*European* **"COST Workshop 94" Optical Telecommunications,** *Nice April 17-21, 1994*

# High-accuracy Brillouin Gain Spectrum Measurements of Single-Mode Fibres and Relation with Fibre Parameters

**Luc THEVENAZ, Marc NIKLES, Jacques BOSCHUNG and Philippe ROBERT**

EPFL Swiss Federal Institute of Technology, Metrology Lab.
CH-1015 Lausanne, SWITZERLAND

The importance of the measurements of the Brillouin gain spectrum has been growing in the past few years owing to its potential use for monitoring strains experienced by optical fibres [1] and for distributed temperature sensing [2]. It is classically measured by launching a highly coherent lightwave into a test fibre and by observing the amplification of a weak probe signal propagating in the backward direction [3]. The optical frequency of the probe signal must be precisely tunable to properly scan the Brillouin gain spectrum. This spectrum lies 12-13 GHz below the pump frequency at a wavelength of 1300 nm and has a Lorenzian line shape with a few tens of MHz FWHM. Generally two different laser sources are used to generate pump and probe signals. A stable frequency difference with less than 1 MHz fluctuations is difficult to generate, so that highly accurate measurements are not available so far and large discrepancies are noted between results reported by different authors.

In this contribution, we present a novel method using a single laser source for BGS measurements. It makes possible reference measurements owing to its ideal inherent frequency stability. Systematic measurements of fibres having different index profiles and manufactured through different processes were performed. A general behavior was observed and a relations between Brillouin Stokes frequency shift, Brillouin gain linewidth and fibre optical parameters were established.

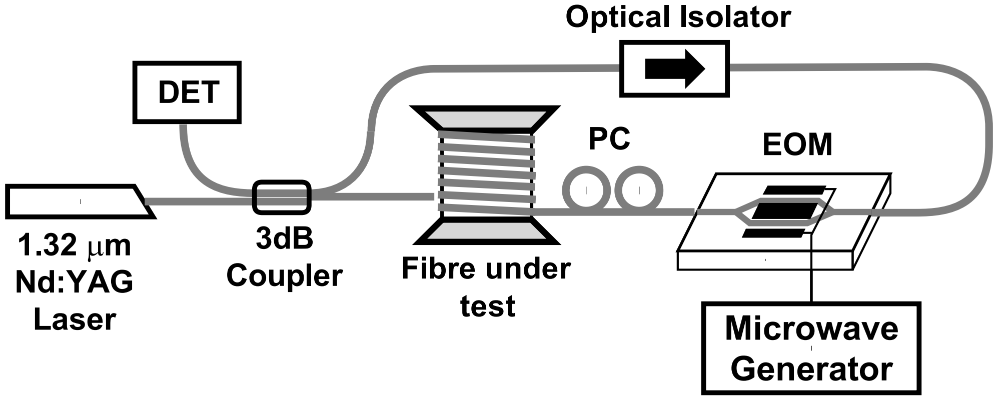

*Fig. 1. Experimental setup for Brillouin gain spectrum measurements*

The experimental setup is schematically shown in Fig. 1 and its principle is explained in details elsewhere [4,5]. For better understanding let just mention that test signal is generated by modulating the pump signal using an ultrawideband electro-optic modulator driven by a synthetised signal generator. This creates two sidebands in the optical spectrum that are separated from the pump frequency by the modulation frequency. When this frequency corresponds to the Stokes shift, Brillouin interaction may occur. The lower sideband experiences gain and grows exponentially as it propagates along the fibre under test, whereas the upper sideband is depleted and decays exponentially. The sum of this two effects yields an hyperbolic cosine relationship between amplification and gain coefficient.

$$I(L) = 2 I_o \cosh\left\{ g_B(\nu) I_P L_{eff} \right\}$$

where $I_0$ is the test signal input intensity, $g_B$ is the Brillouin gain coefficient, $I_p$ is the pump intensity and $L_{eff}$ is the usual effective fibre length for the nonlinear interactions. This relationship is only strictly valid under the assumption that any effect on the pump signal (gain or depletion) is negligible.

