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Highly Accurate Measurements of Temperature and Strain-dependence of Brillouin Gain in Single-Mode Fibres

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Distributed Brillouin gain measurements along single mode fibres have demonstrated their potentiality for local temperature sensing and monitoring strains experienced by optical fibres [1,2]. The results of such measurements is directly related to the acoustic properties of the fibre medium that are temperature- and strain-dependent. The Brillouin gain spectrum (BGS) is classically measured by launching a highly coherent pump lightwave into a test fibre and by observing the amplification of a weak probe signal propagating in the backward direction [3]. This spectrum lies 11-13 GHz below the pump frequency at a wavelength of 1300 nm and has a Lorenzian line shape with a 30-50 MHz FWHM linewidth. The optical frequency of the probe signal must be tuneable to properly scan the Brillouin gain spectrum.

We recently proposed a novel method providing highly accurate BGS measurements with a 100 kHz accuracy on the central frequency and a 200 kHz accuracy on the FWHM linewidth over a 100 m fibre sample covering an extended range of GeO_2 doping core concentration [4]. This method uses a small part of the pump light to generate the probe signal using a broadband electro-optic modulator. The modulation sidebands are demonstrated to make a suitable probe signal for this measurement. Distributed strain and temperature measurements were successfully achieved using this technique by pulsing the lights signals [5,6].

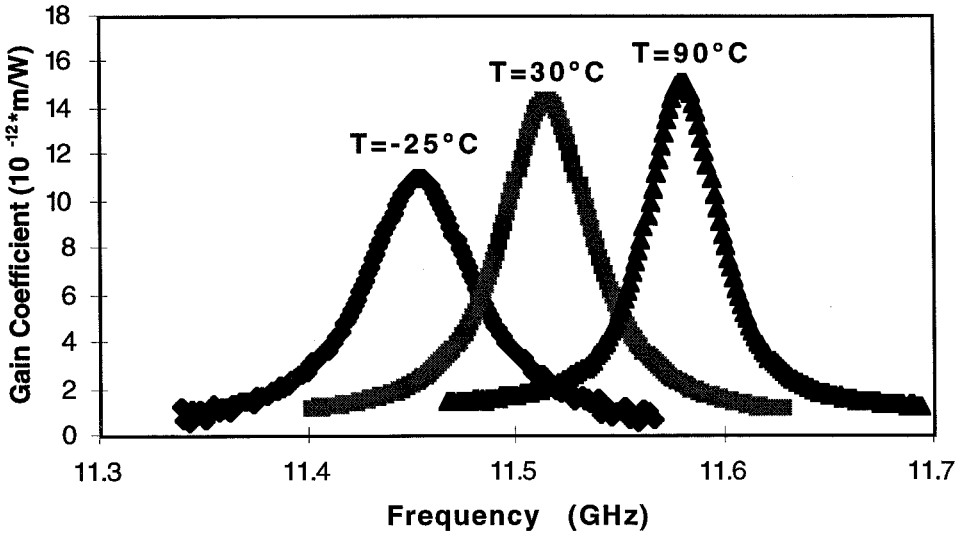

Fig.1 Brillouin gain spectrum of a single mode fibre measured at different temperature, showing the effects of temperature on the central frequency, the linewidth and the maximum gain.

In this contribution we report measurements to a high accuracy of the influence of temperature and strain on the Brillouin gain spectrum using our technique. Some authors have quantitatively presented the effect of these quantities on the Brillouin gain central frequency ν_B [7]. The reliability of the measurement is here improved to a high confidence level and can be used as reference. Besides it is completed through the evaluation of the effect on all the three BGS characterising parameters, i.e. central frequency ν_B, linewidth $\Delta\nu$ and maximum gain g_0.

Temperature effects

The effect of temperature on the BGS can be seen on the measurements shown in Fig. 1. The linearity of the central frequency dependence on temperature claimed by all authors is here confirmed to a high confidence level, as shown in Fig. 2 (left). The slope coefficient of ~1.3 MHz/°C slightly decreases for a higher GeO_2 core content. All fibre samples are only coated with a 250μm acrylate microjacket, so that the coating influence is expected to be kept below 0.1 MHz/°C [7].

A new interesting feature is the decrease of the Brillouin linewidth with temperature, as shown in Fig. 2 (right). The dependence is not linear and converges to a constant value at higher temperature for all fibre types. According to works achieved using fused quartz [8], the phonon absorption peaks at a temperature close to 100K where the Brillouin linewidth must be maximum, accordingly. The observed linewidth decrease with temperature represents the upper tail of the absorption peak. The broader BGS observed at room temperature for fibre with higher GeO_2 core content is thus due to either a higher absorption peak or a higher temperature for the maximum absorption. Measurements of Brillouin linewidth in the 100K temperature range are necessary to discriminate between these two possibilities.

