Application note

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Time-resolved Brillouin light scattering with *the software platform thaTEC:OS* and the *Time Tagger* from *Swabian Instruments*

Brillouin light scattering (BLS) is a powerful tool to investigate phonon- or spin-wave spectra in the frequency domain. THATec Innovation offers not only solutions for the automation of BLS spectroscopy or BLS microscopy but also the unique option to obtain time-resolved BLS spectra for a substantially better insight into the investigated system.

Since the development of the Tandem Fabry-Pérot Interferometer (TFPI) by John Sandercock (www.tablestable.com), Brillouin light scattering is widely used in scientific research. However, the maintenance of this complex instrument as well as its synchronization and coordination with additional laboratory devices is a challenging task [1].

To tackle these challenges, our platform *thaTEC:OS* in combination with the software module TFPDAS5 offers software solutions with routines for the auto-alignment of the TFPI as well as for its active stabilization during measurements to obtain an optimized contrast and frequency resolution. In addition, the software allows for versatile scan definitions with multiple frequency regions and individual scan speeds to minimize the measurement time. Furthermore, *thaTEC:OS* offers an easy and intuitive way to combine our different software modules to set up automated measurements with a wide range of peripheral devices without any programming.

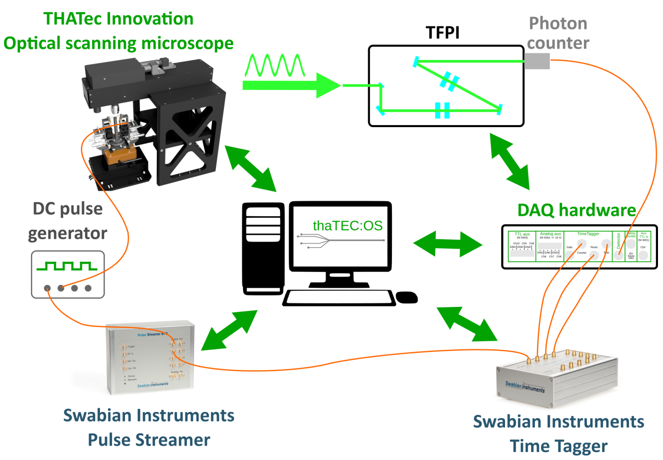

Figure 1: Typical measurement setup.

While BLS is a powerful tool for the investigation of phonon- or spin-wave spectra in the frequency domain, a thorough understanding of several phenomena, e.g. relaxation processes, nonlinear processes, or propagation characteristics, requires additional information. For this purpose, our software TFPDAS5 can be extended by hard- and software modules to generate and detect additional outputs for the fully-automated acquisition of *time-resolved* BLS spectra.

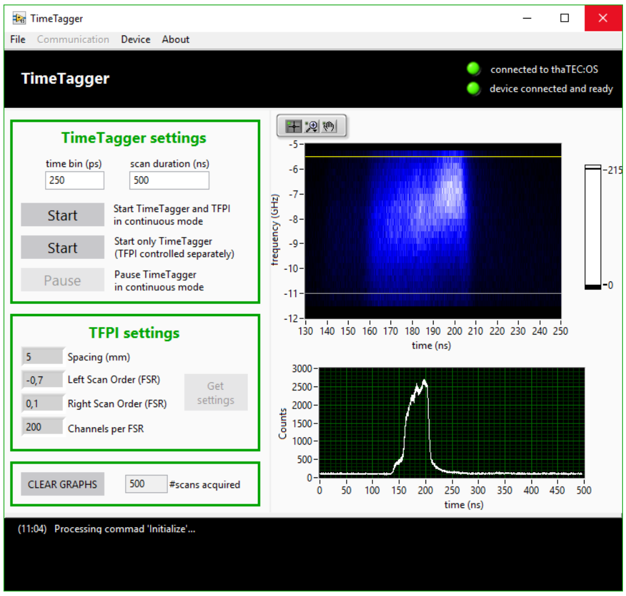

Figure 2: thaTEC:TimeTagger software module.

