Brillouin Gain Spectrum Measurements using a Single Laser Source

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Abstract

Brillouin gain spectrum measurements in fibres are presented, where a single source is used to generate the pump and probe signals, giving highly reliable results.

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Introduction

Stimulated Brillouin scattering (SBS) is a non-linear process that occurs in optical fibres at much lower pump power than most other non-linear effects. The pump wave is scattered into a backward-propagating Stokes wave that experiences a frequency shift lying in the 12-13 GHz range at 1300 nm. This shift is proportional to the acoustic velocity within the fibre, making SBS an efficient tool for sensing applications, e.g. for monitoring strains in installed fibres [1].

For these applications the determination of the spontaneous Brillouin gain spectrum (BGS) is a key measurement, because it contains important information, such as the Brillouin frequency shift ν_B and linewidth $\Delta\nu_B$, that depends on environmental quantities.

Many techniques have been proposed to date to perform this gain spectrum measurement [2,3,4]. All these methods require two distinct sources to generate the pump and probe signals. This results in several experimental constraints that are difficult to meet, such as simultaneous power and frequency stability of the two lasers, low jitter and narrow linewidth, accurate tunability within the Brillouin gain band. The reported measured $\Delta\nu_B$ using these techniques are at least twice larger than the predicted value for fused silica and this discrepancy is so far not fully understood.

In this paper the measure of spontaneous Brillouin gain spectrum using a single source is presented. With this method the probe signal is generated by modulating the pump wave using a microwave generator and a LiNbO3 guided-wave modulator, so that the probe wave actually corresponds to the lower sideband. This scheme offers many advantages: any laser frequency drift is automatically compensated and no tunability of the source is required. The Brillouin gain curve can be scanned with ideal accuracy and stability by sweeping the frequency of the microwave generator.

Measurements performed using this method show an excellent agreement with those obtained using two-sources techniques. In addition the optical scheme of the method can be modified, so that the access to one fibre end is necessary to perform the measurement.

Generation of the probe signal

As mentioned above, the traditional measurement scheme using a probe and a pump signal can be improved and simplified by using an electrooptic modulator (EOM). In this case the probe signal is one of the generated sidebands. Fig. 1a shows the optical frequency sidebands generated by intensity modulating a CW light using a $LiNbO_3$ EOM. Among the carrier and harmonics only the lower first sideband is of use. However, by properly setting the DC bias applied to the EOM electrodes, the carrier ν_0 can be fully suppressed and the power transferred into the first harmonics maximised, as shown in Fig. 1b. The unused upper sideband cannot be easily filtered out and be distinguished from the probe signal in the detection stage, but it only causes an intensity offset that needs to be subtracted before processing the data.

A major issue is the EOM modulation bandwidth that must be in excess of the Brillouin frequency shift (13 GHz), but such devices are now widely available. However, another modulation scheme was also tested that has the advantage to require a much smaller EOM bandwidth. When the DC bias of the EOM is set to suppress the carrier, the first order sidebands are separated by twice the modulation frequency f_m. Provided that this frequency is half the Brillouin frequency ($2f_m \approx \nu_B$), the upper sideband corresponds to the pump and the lower to the probe.

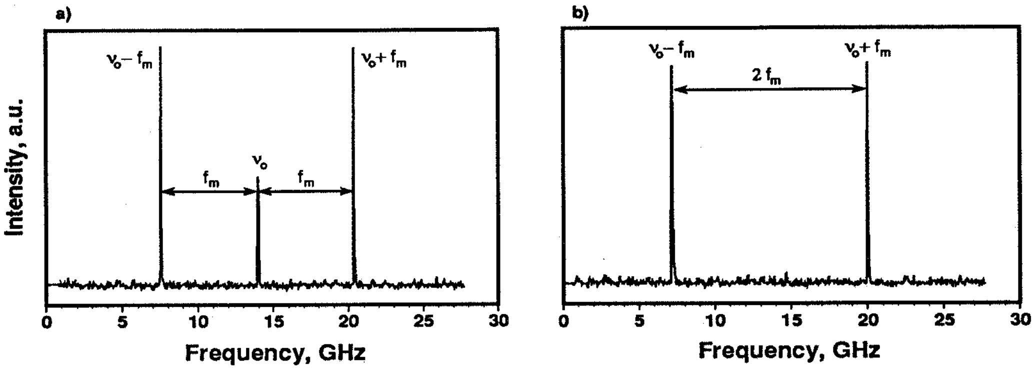

Fig. 1 Optical spetra of CW light modulated using a EOM.
a) Carrier and first oder sidebands b) Suppression of the carrier by properly setting the DC bias.