The maximum gain increases with temperature and should be proportional to $\Delta\nu^{-1}$, so that the Brillouin gain spectrum integrated over all frequencies remains constant. The product $g_0 \times \Delta\nu$ was checked to be temperature-independent, so that it demonstrates the invariance on temperature of the

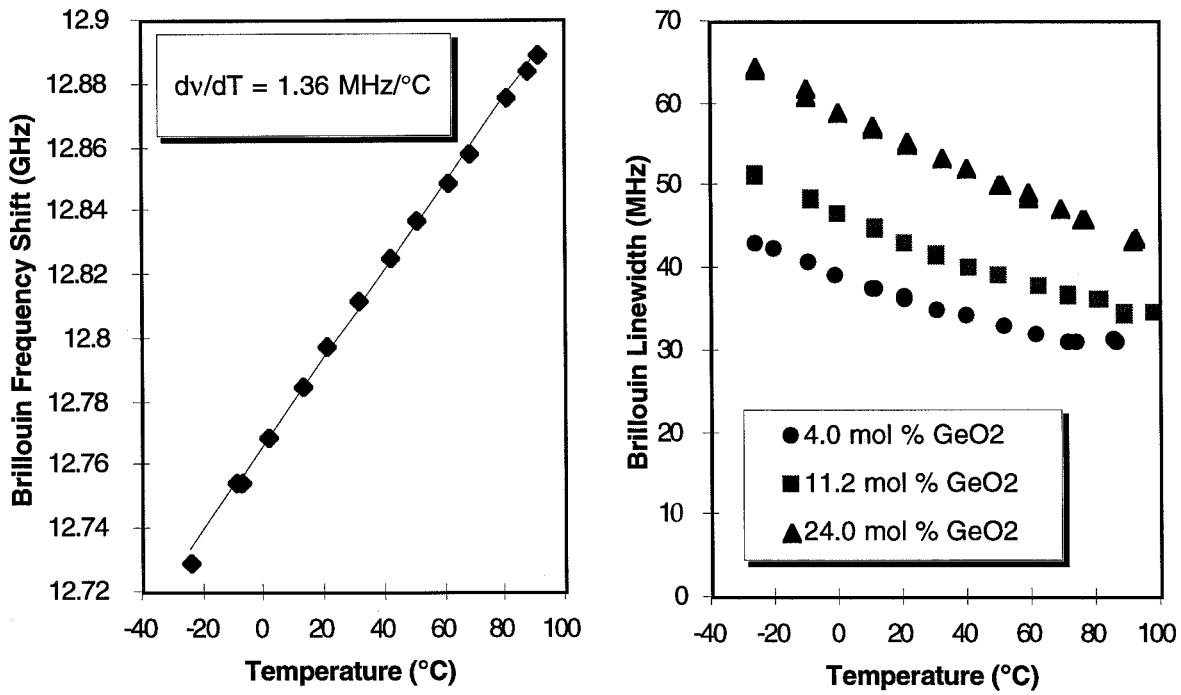

Fig.2 *Central frequency (left) and linewidth (right) of the Brillouin gain spectrum as a function of temperature. Linewidth measurements are shown for fibres with different GeO_2 core content.*

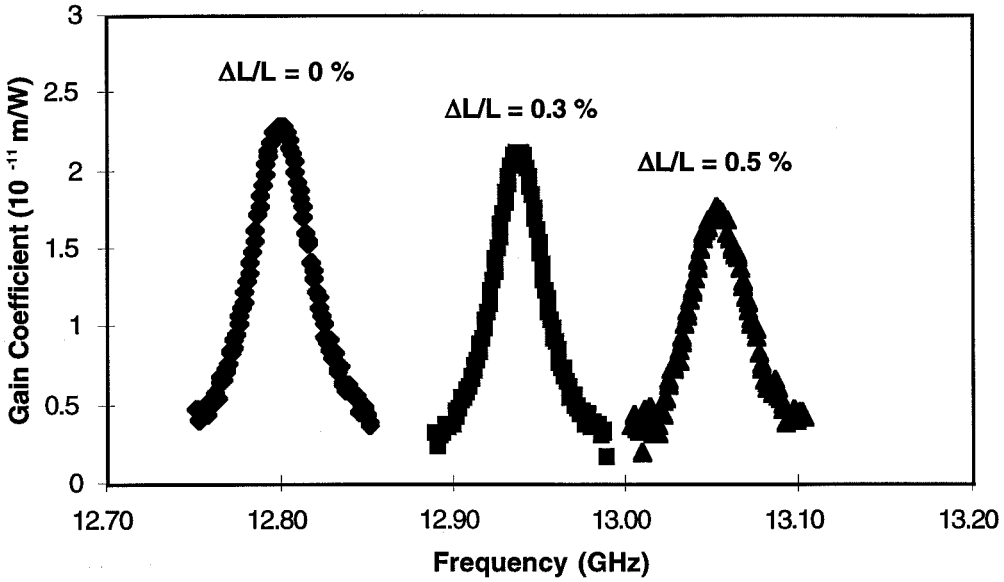

Fig.3 Brillouin gain spectrum of a single mode fibre measured for different fibre elongation, showing the effects of strain on the central frequency, the linewidth and the maximum gain.

electrostrictive strength responsible for the stimulation of Brillouin scattering. It turns out that the gain increase with temperature is only due to its spectral narrowing and thus phonon smaller absorption.

