Study of the radiation effects on the properties of Brillouin scattering in standard Ge-doped optical fibres

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ABSTRACT

Distributed fibre optic sensors are being evaluated by the nuclear industry for monitoring purpose. We evaluate the radiation tolerance of distributed Brillouin sensors up to very high total gamma doses.

1. INTRODUCTION

Fibre optic sensing technology can bring promising alternatives to classical measurement techniques in harsh nuclear environments[1][2][3]. Distributed fibre optic sensing technologies would allow structural integrity monitoring of reactor containment buildings, nuclear waste repository monitoring and remote-safety control of nuclear installations. The potentialities of Raman distributed temperature sensors have already been studied in radiation environments[5][6][7] .

Exposing optical fibres to ionizing radiation results in a wavelength-dependent attenuation increase. This effect limits the radiation-acceptance level of intensity-based fibre optic sensors in nuclear environments. The narrow wavelength encoding of the sensing information, however, helps to avoid the influence of the broadband radiation-induced loss, as we already show for fibre Bragg grating sensors[4].

Distributed sensors based on stimulated-Brillouin-scattering have an interesting potential for distributed strain and temperature monitoring in the nuclear industry. Since the sensing information is frequency-encoded, i.e. therefore potentially radiation tolerant, it was interesting to study the radiation effect on the Brillouin shift for application in ionizing environments.

In this paper, we present our preliminary results on the properties of the Brillouin gain spectrum in a gamma-irradiated commercially-available optical fibre.

2. EXPERIMENTAL DETAILS

We investigated the effects of ionising radiation on the characteristics of the Brillouin gain spectrum in standard Ge-doped telecom single mode fibres (Lucent Allwave™). During this irradiation campaign, four fibre samples, cleaved to a common length of 50 m, have been irradiated off-line in the BRIGITTE gamma irradiation facility[8] (SCK•CEN, Belgium) at the same dose rate of 27 kGy/h but at different total doses. Table 1 lists the total dose absorbed by each fibre.

Fiber sample	Length	Dose (MGy)
1	50 m	0.33
2	50 m	0.97
3	50 m	4.70
4	50 m	9.90
Reference	50 m	0

Table 1: Samples of Lucent Allwave™ single mode fibers used in this work

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Wolfgang Ecke, Julian Jones, Brian Culshaw, eds., Proceedings of SPIE Vol. 5855
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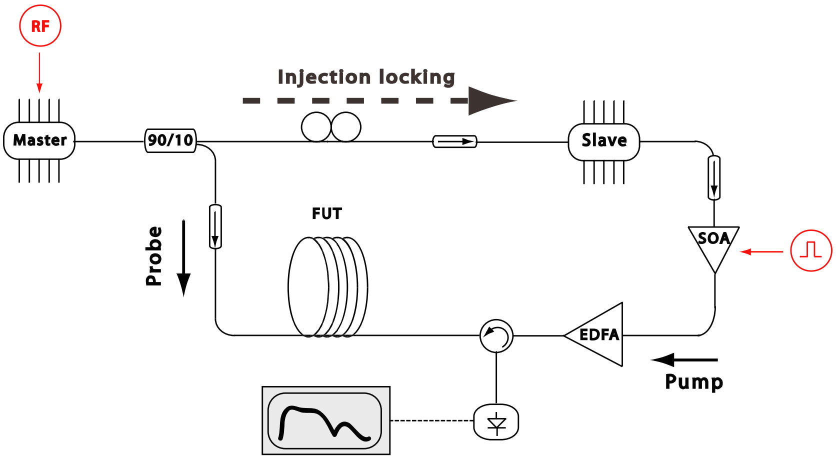

Fig. 1. Schematic diagram of the injection-locking based configuration for Brillouin sensing. Master, Slave: distributed-feedback lasers; SOA: semiconductor optical amplifier; EDFA: erbium-doped fibre amplifier; FUT: fibre under test.

The experimental configuration used for Brillouin sensing is schematically shown in Figure 1. Two distributed-feedback lasers (called Master and Slave) generate two counter-propagating lightwaves at 1550 nm (called respectively probe and pump) whose frequency separation must be kept constant and close to the Brillouin shift (υ_B) of the fibre under test. An efficient technique to obtain these waves is by modulating[9] the master laser at the Brillouin frequency (10-11GHz) and by injection-locking the slave laser on the sidebands of the master[10]. This is achieved by coupling a portion of the light of the master into the cavity of the slave. Distributed measurements are simply obtained by gating the pump signal through a semiconductor optical amplifier (SOA); pulses are then boosted through an erbium-doped fibre amplifier (EDFA). The probe signal is finally detected by a photodetector and analysed on an oscilloscope.

By varying the modulation frequency of the master, the fibres are completely scanned; the oscilloscope traces are collected and processed in order to calculate the Brillouin shift and the Brillouin linewidth. The injection-locking technique being intrinsically stable the Brillouin gain curves can be measured with high accuracy.

3. EXPERIMENTAL RESULTS

We measured the total radiation-induced attenuation in the 1550 nm window for each sample with an OTDR analyser. The results, summarised in Table 2, are comparable with previous works[11].

Figure 2 shows and compares the spectral responses of the radiation-induced absorption. This behaviour is typical of doped-optical fibres when exposed to ionising radiation[11] . However despite of the significant radiation-induced absorption, frequency-based systems, like Brillouin distributed sensors, still operate correctly. The radiation-induced attenuation only affects the signal-to-noise ratio.

	Reference	Sample 1	Sample 2	Sample 3	Sample 4
Dose (MGy)	0	0.33	0.97	4.7	9.9
Attenuation (dB/km)	0.43	44.94	62	144	170

Table 2. Attenuation measured with an OTDR at 1550 nm.