Various Brillouin gain spectra of different fibres are shown in Fig. 2. For any fibre type the gain curve $g_B(\nu)$ perfectly fits a Lorentzian function, as shown in Fig. 2.b and 2.d. For triangular-shaped core fibres a second peak of smaller amplitudes was observed a few hundreds of MHz higher in frequency (Fig. 2.a) and is probably due to a higher order guided acoustic mode. For PCVD processed fibres, two close peaks

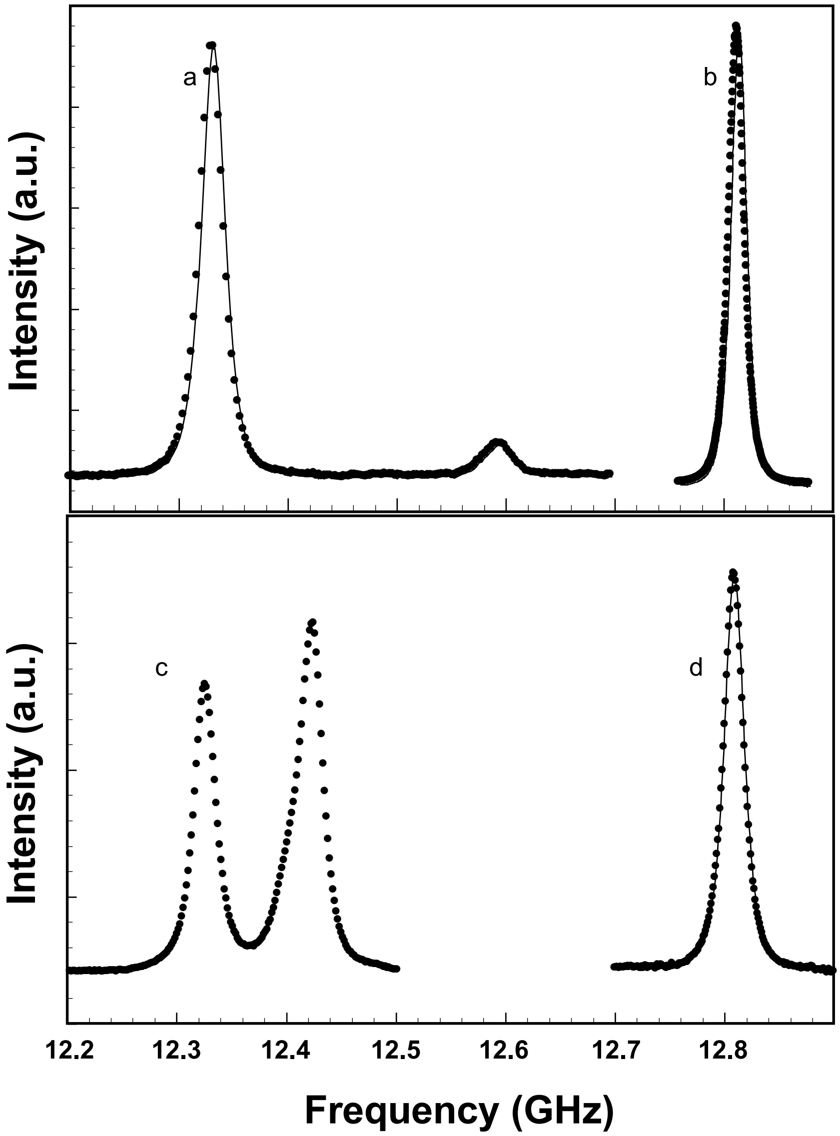

*Fig. 2. Brillouin gain spectra of different single mode fibres: a. triangular profile ($\Delta n$=14x10$^{-3}$), b. step profile ($\Delta n$=5x10$^{-3}$), c. W-profile, d. triangular profile ($\Delta n$=5x10$^{-3}$).*

| **Core type** | **Index change** (x 10 $^{-3}$) | **Brillouin shift** (GHz) | **Linewidth** (MHz) | **Manufacturing process** |
|---|---|---|---|---|
| n.a.(bulk silica) | 0 | 13.1000 | 23.0 | |
| step | 4.5 | 12.8527 | 34.5 | MCVD |
| step | 5.0 | 12.7960 | 35.7 | MCVD |
| triangle | 5.0 | 12.8088 | 35.4 | OVD |
| step, depressed cladding | 6.5 | 12.8001 | 36.3 | MCVD |
| step | 8.0 | 12.7191 | 34.5 | MCVD |
| triangle | 10.5 | 12.3886 | 40.6 | MCVD |
| triangle | 14.0 | 12.3309 | 42.5 | MCVD |
| step | 30.0 | 11.5094 | 52.4 | MCVD |

