Laser linewidth determination in the sub-Megahertz range using a Brillouin fibre laser

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The Brillouin fibre laser has experimentally demonstrated its suitability for narrow laser linewidth measurement. This simple and affordable solution requires only standard optical supplies and is applicable over a broad wavelength range using the same set-up.

Recently developed laser sources show improved coherence properties and linewidth in the sub-megahertz range will be available in a near future even in monolithic semiconductor lasers. The linewidth measurement of such lasers is a new challenge, since classical self-homodyne or self-heterodyne techniques require excessive lengths of delaying fibre and are thus not practicable. The linewidth can also be evaluated by analysing the beat signal resulting from the interference with another uncorrelated laser. This requires another laser either with a comparable well-known spectrum or with an extremely narrow and thus negligible linewidth. A novel configuration using the second option is reported here using a simple set-up based on a Brillouin fibre laser.

Stimulated Brillouin scattering (SBS) is a non-linear inelastic process occurring in any single mode fibre and its observation threshold is the lowest among all non-linear effects. It leads to an amplification of a backward-propagating Stokes wave shifted in frequency by :

$$\nu_b = 2\, n\, V_a \,/\, \lambda \qquad (1)$$

where V_a is the acoustic velocity within the fibre, n is the refractive index and λ is the wavelength of the incident light. SBS laser emission can be achieved using an all fibre resonator and the low round-trip loss can lead to a threshold pump power in the sub-miliwatt range [1]. The two incident and backward optical waves and the acoustic wave are tightly coupled in amplitude and phase, so that any phase fluctuation of the incident wave should affect the phase of the two other waves. But a remarkable feature of Brillouin interaction makes the phase noise to be almost entirely transferred to the acoustic wave and the phase of the Brillouin amplified wave remains virtually constant. This results from the strong damping experienced by the acoustic wave that gives rise to a quasi-immediate phase and amplitude change. The Brillouin laser emission can thus show an excellent spectral purity, much better than the incident light. This has been confirmed experimentally [2] and a 100-kHz linewidth incident light has generated a 4-Hz Brillouin emission in a fibre ring cavity [3].

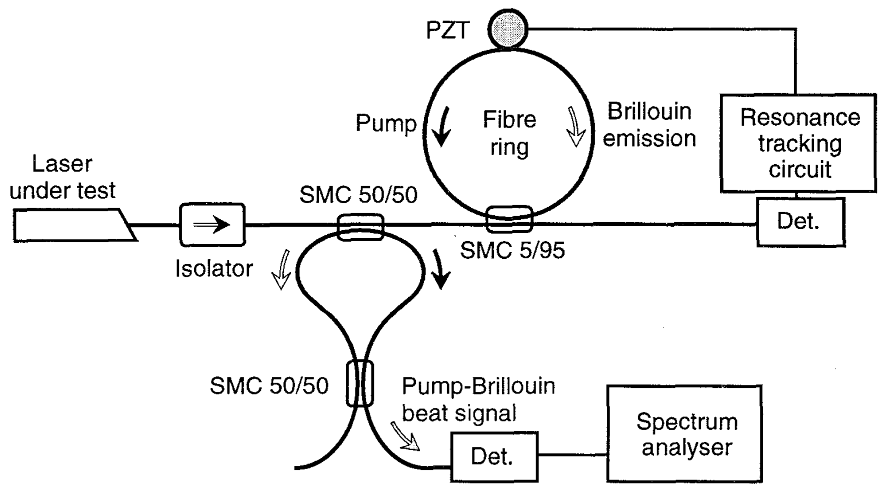

Fig.1 Schematic diagram of the experimental set-up using a Brillouin fibre laser to generate the reference signal combined with the light from the source under test.

A system based on such a Brillouin fibre laser and shown in figure 1 has been developed for the characterisation of sources with sub-megahertz linewidth. The light from the source under test is launched into a fibre ring cavity and generates a Brillouin emission in the opposite direction at the fixed frequency ν_b below the source frequency. This reference signal is then combined with the light from the source to produce a beat signal in the 10-13 GHz range depending on the source wavelength. A wideband detector and a microwave spectrum analyser then measure the beat signal spectrum. The fibre resonator was made of a weakly coupling 3/97 coupler and of 30 m of standard single mode fibre. A PZT stretcher tunes the cavity length and a tracking electronic circuit keeps the incident light in resonance with the cavity. The circulating power is much higher than the incident power in such a high-finesse cavity, so that Brillouin emission was observed for an incident power as low as 0.4 mW, leaving a comfortable power margin. The bandwidth of the electronic is carefully designed to follow only the source jitters and the thermal drifts. It's side effect is to remove low frequency components of the spectrum, limiting the minimum detectable noise frequency to about 500 Hz.

