Gonzalez-Herraez, M., 2008 “Slow Light Based on Stimulated Brillouin Scattering: New Possibilities and Open Questions," in Slow and Fast Light, (Optical Society of America), paper STuC1.

Available at http://doi.org/10.1364/SL.2008.STuC1

Slow light based on stimulated Brillouin scattering: new possibilities and open questions

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Abstract: Slow light based on stimulated Brillouin scattering offers new capabilities that are unique to this interaction. These capabilities are reviewed, and the limits and potential applications of this technique are analyzed.

OCIS codes: (999.9999) Slow light; (060.4370) Nonlinear optics, fibers; (290.5900) Scattering, Brillouin

1. Introduction.

The control of the speed of light in optical fibers through Stimulated Brillouin Scattering (SBS) offers new and unprecedented capabilities in the context of all-optical signal processing. This paper analyzes some of the new possibilities that have been opened with the latest research in the field, and also addresses the questions that emerge given these advances.

SBS as a process to produce slow light was introduced in a set of experiments published in early 2005 [1,2]. In these experiments, the amount of delay achieved was limited to roughly 30 ns (with 20-50 ns pulses) in several km-long fibers, and the group delay changes induced in the fiber were in the order of 10^{-3}. In [3] it was experimentally demonstrated that arbitrarily large optically-controlled delays could be obtained by preventing pump depletion and amplified spontaneous Brillouin scattering. This simply required the insertion of unidirectional broadband attenuators in the signal path, leaving the pump path lossless. Later, similar delaying results were reported in just 2 meters of fiber [4], showing that an extremely wide group velocity control in the fiber (group index changes in the order of 1) is possible using SBS. These experiments were later extended to other kinds of fibers with highly improved efficiency, requiring significantly less pump power [5,6].

2. New schemes with enhanced functionalities: spectral tailoring and stored light

SBS has proved to be extremely useful for the generation of slow light regarding its spectral tailoring capability. Indeed, a large variety of gain spectral profiles can be obtained by properly modulating the pump spectrum. When a perfectly coherent pump is used in the stimulated Brillouin interaction, the gain window appearing in the fiber transmission spectrum has a lorentzian shape whose characteristic spectral width is around 35 MHz in conventional single-mode fibers pumped at 1.55 μm. This is why normally SBS is viewed as a narrowband process, in which the bandwidth of the signal cannot exceed several tens of MHz. However, when the pump is modulated the gain bandwidth is given by the convolution of the pump spectrum and the Brillouin gain curve (see figure 2). This strategy can be used to match the spectral width of the interaction and that of the signal. A particularly useful case arises if the pump spectrum can also be approximated by a Lorentzian [7]. This pump spectrum can be created if the pump laser current is modulated with a noise signal, such as the output of a PRBS generator. In such conditions, the effective Brillouin gain shape is also a lorentzian whose width is the sum of the characteristic Brillouin gain width and the pump spectral width. In this case, to obtain the same fractional delay in the pulse (i.e. the delay divided by the pulse length) the same fractional delay with a tenfold increase in the bandwidth can only be achieved with a tenfold increase of the pump power. This technique was extended to

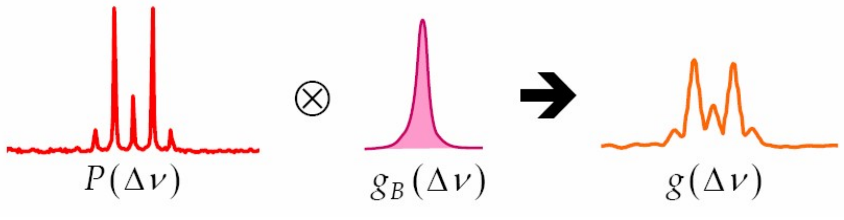

Fig. 2: Principle of spectral tailoring of Brillouin slow light devices. The effective gain spectrum created in the fiber results from the convolution of the pump spectrum and the characteristic gain spectrum of the Brillouin process. This is effectively translated into phase index changes that will affect notably the group velocity of the

achieve 12-GHz bandwidth slow light [8], which is the maximum bandwidth achievable with a single pump due to the Brillouin loss process. With two pumps, 25 GHz-bandwidth slow light has been demonstrated [9] by compensating the Brillouin loss process by a secondary pump creating a gain spectrum overlapping the loss induced by the primary pump. With these ideas, it is clear that the bandwidth of the SBS slow light process can be scaled to the value required by the application.

The unique spectral tailoring capability in SBS has been also used to manage the distortion of the pulses traveling in the slow light system. The idea is to optimize the pump spectrum so as to minimize the distortion in the signal pulse. This possibility has been explored by several groups [10,11], and twofold improvements in the fractional delay have been demonstrated, keeping a maximum distortion constraint on the pulse. Another issue in SBS slow-light systems is the amplitude change suffered by the pulse as it is delayed or advanced. To solve this problem, a scheme using the gain and loss processes has been devised and demonstrated [12].

From the perspective of packet delaying applications, all the above-mentioned schemes are not practical, since the achievable fractional delays are limited to 1-3 pulse lengths. Recently, light storage using SBS was experimentally demonstrated [13]. In this scheme, the light pulses are converted into long-lived acoustic excitations through SBS, which can be read out again by a subsequent pump pulse. This method can store data packets of several bits, and its only limitation is the acoustic lifetime that determines the maximum time that the pulses can be stored. This lifetime can be greatly increased by working at cryogenic temperatures [14].

3. Open questions

A largely unsolved question in slow light techniques is what is going to be their real application. It is still highly arguable that SBS-based slow light will be used in communication systems (see, for instance [15]), although the light storage techniques do seem to open some real possibilities in this area that have yet to be explored. A view shared by many researchers in the field is that using slow light to generate delays creates difficult trade-offs to turn around. It seems that a more interesting approach is to use slow light techniques to actually benefit from the fact that the light travels more slowly than in a conventional medium, i.e. to obtain enhanced light-matter interactions. For instance, it has been shown that nonlinear electro-optical effects are enhanced in slow light media [16]. Work is under way to try to demonstrate this enhancement effect in optical fibers through SBS. If such an enhancement effect is observed, nonlinear processing based on optical fibers could receive a great push forward.

It was also recently claimed that suitably engineered slow light media can be used to enhance Beer-Lambert absorption by orders of magnitude [17]. This, however, does not seem to hold for traveling-wave slow-light systems like SBS.

4. Acknowledgements

I deeply acknowledge all the work and discussions that I have had with Luc Thévenaz along these last years. Partial financial support was provided by Spanish government project TEC2006-09990-C02-02 and by Comunidad de Madrid, Project S-0505/AMB-0374.

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