Brillouin Scattering based Distributed Sensing of Temperature

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Abstract: ***We characterize the temperature dependent gain spectrum of Stimulated Brillouin scattering in an optical fiber by using a probe signal generated through carrier suppressed modulation. Probe amplification with pulsed pump is analyzed using these results.***

Keywords: Brillouin Scattering, Temperature, Distributed Sensing

1. Introduction

Stimulated Brillouin Scattering (SBS) is a process resulting from the interaction between an incident optical field and the acoustic waves in the material. SBS in standard single mode fibers has been widely utilized in temperature and strain sensing, and in spectroscopy [1]. Sufficiently intense light incident on an optical fiber results in a strong back-scattering, and the scattered light is found to be Stokes-shifted with respect to the incident light due to SBS. The gain spectrum of SBS depends on the nature of material. This is very attractive since the bare fiber can be used as sensing element without any special fiber processing. Standard optical fibers may thus be used, resulting in a low cost sensing element. For standard single mode fiber, the Brillouin gain spectrum is typically found to have a Lorentzian line shape with line width ~ 30 MHz and with gain peak down-shifted in frequency from the pump, by ~ 11 GHz [2,3]. The gain spectrum characteristics of SBS have been utilized recently for the generation of slow light and the demonstration of all-optical buffers [4]. For all the applications that utilize SBS, it is very critical to extract the Brillouin gain spectrum of the fiber used. The narrow linewidth of the gain spectrum makes it challenging to extract the same with reasonable degree of accuracy.

In this paper, we demonstrate a method to extract the line width and the center frequency of the Brillouin gain spectrum of a standard single mode fiber with the modulation of a counter propagating probe in the carrier suppressed configuration. The temperature dependence of the center frequency of the gain spectrum is established quantitatively [2]. These peak values of gain coefficients obtained from these experiments are further used in simulations to compare with the experimental results on the amplification of probe in a pulsed-pump scenario. The results obtained are directly relevant to its application in temperature/strain sensing and for the generation of slow light.

2. Experimental Setup

The experimental setup for the Brillouin amplifier configuration to obtain Brillouin profile is shown in Fig 1. Amplified light from a narrow-line-width tunable laser (line-width ~ 30 kHz) is used to generate the pump and the counter-propagating probe in the Brillouin amplifier, using a 3-dB coupler. The use of single CW laser as probe and pump enhances the stability of the system. One output of the coupler (pump) is propagated through a standard single mode fiber of length 25 km to generate SBS in the system. The output from the second port (probe) of the coupler is amplitude modulated in carrier suppressed mode, using a high speed lithium-niobate electro-optic modulator (EOM) driven by high frequency microwave signal generator; this modulated beam is counter-propagated through the same fiber. When the down-shifted frequency component in the probe matches with the center frequency of Brillouin gain spectrum of fiber, it is amplified as the probe propagates through the fiber. To extract the gain spectrum, the modulation frequency is swept in steps of 1 MHz, and the received power is detected on a power meter. The experiment is repeated with the test fiber placed inside an oven, and the gain spectrum is again measured at different temperatures. In an independent experiment, the pump is further pulsed and the time domain trace of the amplified probe is extracted using a low noise amplifier, and the exponential amplification signature thus obtained is recorded on an oscilloscope. The length of the fiber used in all experiments is 25 km.

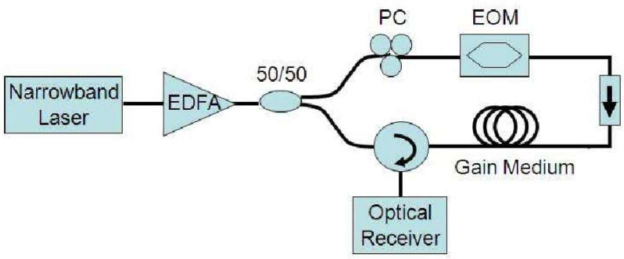

Figure 1: Experimental setup to extract the Brillouin gain spectrum of the fiber. EDFA : Erbium doped fiber amplifier, PC: Polarisation Controller