Strain effects

The acoustic velocity V_a is strain-dependent in silica fibres [2], so that the BGS central frequency ν_B is expected to vary when the fibre is under tension. Calibrated elongation was applied to 60 m fibre samples and the BGS were measured up to the fibre breaking point (~1% elongation) using our set-up.

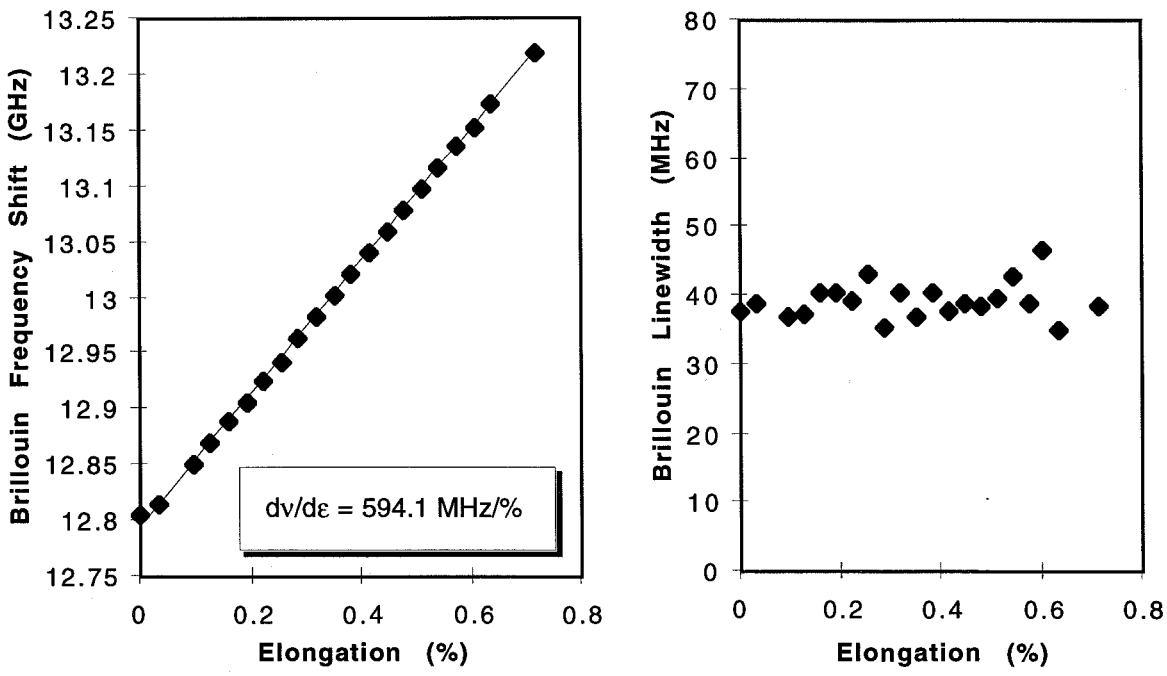

Fig.4 Central frequency (left) and linewidth (right) of the Brillouin gain spectrum as a function of elongation.

The global effect of strain on BGS is shown in Fig. 3. As previously reported [2], the central frequency ν_B shows a strong dependence on strain of several tens of MHz for a 1‰ elongation. The high accuracy of the experimental set-up clearly demonstrates that the linewidth $\Delta\nu$ remains unchanged with strain, while the gain g_0 decreases for elongation close to the breaking point. The excellent linearity of the central frequency ν_B on strain and the invariance of the linewidth $\Delta\nu$ is confirmed in the detailed measurement shown in Fig. 4.

The measured normalised slope coefficient $\frac{1}{\nu_B}\frac{d\nu_B}{d\varepsilon}$ ranges from 4.64 to 4.73 for standard fibres at 1320 nm. This value is slightly higher than the previously reported 4.4 coefficient [2], resulting in a central frequency shift very close to 600MHz per percent elongation. This coefficient was checked to be negligibly dependent on the fibre jacket type, confirming the great potentiality of BGS analysis for monitoring strains actually experienced by fibres.

The gain coefficient g_0 depends on many structural quantities such as material density ρ and refractive index n, that may change in a non-negligible fraction for high strain. This may explain the gain decrease for strain in the percent range. It is remarkable that the central frequency dependence on strain keeps linear under such extreme conditions.

Conclusion

The three parameters characterising the Brillouin gain spectrum (BGS) are measured with a high accuracy under different temperature and strain conditions. This was performed using an original single source measuring technique providing highly reliable results.

Thanks to these measurements one can conclude that the Brillouin central frequency ν_B depends very linearly on either temperature or strain over an extended range (-30°C < T < 100°C, $0 < \varepsilon < 1\%$). The effects of temperature and strain cannot be discriminated by just measuring the central frequency ν_B. The BGS linewidth is temperature-dependent owing to the presence of an absorption peak at low temperature (~100K), while an applied strain leaves the linewidth unchanged. The linewidth measurement in addition to the central frequency determination could therefore decorrelate temperature from strain effects, provided that no significant change on these quantities occurs within the measurement spatial resolution.

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