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Optical low coherence reflectometry for measuring a stationary Brillouin grating induced under uniform pumping in a short optical fiber

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ABSTRACT

We demonstrate that valuable information on the distributed Brillouin spectra of an optical waveguide can be derived from a stationary Brillouin grating measurement under uniform pumping with optical low coherence reflectometry. We up-convert the frequencies of the probe and pump light waves by the Brillouin frequency and detect the Stokes light in the same way that we detect the Fresnel and Rayleigh backreflections in the fiber. The pump light wave that propagates toward the optical balanced mixer is blocked by using a polarization diversity technique and the distributed Brillouin gratings excited in an 82-cm long non-birefringent single mode fiber are measured at a spatial resolution of the order of 1 mm.

1. Introduction

Optical low coherence reflectometry (OLCR) has been widely used for diagnosing optical waveguides and optical modules by measuring Fresnel and Rayleigh backreflections produced in the devices [1,2]. The reflection distribution (or reflectogram) of the device is measured by changing the optical path length of the local oscillator (LO) light with a variable optical delay line. A feature of the reflectometry is that the spatial resolution is determined by the spectral width of the employed light source. This means that we can achieve a micrometer-scale spatial resolution easily by employing a broadband light source, such as an amplified spontaneous emission (ASE) source, using an erbium-doped fiber [3]. In this report we describe the addition of a new function to the OLCR, namely diagnosing the waveguide by employing a stationary Brillouin grating induced through uniform pumping over the waveguide by counter-propagating two non-phase-modulated light waves. We show that valuable information on the distributed Brillouin spectra of the waveguide can be derived from a stationary Brillouin grating measurement with uniform pumping.

A Brillouin grating has been produced in an optical fiber by counter-propagating pump light waves and adjusting their frequency difference to the Brillouin frequency at the fiber [4–7]. Since the Brillouin frequency is dependent on the property of the silica glass material such the refractive index and the velocity of sound at every location in the fiber, the distribution measurement of the Brillouin grating with a micrometer spatial resolution is considered to be an important diagnostic item for optical waveguide devices. Although Brillouin gratings have been measured at a millimeter or centimeter-scale spatial resolution [8,9], there have been few reports on the use of OLCR with a micrometer-scale spatial resolution to measure a stationary Brillouin grating induced under uniform pumping by counter-propagating two non-phase-modulated light waves. Although we have described the measurement principle of the OLCR for the Brillouin grating measurement in a previous paper [10], it was rather difficult to detect the reflection from the Brillouin grating due to intrinsic noise which resulted from the interference between the LO light and the pump light wave which propagated toward the optical balanced mixer. In this paper we reduce the pump light wave drastically by employing a polarization diversity technique [8,9,11] to reveal the reflection profile of the distributed Brillouin gratings in a non-birefringent single mode fiber.

2. Experimental setup

A schematic diagram of our OLCR configuration is shown in Fig. 1. The conventional OLCR configuration is shown by the bold lines. The Brillouin grating is induced by counter-propagating two pump light waves with different frequencies. A polarization diversity technique using polarization beam splitters PBS1 and PBS2

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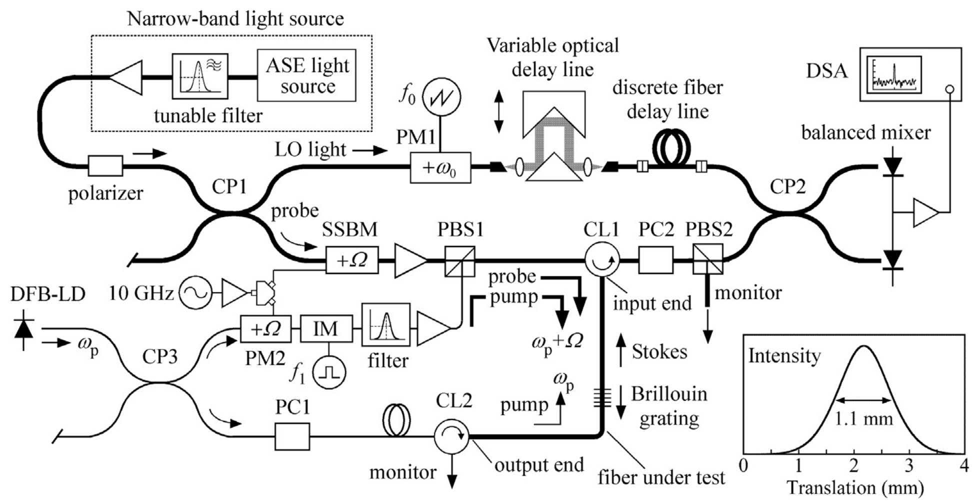

Fig. 1. OLCR Configuration for measuring a Brillouin Grating in a Fiber. CP1–CP3: fiber couplers, PC1 and PC2: polarization controllers, CL1 and CL2: optical circulators, PBS1 and PBS2: polarization beam splitters, SSBM: single-side band modulator, PM1 and PM1: phase modulators, IM: intensity modulator. DSA: dynamic signal analyzer. The inset shows the mean squares of the beat signal of the balanced mixer output as a function of the stage translation when we detect a Fresnel reflection in a fiber after switching off the up conversion of the probe light wave.