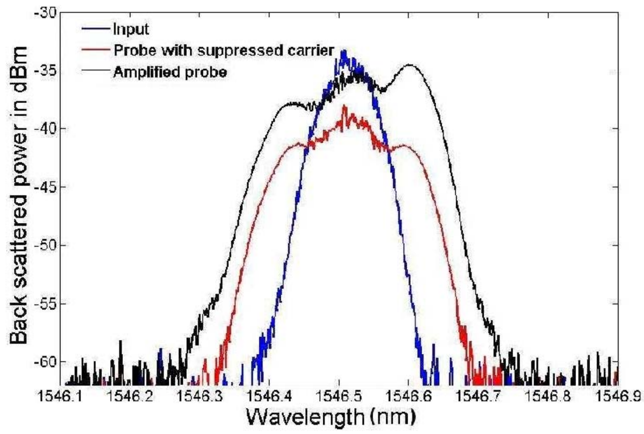

Figure 2: Optical spectrum of the probe input without modulation (blue), modulated probe in the carrier suppressed configuration (red), amplified probe (black) indicating SBS gain for the downshifted frequency

3. Results and Discussion

The optical spectrum of the un-modulated and the modulated probe recorded on an optical spectrum analyzer (resolution bandwidth of 0.08 nm) is shown in Fig. 2. The bias voltage of the modulator is adjusted such that the modulator works in the carrier suppressed configuration, as seen in Fig. 2. The amplified probe is also shown in the figure, indicating amplification for the lower frequency sideband. The RF frequency is adjusted to 10.882 GHz, in order to yield maximum Brillouin gain for an input pump power of 8 dBm to the fiber.

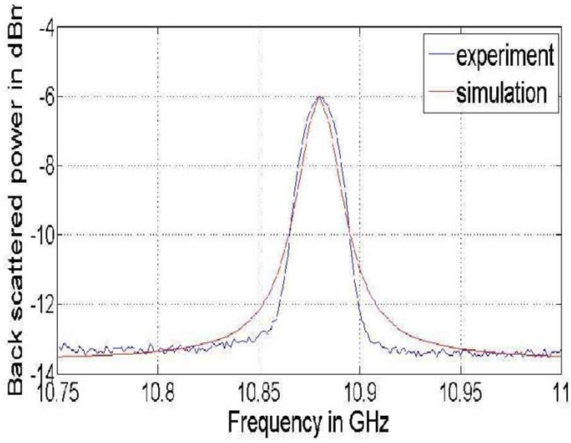

Figure 3: Probe power for different values of RF frequency applied to the modulator.

The figure shows the gain spectrum corresponding to room temperature. The pump power is 8 dBm in this case. The corresponding simulated result is shown in red.

To extract the gain spectrum, the RF frequency applied to the modulator is swept across 11 GHz with a resolution of 1 MHz. The results are shown in Fig. 3. Brillouin gain is found to be maximum corresponding to a frequency shift of 10.882 MHz, and the line width is of the gain spectrum is found to be 28 MHz. The peak gain experienced by the probe is found to be in 7.4 dB for a pump power of 7.45 dBm.

The Brillouin amplifier system is modeled using the standard coupled differential equations for the propagation of pump and the counter propagating probe. The peak value of SBS gain coefficient (g_0) is estimated by fitting the experimental data with the simulated results. Fig.3. also shows the results of the numerical simulation which uses the estimated value of g_0= 1.55x10^{-12} m^{-1} for the fiber under test.

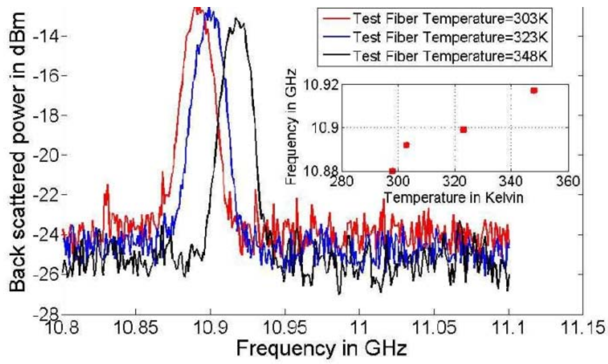

Figure 4: The gain spectrum when the test fiber is kept at different temperatures.

