

Polarisation state optimisation in observing Brillouin scattering signal in polymer optical fibres

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In general, the state of polarisation (SOP) should be adjusted to optimise the signal-to-noise ratio of Brillouin measurement based on self-heterodyne detection. Although Brillouin Stokes power in silica fibres is known to be enhanced by optimising the SOP, the role of SOP optimisation in polymer optical fibres (POFs) is quite different from that in silica fibres. In this reported work, it is clarified that the role of SOP optimisation in POFs lies not in enhancing the Brillouin Stokes power but in suppressing the tail of the Rayleigh-scattered light spectrum.

Introduction: Brillouin scattering in optical fibres [1] has been applied to a number of devices, such as lasers, microwave signal processors, slow light generators, optical storages and strain/temperature sensors [2–4]. To improve the performance of these devices, Brillouin scattering properties have been investigated not only in glass optical fibres (including silica fibres, tellurite fibres, chalcogenide fibres, photonic crystal fibres and rare-earth-doped fibres) but also in polymer optical fibres (POFs) (including perfluorinated graded-index (PFGI-) POFs [5, 6] and polymethyl methacrylate (PMMA)-based step-index (SI-) POFs).

In general, self-heterodyne detection is employed to obtain Brillouin gain spectra (BGS) with a high-frequency resolution [3, 5], where the relative state of polarisation (SOP) between the Stokes light and the reference light needs to be adjusted. In some applications (for example, sensing), the measurement stability is enhanced by making the BGS polarisation-independent based on adaptive polarisation control [7], polarisation diversity [8], Faraday rotation [9] and polarisation scrambling [10]. However, in evaluating the Brillouin properties, the signal-to-noise ratio (SNR) of the BGS measurement is often maximised using polarisation controllers (PCs) [5, 6]. Although it is well known that the role of SOP optimisation in silica fibres is to simply maximise the Brillouin Stokes power [1], the role of SOP optimisation in POFs has not been clarified yet. In this Letter, we experimentally show that the role of SOP optimisation in POFs consists in suppressing the tail of Rayleigh-scattered light spectrum, not in maximising the Stokes power itself.

Theory: In silica single-mode fibres (SMFs), the Brillouin frequency shift (BFS) is known to be approximately 10.9 GHz at 1.55 μm wavelength, and their Brillouin threshold power is as low as <1 mW (for km-order-long SMFs) [1], leading to high Brillouin Stokes power. Thus, the tail of the Rayleigh-scattered light spectrum has hardly any influence on the Stokes signal, which can be directly optimised by adjusting the SOP. In contrast, in PFGI-POFs, the BFS is reported to be as low as approximately 2.8 GHz at 1.55 μm [5], and their Brillouin threshold power is as high as ~ 13 W (for PFGI-POFs longer than ~ 50 m) [6]. Consequently, the Stokes signal is easily overlapped or buried by the Rayleigh tail, the power of which drastically changes according to the SOP. As a result, in PFGI-POFs, the maximum SNR is achieved not by maximising the Stokes power but by minimising the Rayleigh tail power using PCs.

Experiments: The fibres under test (FUTs) employed in the experiment were: 1. a 1 km-long silica SMF with core diameter of 9 μm , core refractive index of ~ 1.47 , numerical aperture (NA) of 0.13, and the propagation loss at 1.55 μm of ~ 0.5 dB/km, and 2. a 1-km-long PFGI-POF with core diameter of 50 μm , core refractive index of ~ 1.35 , NA of 0.185, and the loss at 1.55 μm of ~ 250 dB/km. The experimental setup based on self-heterodyne detection was similar to that previously reported in [5]. A distributed-feedback laser diode (DFB-LD) at 1547 nm was used as a light source. Index-matching oil was placed on one end of the silica SMF to suppress the Fresnel reflection. One end of the PFGI-POF was optically butt-coupled to port 2 of a circulator composed of a silica SMF, and the other end was kept open (note that the Fresnel reflection need not be taken into consideration [6]). A polarisation scrambler with 700 kHz modulation frequency was inserted in the pump path after an erbium-doped fibre amplifier (EDFA), and two PCs were inserted in the pump and the reference paths.

Fig. 1 shows the measured BGS in the silica SMF with optimised, anti-optimised and scrambled SOPs when the pump power was fixed at 18.7 dBm. The BFS was 10.89 GHz. As the SOP changed, the Stokes power also changed drastically (by over 20 dB), but the noise floor remained almost the same. This behaviour agrees well with the theory [1]. Fig. 2 shows the measured BGS in the PFGI-POF with optimised, anti-optimised and scrambled SOPs. The pump power was also 18.7 dBm. The BFS was 2.77 GHz. The Rayleigh power was so much higher than the Stokes power that even its tail had clear influence on the Stokes signal. When the SOP was changed, the corresponding change was by far larger in the Rayleigh tail power (~ 10 dB) than in the Brillouin Stokes power (<2 dB). In consequence, the highest SNR of the BGS detection was obtained when the SOP was adjusted so that the Rayleigh tail power was suppressed as much as possible; the SNR was lowest when the Rayleigh tail power was highest. We should also note that the apparent Stokes power was negatively correlated with the SNR, which goes against the conventional concept of SOP adjustment in silica fibres [1].

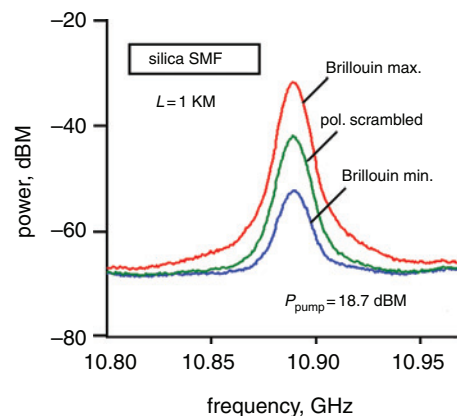


Fig. 1 Measured BGS in silica SMF with SOP optimised, anti-optimised and scrambled

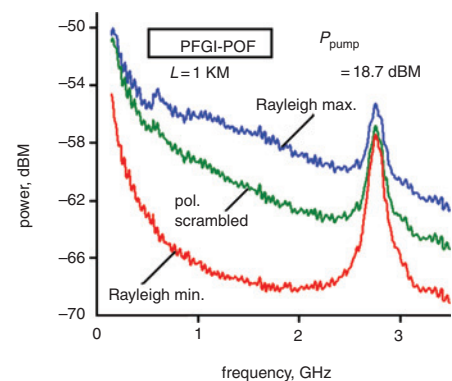


Fig. 2 Measured BGS in PFGI-POF with SOP optimised, anti-optimised and scrambled

It has been reported that the Brillouin Stokes power in POFs is, compared with those in glass fibres, extremely low because of their multi-mode nature (or large core diameter) and high Brillouin threshold power (or high propagation loss) [5, 6]. The fact that the Stokes power itself cannot be enhanced by SOP adjustment seems to be another reason for their small Brillouin signal. The SNR deterioration by polarisation scrambling is also a big issue for applications that require measurement stability [2–4]. Though some methods to enhance the Brillouin signal in POFs have been developed up to now [11], further improvement is needed, for example, by using a lower wavelength at which the propagation loss is much lower [6].

Conclusion: We have experimentally shown that, in order to maximise the SNR of the BGS measurement in POFs by SOP optimisation, its role is not to enhance the Stokes power itself but to suppress the tail of the Rayleigh-scattered light spectrum. We believe that this result is extremely important as technical knowledge in further investigating the

Brillouin properties in POFs and in developing relevant devices and systems in the future.

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One or more of the Figures in this Letter are available in colour online.

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