Localized Measurement of Linear Polarization Rotation Parameters in Short Optical Fibers

Evgeny Myslivets(1), Nikola Alic(1), and Stojan Radic(1)

(1) Department of ECE, University of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92037, USA, ymyslive@ucsd.edu

Abstract *We present a novel measurement technique for precise longitudinal characterization of polarization parameters in optical fibers based on the modified counter-colliding scanner technique.*

Introduction

Polarization characteristics play a critical role in virtually all applications of fiber optics of high practical interest: from communications, to all-optical processing, and sensing applications. After a decade of research of polarization mode dispersion and its mitigation, the developed characterization techniques were focused on global polarization characteristics[1]. The recent advances in fiber optics and signal processing, however, have put forth the importance of local waveguide properties. In this contribution, we extend the previously introduced counter-colliding power delivery class[2] of characterization methods to spatially resolved characterization of fiber polarization parameters. The method avails meter-scale polarization characterization, and thus the full visualization of optical field polarization evolution in the fiber. Aided by the novel technique, we demonstrate linear polarization preference of the Brillouin gain in optical fibers for the first time.

Principle of operation

Linear polarization evolution of a monochromatic wave in fibers can be fully characterized if the birefringence vector $\boldsymbol{\beta}$ is known at every spatial point[1]. Provided that the local orientation of the principle axis is fixed, a full revolution of the field occurs at a distance equal to the fiber beating length Λ_B. The second parameter, correlation length, describes the spatial orientation statistic of the vector $\boldsymbol{\beta}$. Several methods based on the polarization OTDR technique[5] have been proposed to measure the described linear rotation parameters.

Recently, the technique of the localized power delivery[2] by a strong counter-propagating pump pulse has been introduced and applied to high resolution spatial dispersion measurements in optical waveguides. In its first realization, the polarization states of the week pulse (probe) and pump launched at opposite ends were controlled independently in order to maximize the Brillouin gain. Such operation, however, provides only local polarization synchronization since the counter-propagating signals evolve along different optical passes. The aforementioned setting implies that the pump and probe polarization states providing maximized gain even at adjacent points can be uncorrelated. The described practical difficulty can be alleviated by polarization reversal. The experimental setup introduced here utilizes a Faraday mirror for polarization rotation inversion and provides direct measurement of polarization evolution in optical fibers. The proposed technique utilizes the fact that the strength of the nonlinear amplification strongly depends on the polarization state (PS) of the interacting signal(s).

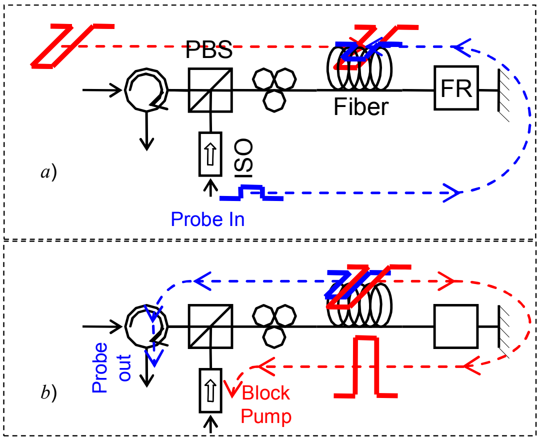

Fig. 1: The principle of operation. CIR – circulator, PBS – polarization bean splitter, FR – Faraday rotator, PC – polarization controller, ISO – isolator.

The concept is illustrated in Fig.1: Assume that a pump and a probe are launched at one fiber end

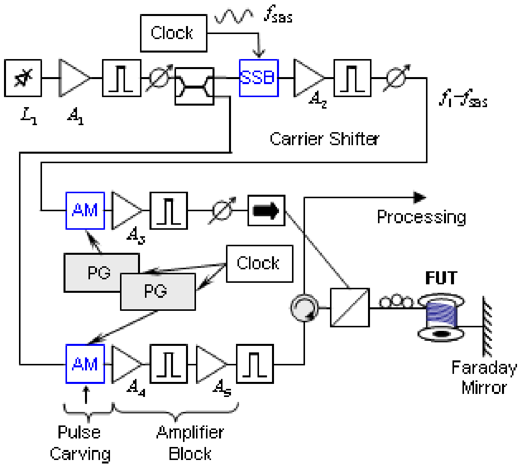

Fig. 2: Experimental setup.

orthogonally polarized using a polarization beam splitter (PBS). At the other end of the fiber, the pulses are reflected by a Faraday mirror guarantying the

978-3-8007-3173-2

preservation of the strict orthogonality of the polarization states of the forward and reflected waves at every point of propagation. If the pump (separated in time from the probe by a precise interval) is launched at orthogonal states to that of the probe and collides with a backward-propagating probe, their polarization states will be perfectly aligned at the collision point, maximizing the Brillouin gain.