*Table I. Summary of measurements performed and fibres characteristics.*

of comparable amplitude are measured and this structure is still unexplained (Fig. 2.c). The length of the fibres was in the 100m-600m range and were wound by hand to avoid any tension. Regular mechanical winding induces stresses that were observed to bias the measurements by causing an inhomogeneous broadening of the gain curve. Care was also taken to decrease the test signal amplitude until no effect on the gain curve are measured, meaning a negligible pump depletion.

Table I summarizes the measurements performed on theses fibres, together with other fibres characteristics. The Brillouin Stokes shifts range from 11.5 GHz to 12.8 GHz and a clear relationship is observed between Stokes shift and core-cladding index differences, as shown in Fig. 3. An interesting feature is the excellent agreement between the extrapolated value for $\Delta n$=0 and the Stokes shift calculated for bulk silica.

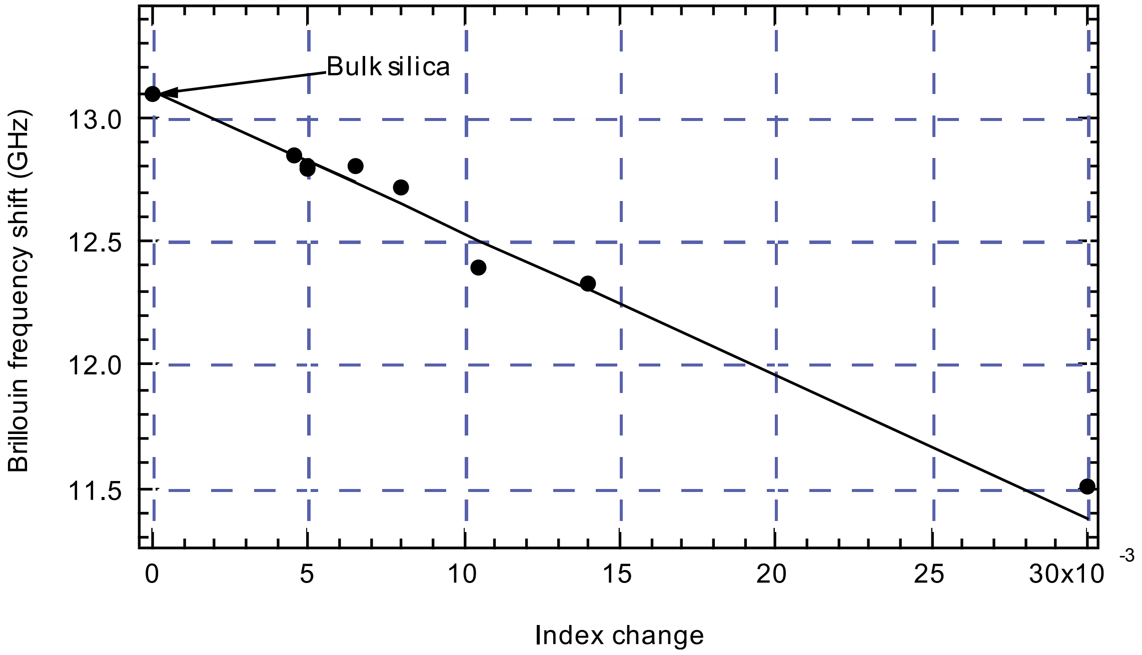

*Fig. 3. Relationship between the frequency of the Stokes shift and the core-cladding index differences.*

Another relationship was found between Stokes shift $\nu_B$ and Brillouin gain line width, as shown in Fig. 4. The extrapolated value for $\Delta n$=0 is close to the bulk silica value, but the agreement is not perfect. This may be due to excess phonon damping occurring in the fibre waveguide, though the confidence level of the measurements made in bulk silica is not known.