The 4.2 kHz linewidth of a compact diode-pumped Nd:YAG laser at 1319 nm was successfully and comfortably measured using this system, as shown in figure 2. This spectrum is representative of the source spectrum, provided that the Brillouin

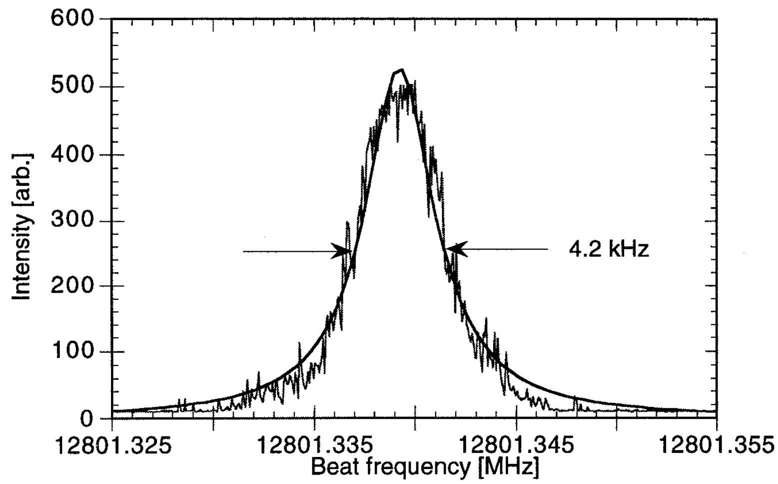

Fig.2 Measured spectrum of a compact diode-pumped Nd:YAG laser, emitting at 1319 nm.

emission noise contribution is negligible. This was checked using another identical Brillouin fibre laser and the resulting *long-term* beat spectrum between the two Brillouin emissions was narrower than 1 kHz. In that case most of the broadening is due to the uncorrelated thermal drifts of the two distinct cavities, so that the effective reference linewidth in the measurement set-up is expected to be much lower than 1 kHz.

This system is surprisingly more limited for larger linewidth than for highly coherent sources. The resonance spectral width of the 30-m fibre cavity is about 100 kHz, so that only light with a substantially narrower spectral width than the resonance can be efficiently launched into the resonator, as shown in figure 3. A broader resonance width means either a shorter cavity length or a reduced finesse, both resulting in a reduced Brillouin round-trip gain and a higher Brillouin emission threshold, accordingly. It turns out that an incident power in excess of 20 mW is actually needed to measure a 1 MHz linewidth source.

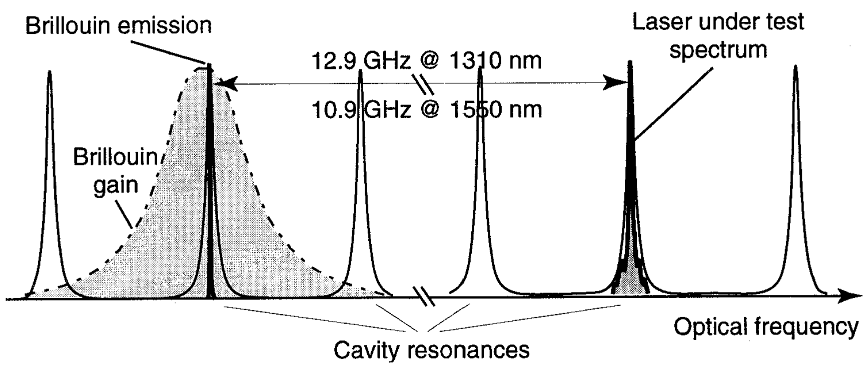

Fig.3 Principle of operation of the Brillouin laser. The incident light spectrum must fit in a cavity resonance and the backward emission takes place in another resonance at a lower frequency corresponding to the Brillouin shift.

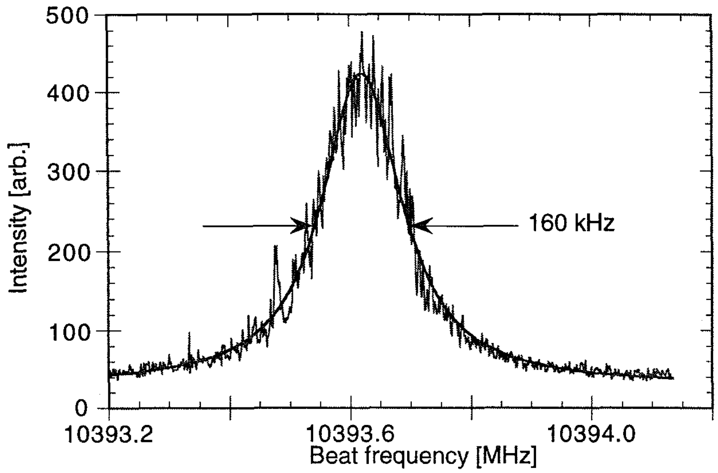

Fig.4 Measured spectrum of a spectrally-narrowed semiconductor laser. A substantial linewidth reduction is achieved with a minor reflection and can be accurately measured.

A short 3-m cavity Brillouin laser was used to generate the reference signal to accurately analyse the effect of spectral narrowing by optical feedback on a semiconductor laser. The 160-kHz measured linewidth shown in figure 4 was in excellent agreement with measurements performed using the standard self-homodyne technique.

In conclusion the Brillouin fibre laser has experimentally demonstrated its suitability for the measurement of laser linewidth in the 1 kHz to 500 kHz frequency range. A major advantage of this system is to be widely independent of the source wavelength by generating the uncorrelated reference signal at a fixed frequency below the source under test. This solution is simple and affordable, since it only requires widely available standard optical supplies.

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