The experimental setup is shown in Fig. 2. Both interacting pulses were formed from a single laser output, split into two branches. The carrier of the upper branch was downshifted by a single sideband modulator (SSB) driven by a single harmonic with frequency exactly matching the SBS shift. The two carriers were next passed through amplitude modulators, carving the isolated pulses and amplified by specially designed low-noise erbium doped fiber pre-amplifiers. The amplitude modulators were driven by two pulse generators synchronized by a single clock reference. The wide band WDMs (> 20 nm) were used to eliminate the spontaneous noise after the amplifiers. Both pump and probe pulses have 10 ns duration, corresponding to a 2 m spatial extent. The fiber under test (FUT) used was a 210 m-long sample of highly nonlinear fiber. The pump pulse position is strictly controlled along the fiber. Finally, the output probe power is measured as a function of the collision coordinate. The maximum length of the FUT amenable to the introduced technique depends on the fiber loss and nonlinear effects such as spontaneous Raman scattering depleting the pulse peak power. In practice, a gain of only several decibels is required allowing 500 m samples to be characterized using the introduced technique.

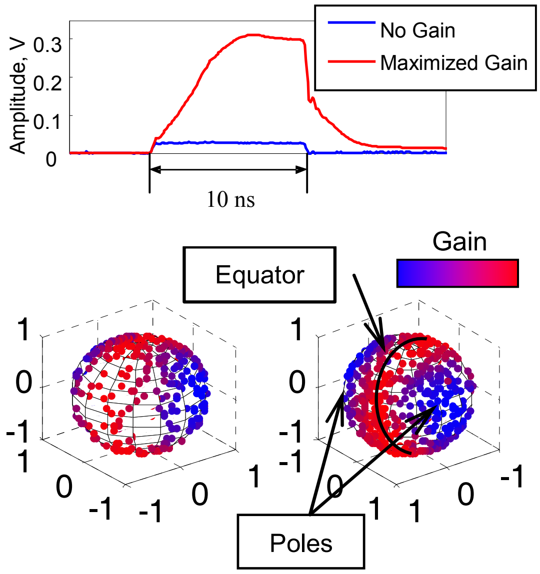

Fig. 3: *a*) Pulse waveforms measured at same collision point for polarization states corresponding to maximum and minimum gain. *b*) Measured longitudinal SBS gain as a function of polarization coordinate on a Poincare

It is important to note that the previous experiments on the Brillouin gain of CW signals[3,4] implied pump and signal co-polarization as a sufficient condition for SBS gain maximization. According to this reasoning, since the interaction is strictly localized and the proposed configuration ensures strict polarization co-alignment, the SBS gain should be equalized gain along the fiber. Nevertheless, the experimental results shown in Fig. 3 clearly exhibit that the maximized gain is achieved for specific polarizations lying in the plane corresponding to the *linear polarization*.

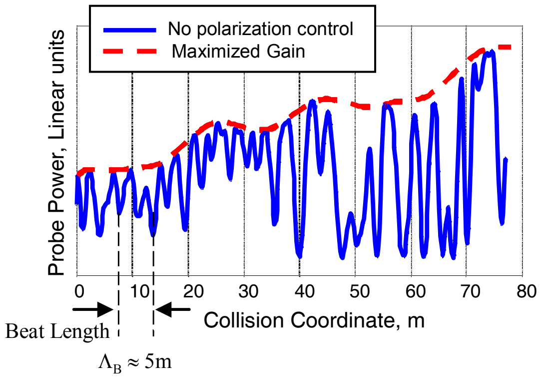

Fig. 4: Measured probe power as a function of collision coordinate. Pulse length: 2 m, scanning step: 20 cm.

Fig. 4 demonstrates an example of the scanned probe power as a function of collision coordinate. Throughout the measurement, the temporal position of the pump changed keeping the position of the probe pulse unaltered. Note that even though the pump and the probe are co-polarized throughout the measurement, the amount of Brillouin gain varies significantly, clearly demonstrating the dependence on the absolute polarization orientation. The interval between the two nearest minima corresponds to a half of the beating length in the case when the polarization vector crosses the equatorial plane twice during one full period of rotation. The measured beating length was approximately 5 m and varies along the fiber.

Conclusion

We demonstrated a simple non-destructive method for measuring the linear polarization rotation parameters in short fibers. The sample of the highly nonlinear fiber with 5-m beating length has been characterized. Finally, aided by the newly introduced method, we have for the first time demonstrated the clear preference for the linear polarization of pump and probe waves in Brillouin amplification.

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