[8,9,11] was incorporated into the OLCR to prevent one pump light from entering the optical balanced mixer with PBS2 and generating a serious noise as a result of interference between the pump and LO light waves. There was another noise source created by the low directivity in the employed optical circulator as described later, and we constructed a narrow-band light source, whose configuration is outlined in the figure by the dotted lines, to increase the signal level and thus improve the S/N. We filtered a broadband light from an ASE light source with a tunable bandpass filter whose spectral width was 0.7 nm, amplified the resultant narrow-band light with an erbium-doped fiber amplifier, and passed it through a polarizer. The polarized light was divided by a fiber coupler (CP1) for use as the LO light and the probe light. The LO light passed through a phase modulator (PM1) that we drove with a ramp waveform at $f_0=140$ kHz to produce the carrier frequency $\omega_0=2\pi f_0$ in the interference signal. The optical path length of the LO light was varied with a bulk-optic variable delay line and a fiber patch cord as the discrete delay line.

We up-converted the optical frequency of the probe light with a single sideband modulator (SSBM) by Ω ($\approx 2\pi \times 10$ GHz), which we varied with an RF synthesizer. We then amplified the up-converted probe with an optical fiber amplifier and launched it into a non-birefringent single mode short fiber under test after passing it through splitter PBS1 and optical circulator CL1. The Stokes light, which was generated by the reflection of the probe light by the Brillouin grating and whose frequency was down-converted to the original frequency, was combined with the LO light by a fiber coupler (CP2) after passing through circulator CL1. We detected the intensity of the interference signal from a balanced mixer with a dynamic signal analyzer (DSA).

It would the best way to determine the spatial resolution of the OLCR by detecting a localized Brillouin grating whose length was considered to be much shorter than the spatially-resolved distance achieved by the OLCR. Since we pumped the test fiber uniformly, we could not generate such a point-like grating in the test fiber. On the other hand it is clear from the following Eqs. (1) and (2) the OLCR output signal is described by the same expression as that derived when we measure Fresnel and Rayleigh backreflections with a conventional OLCR. The simple way to estimate the spatial resolution was to measure the response of the OLCR against one Fresnel reflection. Before performing a Brillouin experiment, therefore, we switched off the up conversion of the probe light wave, acquired the interference beat signal from a Fresnel reflection in the test fiber while translating the stage in the variable optical delay line, and calculated the mean squares of the beat signal as a function of the stage translation as shown in the inset of the figure. Since the full width at half maximum of the derived response waveform was 1.1 mm, we estimated the nominal spatial resolution of our OLCR to be 1.1 mm/n=750 μm when we measure a reflection from a Brillouin grating in a silica-based optical fiber and waveguide with n=1.46. It is pointed out that the actual spectrum of the narrow-band light was neither Gaussian nor Lorentzian and the measured width of 1.1 mm was slightly different from the ones calculated theoretically by substituting the spectral bandwidth of 0.7 nm into either spectral shape.

We used a frequency-fixed laser diode (DFB-LD) operating at 1550.12 nm and we divided its output into two with a fiber coupler (CP3) for use as two counter-propagating pump waves. We describe the fixed frequency as ω_p in the figure. To shift the frequency of the pump light by the same frequency Ω as the probe light, we applied phase modulation at Ω to the pump light with another phase modulator (PM2) and extracted the up-converted light component with an optical narrow-band filter. The resultant pump light at $\omega_p+\Omega$ was amplified with an erbium-doped optical amplifier, combined with the up-converted probe light at PBS1 with their polarization states orthogonal to each other, and launched into the test fiber after passing through circulator CL1. The other LD output was launched into the fiber from the output end of optical circulator CL2 for use as a pump at ω_p.

We adjusted the polarization controller (PC1) to maximize the Brillouin amplification in the test fiber. The powers of the pump light at $\omega_p+\Omega$ and the probe light that were coupled into the test fiber were 21 and 15 dBm, respectively. The power of the pump light at ω_p that was launched into the test fiber from circulator CL2 was -1 dBm. The phase modulator (PM1) induced undesired intensity modulation at f_0 into the LO light, which masked the signal from the Brillouin grating at the detection frequency of f_0. Thus we applied the intensity modulation to the up-converted pump light at $f_1=215$ kHz with an intensity modulator (IM) and detected the signal component at f_1–f_0=75 kHz with the DSA. This was because with this modulation the Stokes light wave was also intensity modulated at the same frequency, and the desired component from the balanced mixer, which was produced by interference between the LO and the Stokes light wave, should have the component at f_1–f_0.