Measurement setup

For a time-resolved BLS measurement, the following signals need to be taken into account: a signal that defines the start time of the experiment, a stop signal that indicates the detection of a phonon by the TFPI,

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and additional signals that encode the frequency formation. In our scenario at least 4 signals are used to serve this purpose and are detected by the *Time Tagger* from *Swabian Instruments* (Fig. 1): The first channel detects the start time of the measurement which is typically provided by a pulse generator like, e.g. the *Pulse Streamer* from *Swabian Instruments*. The photon counter of the TFPI provides the second signal while channels 3 and 4 are connected to our BLS DAQ hardware. These channels provide the frequency information which is required to construct the time-resolved BLS spectra.

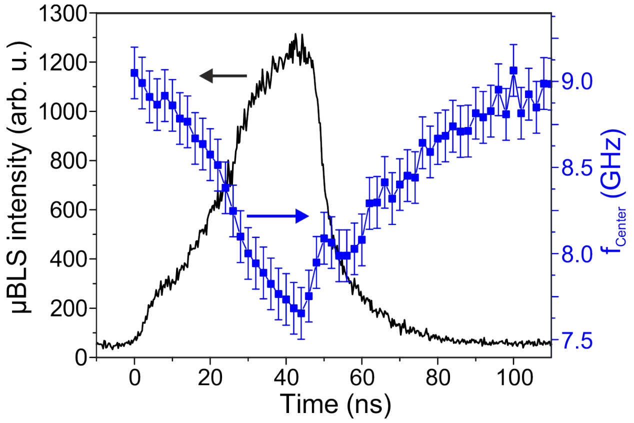

Figure 3: Time-resolved spin-wave intensity and center of the spin-wave frequency spectrum during an applied current pulse.

Performance

The time resolution of the *Time Tagger* modules are in the ps range. However, in analogy to the uncertainty principle, the high frequency resolution of the TFPI limits the time resolution. Thus, the actual time resolution depends on the frequency resolution of the TFPI, i.e. the mirror spacing, used in the actual measurement. In typical experiments, the time resolution for BLS spectra is in the range of ≈ 1 ns.

Exemplary measurements

Using this setup, a wide range of measurements can be performed. In the following, time-resolved spin-wave spectra in a microstructured Cr$|Co_2Mn_0.4Fe_0.6$Si$|$Pt layer stack are shown [2, 3]. In this scenario, spin-waves are excited via the spin-Hall effect and the spin-transfer-torque effect caused by a DC current pulse flowing through the microstructure.

To perform the presented measurements, the following peripheral devices are controlled by our software platform thaTEC:OS to allow for a fully automated measurement over several days: DC Pulse generator, power supply for an electromagnet, 3D piezo stage with a feedback from our microscopy software module via a pattern recognition algorithm.

Figure 2 exemplary shows the time-resolved spin-wave spectra (upper panel) and temporal evolution of the spin-wave intensity integrated in a certain frequency range (lower panel) as acquired by our software. Figure 3 shows the time-resolved spin-wave intensity (black curve) and the corresponding center of the spin-wave frequency spectrum (blue curve) extracted from the raw data.

Since the excitation mechanism used in this experiment is based on a DC current pulse that does not impose a defined phase on the excited spin waves, the resulting spin dynamics are incoherent and do not show a distinct phase. Thus, the presented data cannot be measured by any technique measuring in the time domain such as time-resolved magneto-optical Kerr effect. This shows the impressive potential of time-resolved BLS in fundamental research in the field of spin dynamics and, of course, also in phonon dynamics where the same principles apply.

Further Reading

For more information on our hard- and software and a detailed list of features, please visit our homepage and check out the section about Brillouin light scattering spectroscopy: www.thatec-innovation.com.

References

[1] Micro-focused Brillouin light scattering: imaging spin waves at the nanoscale, T. Sebastian *et al.*, Front. Phys. **3**, 35 (2015).

[2] Characterization of spin-transfer-torque effect induced magnetization dynamics driven by short current pulses, T. Meyer *et al.*, Appl. Phys. Lett. **112**, 022401 (2018).

[3] Realization of a spin wave switch based on the Spin-Transfer-Torque effect, T. Meyer *et al.*, IEEE Magn. Lett. **9**, 3102005 (2018).

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