The inset shows the variation of Brillouin frequency shift as a function of temperature. The test fiber is now kept in an oven and is heated successively to temperatures of 308K, 323K and 348K. The corresponding gain spectrum is shown in Fig. 4. The figure shows that the center frequency of the Brillouin gain three distinct peaks in each sweep of modulation frequency corresponding to those frequencies for which the seed laser crosses the Brillouin gain spectrum of the fiber kept at certain temperature. The inset shows the variation of center frequency with temperature, indicating a temperature slope of 1 MHz/degree K.

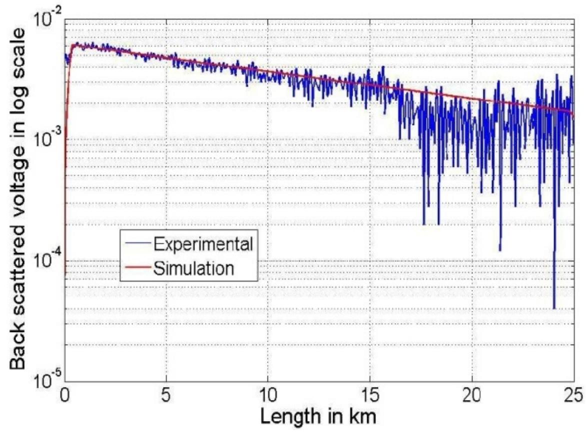

Figure 5: Amplified probe signal, corresponding to pulsed pump, after propagation through a distance of 25 km.

The position information in sensing applications is typically obtained by using a pulsed pump. In order to ratify these results for such applications, the pump is now pulsed using an external modulator, with a pulse width of 2 ms, the test fiber is now held at room temperature. The peak power in the pulse is 8 dBm, and the probe is modulated at 10.882 GHz, corresponding to the Brillouin frequency shift at room temperature, extracted in the previous experiment. The probe experiences amplification in the fiber due to the SBS generated by the propagating pump pulse. The amplified probe after propagation through the 25 km long fiber as observed on an oscilloscope is shown in Fig. 5. The time co-ordinates are converted to distance along the length of the fiber in this figure, and the output is shown in the semi-log scale for better clarity of the fit. The simulated probe power with the gain profile extracted using the previous experiment is also shown in Fig. 5, which shows a reasonable agreement with the experimental observations.

It should be noted that, the receiver noise in the experiment is not included in the simulations. The results thus obtained can be extended to the case where there is a temperature / strain change along the length of the fiber.

Conclusion

A simple method to extract the Brillouin gain spectrum of an optical fiber using a CW laser is demonstrated. The pump and the probe for Brillouin amplification is extracted from the same laser source. The probe is amplitude modulated in the carrier suppresses modulation scheme, and the frequency of modulation is changed in order to extract the Brillouin gain spectrum of a standard single mode fiber. The center frequency of the Brillouin gain spectrum is found to be shifted by 10.882 GHz from the pump frequency and a gain bandwidth of 28 MHz is measured at room temperature, which is commensurate with the earlier reported values. The temperature dependence of frequency shift in SBS is extracted and is found to be 1 MHz/degree K. The gain coefficients extracted using the experimental results is used to simulate the time domain trace of the backscattered signal in pulsed pump scheme. Further analysis on strain and temperature events along the length of the fiber is underway and these results will be reported in the paper.

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Author Profile

Rajeswari Palaniswamy was born in Tamilnadu, India on 1982.She received her Bachelor Degree in Instrumentation Engineering in the year 2004. She has a blend of strong research and Teaching experience as well..Currently she is associated with a reputed college in Tamilnadu, affiliated to Anna University, Chennai for her Master’s in Electronics.