Two-end measurement

The experimental set-up used to measure the BGS is schematically shown in Fig. 2. The light delivered by a 1.32 µm diode-pumped YAG laser is split by a 3 dB coupler. One output serves as a pump for the fibre under test, and the other is launched into the EOM, in order to generate the probe signal. The probe signal is then fed back into the output end of the fibre under test. An in-line isolator is inserted into the loop before the EOM to prevent interferences to occur. As the modulation frequency is swept through the BGS, the relative output level of the probe is recorded, and yields the gain curve after a simple data processing. Polarisation controller are used to match the polarisations of the pump and probe waves, in order to maximise the measurement contrast.

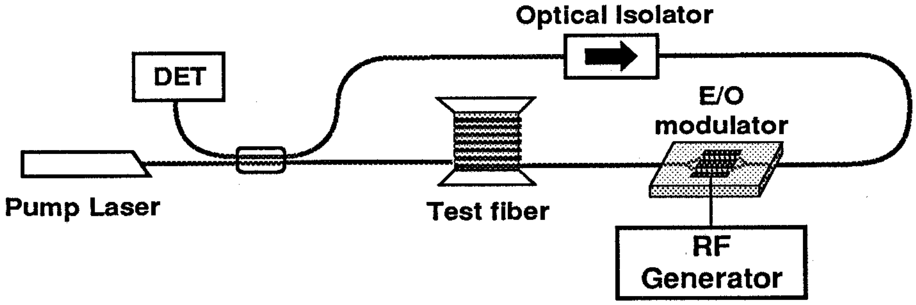

Fig. 2 Expermental setup for BGS measurements using a EOM to generate the probe signal.

Fig. 3 shows the BGS of a 25 km dispersion-shifted single mode fibre. It clearly shows two peaks separated by 260 MHz, which attest the presence of two guided acoustic modes (LO_{0m}) that may exist in this type of fibre (GeO_2-doped core) [4]. Since the linewidth of the sidebands are very narrow (<20 kHz), the resolution of the measurement is excellent. Moreover, the use of a single laser greatly decreases the frequency jitters and consequently improves the resolution on the linewidth determination. The measured FWHM of the BGS is 43 MHz, which is nearly twice the value in bulk silica (22 MHz at 1.3 μm) showing a remarkable fibre homogeneity for such a fibre length.

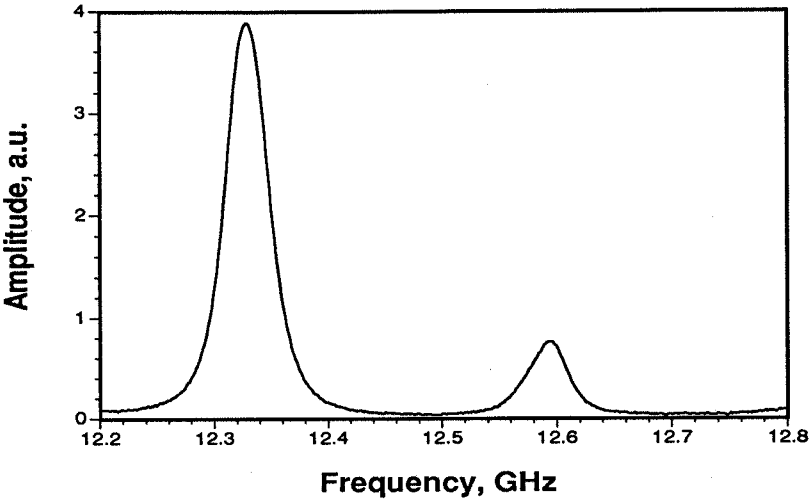

Fig. 3 Brillouin gain spectrum of a 25 km dispersion-shifted single mode fibre.

