Opto-acoustics in Optical Fibres for Sensing Applications

Luc Thévenaz, Zhisheng Yang, and Desmond Chow
EPFL Ecole Polytechnique Fédérale de Lausanne
SCI-STI-LT Station 11, Lausanne 1015, Switzerland

Abstract— Using the most advanced optical interactions, optical fibres open the possibility to realise *distributed sensing*, which means that each point along the fibre can separately and selectively sense quantities, in total similarity to a real organic nerve. The fibre can therefore distinctively inform on the position of the stimulus and on its magnitude.

The sensing systems exploit the effects natively present in the fibre, take advantage of their dependence on environmental quantities — primarily temperature and the strain deforming the fibre — and extract the information with a proper signal conditioning at the accuracy given by the natural response of the exploited effects.

An important class of native effects is those based on opto-acoustic vibrations in the medium: as a result of electrostriction of the medium — in which a gradient of electromagnetic power will cause a mechanical compression in the optical medium — a modulated light signal is able to generate a material pressure wave that will vibrate at the light modulation frequency. This generation is sharply resonant when this pressure wave moves exactly at the acoustic velocity in the medium, resulting in a strong effect that will in turn impact on light through photoelastic modulation.

The advantages of this process are crucial: the light can generate the acoustic vibration through electrostriction and the amplitude of this acoustic vibration can be sensed through photoelasticity. So the mechanical system is activated by light and its amplitude can be read by light. Everything is made optically and the acoustic wave is actually a ghost effect in the system, since existing and sensed but not directly perceived.

This type of opto-acoustic interaction, called *stimulated Brillouin scattering*, is extremely powerful to inform on the acoustic properties of a medium through the sole intercession of light.

Backward stimulated Brillouin scattering (BSBS) is now used for some 30 years to make extremely performing distributed fibre sensors. Two lightwaves, which are counterpropagating within the core of a single mode fibre and are showing a slight frequency difference, will beat by forming a moving interference pattern, causing a pressure wave by electrostriction. For a well-defined frequency difference between the 2 lightwaves this pressure wave can exactly move at the acoustic velocity. The acoustic wave in turn will induce a moving refractive index grating in the fibre core which couples efficiently the 2 lightwaves since they automatically satisfy a Bragg diffraction condition.

By determining at which frequency the resonant coupling is peaking, the value of the acoustic velocity can be accurately determined. This turns the system into a sensor since the acoustic velocity depends on temperature and on the material density, which is strongly impacted by a mechanical deformation experienced by the fibre such as an elongation (strain gauge). It must be noted that all interacting waves (2 optical and 1 acoustic) remains strictly confined in the fibre core and the interaction can be easily made localised for distributed sensing since the optical waves can be pulsed and the coupling will take place only at their crossing point.

Recently, *forward stimulated Brillouin scattering* (FSBS) has been identified like a new approach for optical fibre sensing, offering unprecedented functionalities: as far as this process is concerned, a transverse acoustic wave is generated by an intensity-modulated lightwave, travelling radially from the fibre core and bouncing back at the interface between the fibre and the outer surrounding medium. The resonance condition is given by the acoustic velocity and the fibre radius and this has been used to precisely measure the fibre dimensions. But more importantly, the decay rate of the acoustic wave is given by the acoustic impedance mismatch between the silica and the surrounding medium at the fibre outer interface. This decay rate can be evaluated by measuring the sharpness of the resonance, i.e., its linewidth.

This system is extremely attractive and unique: a property of the outer medium (acoustic impedance) can be optically measured with no direct contact of light with the outer medium. The light remains strictly confined and protected in the fibre core and the acoustic wave play the role of a messenger conveying the information between the outer medium and the fibre core. Acoustic impedance strongly depends on the nature and the density of a material, so that an information can be obtained on the composition of the outer medium. This research is at a very early stage, but the possibility to make distributed sensing has just been demonstrated.