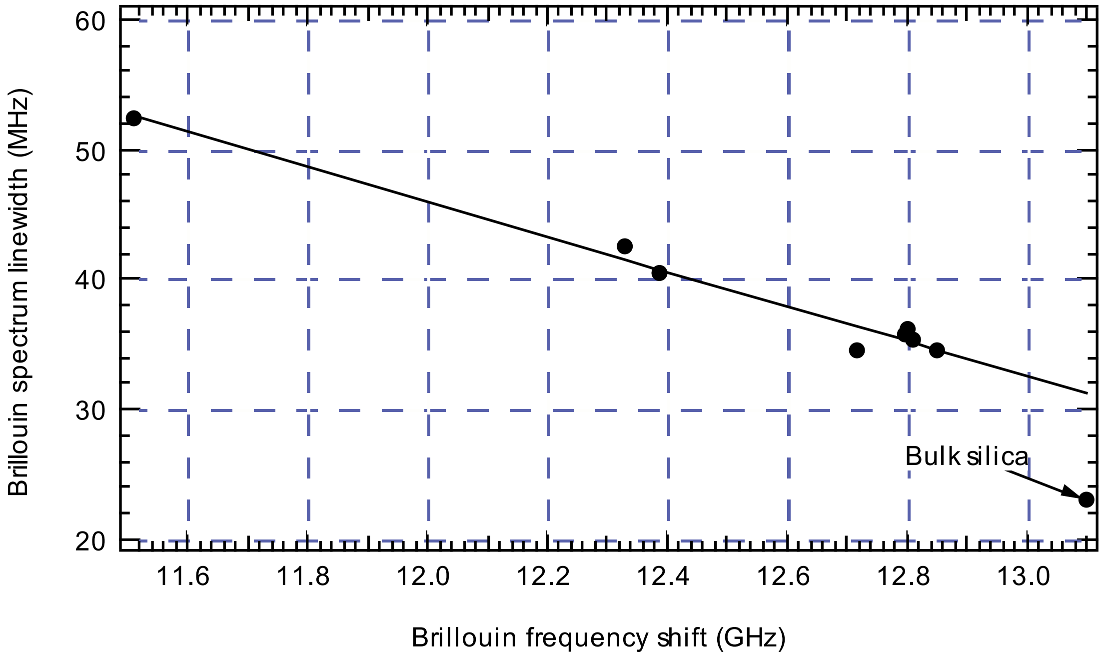

*Fig. 4. Relationship between Brillouin gain linewidth and the frequency of the Stokes shift.*

In conclusion highly accurate measurements of the Brillouin gain curve were performed in fibres with very different guiding characteristics. These measurements explain the differences observed between fibres and bulk silica and the scattered value reported by different authors. They also confirmed that the core doping decreases the acoustic velocity - and thus the Stokes shift - and the phonon lifetime, causing a broader linewidth.

## Acknowledgments

The authors would like to thank the Swiss PTT, Câbles Cortaillod S.A. and PSEL fund for their kind support and Cabloptic S.A. to have, in addition to its support, supplied the different optical fibres

## References

[1] T. Horigushi, T. Kurashima and M. Tateda, "A Technique to Measure Distributed Strain in Optical Fibers", IEEE Photon. Technol. Lett., vol. 2, no. 5, pp. 352-354, 1990

[2] X. Bao, D. J. Webb and D. A. Jackson, "22-km distributed temperature sensor using Brillouin gain in an optical fiber", Opt. Lett., vol. 18, no. 7, pp. 552-554, 1993

[3] N. Shibata, K. Okamoto and Y. Azuma, "Longitudinal acoustic modes and Brillouin-gain spectra for GeO2-doped-core single-mode fibers", J. Opt. Soc. Am. B, vol. 6, no. 6, pp. 1167-1173, 1989

[4] M. Niklès, L. Thévenaz and P. Robert, "Brillouin Gain Spectrum Measurements using a single Laser Source", Proc. Nonlinear Guided-Wave Phenomena (Cambridge 1993), OSA publications, paper MD 5

[5] M. Niklès, L. Thévenaz and P. Robert, "Brillouin Gain Spectrum Measurements of Single Mode Fiber using a Single Laser Source", submitted to Optics Letters