Single-end measurement

The set-up in Fig. 2 requires that the fibre far end is not remote. Fig. 4 shows a simpler scheme that requires only one fibre end to be accessible. After passing through the EOM the modulated light is launched into the test fibre. When the light propagates in the forward direction, the carrier pumps the medium, while the whole light experiences the fibre loss. A small part of the light is reflected at the fibre far end through Fresnel reflection. The lower sideband acts as a probe signal and is thus amplified by the SBS process, the undepleted part of the pump being just attenuated.

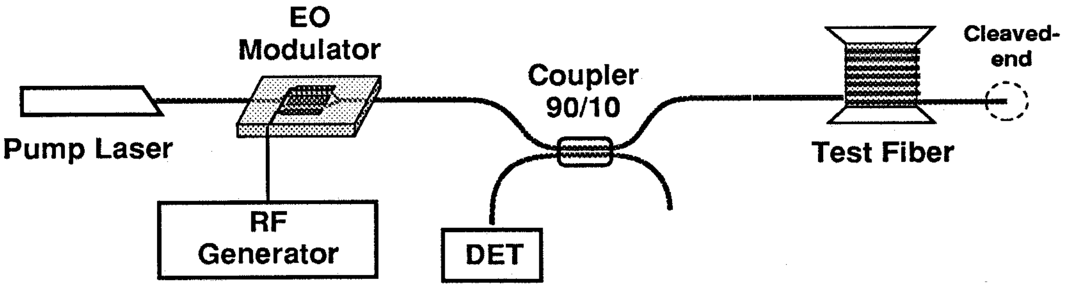

Fig. 4 Experimental setup for single-end Brillouin gain spectrum measurements.

As mentioned above, the necessary EOM bandwidth may be reduced by properly setting the DC bias. In fact, when the carrier is suppressed, the upper sideband pumps the medium in the forward direction while the lower sideband plays the role of the probe after being reflected at the fibre end. When the frequency separation of the sidebands lies within the BGS, the probe is amplified whereas the undepleted pump is attenuated. By sweeping the modulation frequency of the EOM, and monitoring the relative level of the output signal on the detector, we can scan the BGS. The signal to noise ratio can be improved by modulating the EOM RF driving signal in order to perform a lock-in detection. Fig. 5 shows the BGS of a 12.8 km OCVD single-mode fibre. In this modified scheme the pump depletion can in most cases not be neglected, so that the BGS is obtained using a more complicated data processing.

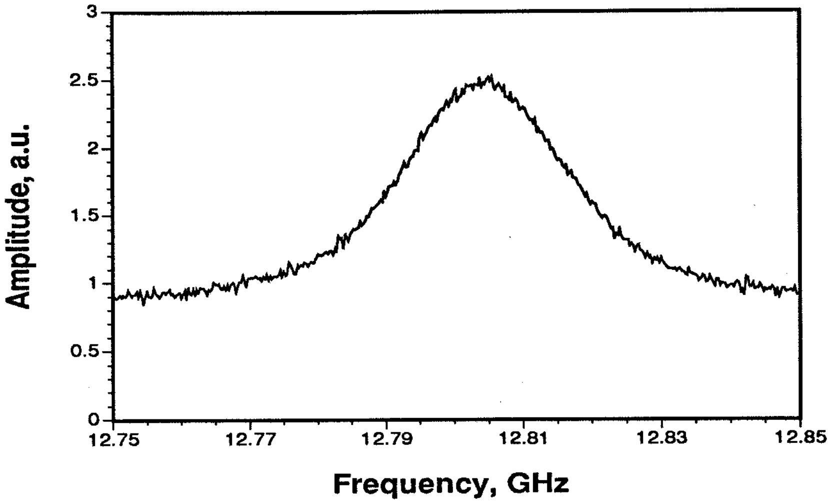

Fig. 5 Brillouin gain spectrum of a 12.8 km OCVD single-mode fibre

Conclusion

The results obtained using this method confirm the latest measurements [3] that the Brillouin gain linewidth in optical fibre (43 MHz) is very close to twice that observed in bulk silica (22 MHz). The inherent high stability of the jitter-free probe signal gives a good level of confidence to this observation and this should hopefully clarify the further discussions.

The generation of the probe signal using a modulator may bring many more advantages in addition to those presented here, such as frequency-domain coding for a more sophisticated and sensitive detection and time-domain coding to address distinct positions along the fibre. These more advanced modulation schemes are currently investigated.

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