characteristics are obtained by calculation following formulas in [1]. On the second, the power threshold in pump-probe configuration, is obtained on numerically solving coupled non linear differential equations as follows :

$$\begin{aligned}\frac{dI_p}{dz} &= -g_B I_p I_s - \alpha'_p I_p \\ -\frac{dI_s}{dz} &= +g_B I_p I_s - \alpha'_s I_s\end{aligned}$$

In those equations  $I_p$  and  $I_s$  stand for the pump and probe intensities expressed in  $W/m^2$  respectively.  $A_{eff}$  represents effective area core fibre,  $z$  means wave position over the fibre (expressed in m),  $\alpha'_{p,s}$  are used for linear attenuation of pump and probe waves respectively and  $g_B$  is the fibre Brillouin gain factor.

The model that is developed for this study has been validated with published experimental results on silica fibre [8]. Table 1 is a summary of the parameters used for validation.

Table 1: Measurement and simulation parameters

Parameters	Value
Pump power	4.2 mW
Brillouin gain	$1.2 \cdot 10^{-11}$ m/W
Effective area core	$86 \mu m^2$
Laser wavelength	1550 nm
Attenuation coefficient of the fibre	0.217 dB/km

Figures 1 and 2 show the results obtained by simulation and experiment that are published for a silica monomode fibre.

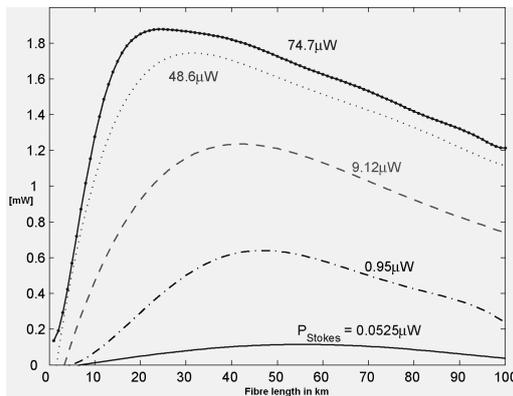


Figure 1: Simulation made from developed model

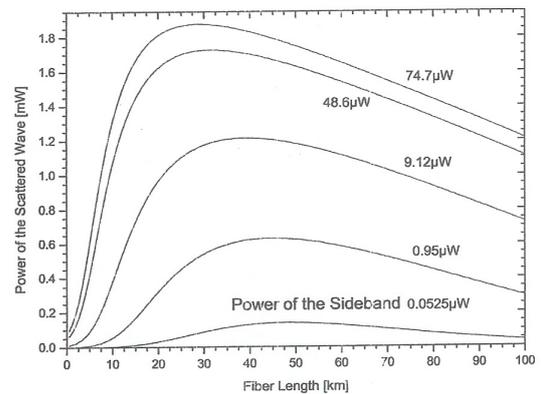


Figure 2: SBS measurement on silica optical fibre from Ref. [8]

To explain the graphs one needs to consider that each curve represents the situation of a couple of well-defined pump and probe powers. The horizontal axis, expressed in km,

indicates for any fibre length, the scattered (Stokes) wave power at the fibre entrance and then for different values of probe power, holding constant pump power.

### Simulation on silica fibres

Figure 3 shows pump and Stokes wave propagation over a 30 km-long silica fibre . Stokes wave is amplified against pump wave.

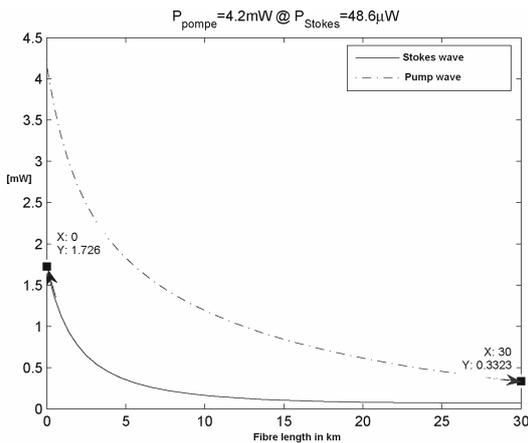


Figure 3: Simulation of pump and Stokes wave evolution over 30 km-long silica fibre