Figure 3 and 4 show the Brillouin frequency (υ_B) and the Brillouin linewidth ($\Delta\upsilon_B$) as a function of the absorbed dose. The results presented here were obtained by averaging on several measurements carried out in the same conditions and at the same ambient temperature, in order to be free of systematic errors which could bias our data.

The results are summarized in Table 3 and show a clear dependence of the Brillouin scattering on the ionising radiation: frequency and linewidth increase *nonlinearly* as a function of the dose.

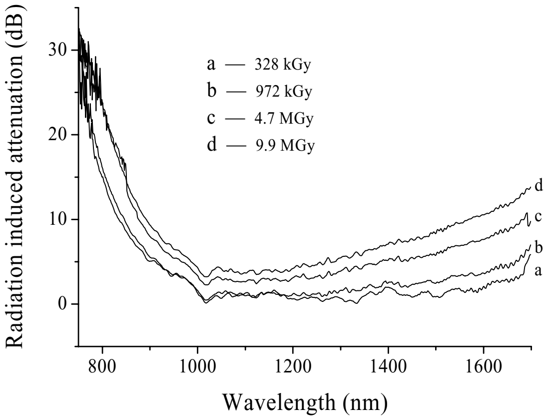

Fig. 2. Spectral response of the radiation-induced attenuation. Curves are normalised with respect to the reference fibre spectrum.

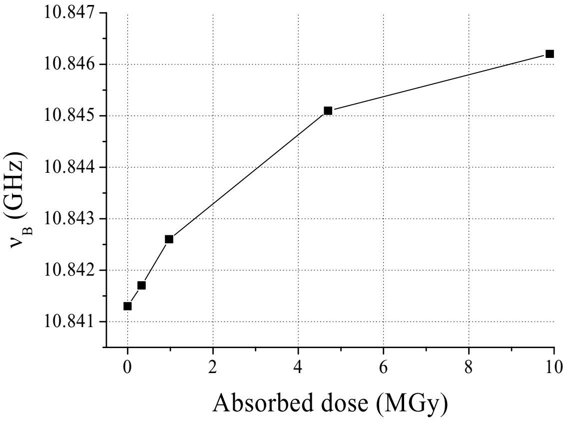

Fig. 3. Brillouin shift measured as a function of the absorbed dose. All measurements were made at constant temperature (T = 295.25K±0.05)

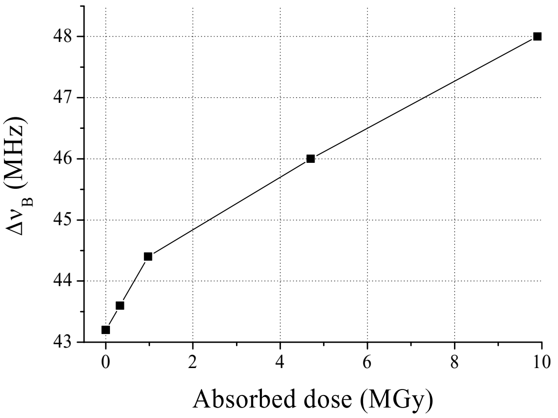

Fig. 4. Brillouin linewidth measured as a function of the absorbed dose. All measurements were made at constant temperature (T = 295.25K±0.05)

	Reference	Sample 1	Sample 2	Sample 3	Sample 4
Dose	0 MGy	0.33 MGy	0.97 MGy	4.7 MGy	9.9MGy
Brillouin frequency (GHz)	10.8413	10.8417	10.8426	10.8451	10.8462
Brillouin linewidth (MHz)	43.2	43.6	44.4	46	48

Table 3. Brillouin characteristics parameters.

4. DISCUSSION

The properties of Brillouin sensors to be able to measure temperature or strain variations is intrinsically related to the physical origin of the Brillouin scattering, resulting of the change in the acoustic velocity propagation according to variations in the silica density.

Our results show a change in the Brillouin shift due to ionisation radiation. The radiation-induction compaction being a non-reversible phenomenon, the Brillouin shift is frozen in the fibre when exposed to ionising radiation.

This tends to indicate a change in the silica density during the irradiation. This phenomenon is known as silica compaction and has already been studied in bulk silica[11]. In our case, we observe a *negative* compaction, i.e. dilatation, due to the ionization. Our results confirms the pioneer work of Starodubstev and Azizov[13] . In addition, Primak showed that the sign of the compaction strongly depends not only on the silica type but also on the type and on the concentration of the dopants [14]. This opens ways for having optical fibres with a reduced Brillouin shift by carefully chosing the dopant concentration and the fiber type.

The reason of the growth of the Brillouin linewidth is still unclear and need further investigations, due to the complex interactions of ionizing radiation with silica. Nevertheless this modest change causes no impairment for the measurement of the Brillouin shift, that is the essential information for sensing.

The frequency variation is about 5 MHz for both frequency and linewidth for the worst case (most irradiated sample), which corresponds approximately to a temperature change of about 5K for a total dose of about 10 MGy. However, it is important to note that the required radiation acceptance level for nuclear monitoring instrumentation is of the order of 10-100 kGy max. Therefore, the radiation induced shift of the Brillouin frequency can be considered to be practically negligible in real application.

5. CONCLUSIONS

The effect of gamma radiation on the Brillouin scattering in commercially-available optical fibres has been studied up to very high total gamma dose. Distributed sensors based on stimulated Brillouin scattering can be considered to be radiation-tolerant up to total doses of about 100 kGy, if the signal-to-noise ratio is kept acceptable . Further work on different fibres with different dopant concentration types will indicate which fibre is more suitable for nuclear environments. In addition, the use of the radiation-induced Brillouin shift as tool analysis will certainly bring new perspectives in the understanding of the compaction mechanism in irradiated amorphous silica.

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