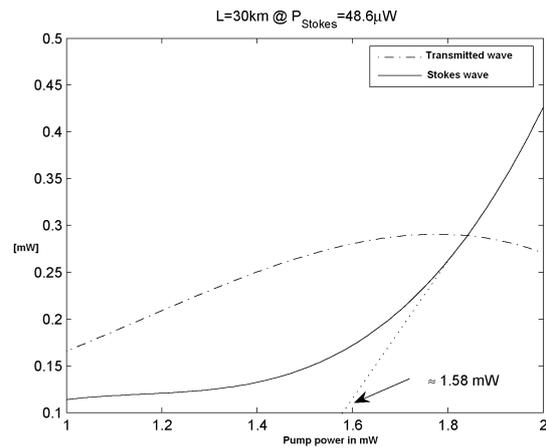


Figure 4: SBS Power threshold simulation on silica fibre with  $P_{pompe} = 4.2 \text{ mW} @ P_{Stokes} = 48.6 \mu\text{W} @ 1550 \text{ nm}$

The power threshold above which SBS appears, as shown in figure 4, is obtained changing the pump power level. It appears that for a probe power equal to  $48.6 \mu\text{W}$  and a 30 km-long fibre, a pump power  $P_{pompe} = 1.58 \text{ mW}$  is sufficient to stimulate SBS. This simulation has been repeated for other combinations of values. Some conclusions can be drawn :

- optimal fibre length needed to observe SBS in silica fibre depends equally on pump and Stokes power.
- using equal pump power, optimal length decreases when injected Stokes power in fibre increases.

### Simulation on polymer fibres

The main problem encountered in simulating SBS in polymer fibres, is that the Brillouin gain factor ( $g_B$ ) is unknown. The computation of  $g_B$  requires first to know one of the material Pockels' coefficients  $p_{12}$ . As its exact value was missing, the coefficient for CYTOP<sup>®</sup> material has been estimated from published values of other polymers [9]. 0,02 has been chosen in SBS simulation in PF-GIPOF.

The two fibres investigated are Chromis and Lucina made fibres which characteristics are summarised in table 2. Unlike silica fibres, the minimal pump power needed to stimulate Brillouin effect in the polymer fibres studied is about 6 or 7 W. We also find that the optimal Lucina fibre length is 196 m for pump and Stokes powers of 11 W and  $1 \mu\text{W}$  respectively.

Table 2: POF parameters

Fibre parameters	Fibre type	
	Chromis	Lucina
Core material	CYTOP <sup>®</sup>	
Fibre density (kg/m <sup>3</sup> )	2.03	2.03
Length (m)	300	300
Core diameter ( $\mu\text{m}$ )	50	120
Effective area core ( $\mu\text{m}^2$ )	84	209
Attenuation (dB/km)	40	25
Refractive index	1.34	1.34

From all simulation, it can be said that optimal POF length depends on pump power only, contrary to silica fibre where optimal length depends equally on pump power and injected Stokes power in the fibre. The main difference between attenuation coefficients on the one hand, and Brillouin gain factors on the other hand, of the different fibres may explain this observation.

It was also noted that maximal power gain and optical fibre length increase when pump power increases.

## Conclusion and perspectives

The innovative aspect of this work is first the "polymer" function/characteristics of the material, and "component" function played by the fibre in sensing devices. The study has enabled the modelling of SBS in polymer optical fibres.

From simulations, a big difference between polymer and silica fibres has been observed. In silica fibres, power threshold decreases when fibre length increases. Moreover it appears that pump-probe configuration allows stimulation of SBS at lower pump powers. Finally, contrary to one-laser configuration, the lower the pump power needed to stimulate SBS the shorter the fibre length.

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