PhD position offer in LAUM

Application of ultrafast optical interferometry for opto-acousto-optical depth-profiling of materials

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Picosecond ultrasonics is an opto-acousto-optical experimental technique based on ultrafast high repetition rate lasers applied for the generation and detection **of nanometers in length** and picoseconds in duration **coherent acoustic pulses**. In optically transparent materials these pulses can be detected along their complete propagation path inside a sample, revealing information on the material properties in their current spatial position. This technique is commonly called either picosecond acoustic interferometry (PAI) [1] or time-domain Brillouin scattering. Continuous-in-time monitoring of the coherent nano-acoustic pulse propagation (Fig. 1) provides a depth-profiling of the sample material inhomogeneity traversed by the acoustic pulse **with nanometers spatial resolution** [2]. First experiments on depth-profiling were conducted in the Université du Maine (Le Mans, France) [2] and in Vanderbilt University (Nashville, USA) [3], through the monitoring of the frequency and of the amplitude of the oscillating part of the transient optical intensity reflectivity signals, $d\tilde{R}(t)/R = 2\,\mathrm{Re}(d\tilde{r}/r)$, respectively. This was possible because, in the nanoporous films [2], the amplitude of $d\tilde{R}(t)/R$ was, for physical reasons, varying much slower in depth than the frequency of the oscillating part, while in the semiconductor samples irradiated by ions [3] the situation was just the opposite. The experiments in [2,4] revealed the spatial profiles of the sound velocity and of the optical refractive index, while those in [3] revealed the spatial profiles of the acousto-optic (photo-elastic) constant. In a general case, when the amplitude and the frequency of $d\tilde{R}(t)/R$ are varying at the same characteristic distances, their precise separation in the signal $d\tilde{R}(t)/R$ is impossible, thereby forbidding independent depth-profiling of different material parameters. In the Université du Maine it was suggested [5] that under these general physical conditions not only the real but both real and imaginary parts of the optical field reflectivity $d\tilde{r}/r$ should be measured experimentally for the independent depth-profiling of several material parameters. The realization of this theoretical proposal requires the monitoring of the laser-generated acoustic pulse propagation not by means of the optical reflectometry (see Fig. 1) but of the optical interferometry (see, for example, Fig. 2).

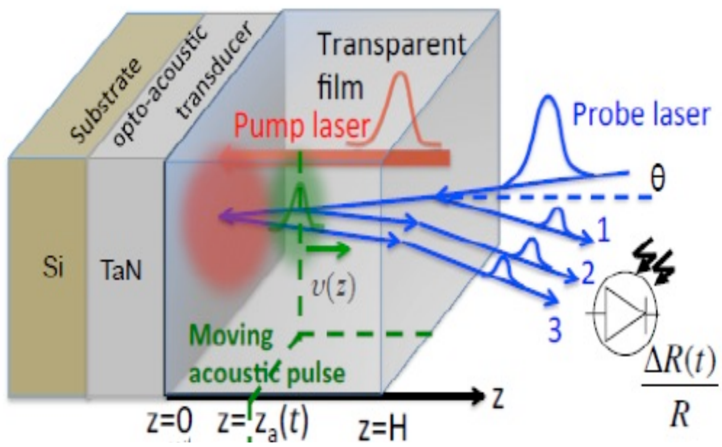

Figure 1. Qualitative illustration of the physical principles of the transparent media depth profiling [4]. Pump laser (in red) excites acoustic pulse (in green) of about 10 nm spatial length. This acoustic pulse scatters probe laser pulses (in blue), which are measuring the transient optical reflectivity of the sample.

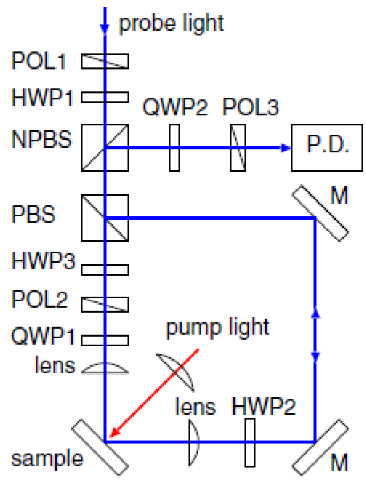

Figure 2. Schematic diagram of the interferometric setup in [6]: HWP, halfwave plate; QWP, quarter-wave plate; PBS, polarizing beam splitter; NPBS, nonpolarizing beam splitter; POL, polarizer; P.D., photodetector; and M, mirror.

The PhD project goal is to design and construct an ultrafast optical interferometer, which will lead to the first ever application of the optical interferometry for the depth-profiling of materials.

The designed and created experimental schema(s) will be applied to the depth profiling of doped ferroelectric granular thin films, polycrystalline optically anisotropic materials, nanoporous thin films, etc.. The PhD research will advance innovative experimental approaches and signal processing methods that could be useful in the future in applications of the picosecond acoustic interferometry for depth profiling in other fields of scientific research dealing with nanoscale resolution imaging inside microscale objects such as: vegetal/animal cells in the Hokkaido University [7] and in the University of Nottingham [8]; materials compressed in diamond anvil cells to megabar pressures in the Université du Maine (LAUM) [9,10]; microelectronics materials/nanostructures, including ion-implanted [3].

The PhD studies will be supervised by the group of researchers from the Université du Maine (where the PhD will be conducted and defended) and from the Hokkaido University (Sapporo, Japan). During the 3 years period of the PhD, the PhD student will have opportunity for the research stay in the optoacoustic laboratory in Sapporo in order to become familiar with innovative opto-acoustic techniques developed there.

The candidates should have confirmed education in optics, optical engineering or laser physics. The knowledge of physical acoustics, solid state physics, signal processing would be advantageous. Documented experience(s) of working with lasers could be extremely important.

The beginning of the PhD could be shifted from the autumn of 2017 to the winter of 2018 for the convenience of the preselected candidate, if necessary.

<u>PhD fellowship:</u> 1 350 € per month, free of charges
<u>PhD tuition fees to the University:</u> 400 € per year

References (publications of the Université du Maine are in bold letters, publications by Prof. O. Matsuda are underlined)

[1] H. T. Graham, H.J. Maris, J. Tauc, IEEE J. Quantum Electron. 25, 2562 (1989).

[2] C. Mechri et al., Appl. Phys. Lett. 95, 091907 (2009).

[3] A. Steigerwald et al., Appl. Phys. Lett. 94, 111910 (2009).

[4] A. M. Lomonosov et al., ACS Nano 6, 1410 (2012).

[5] V. Gusev et al., J. Appl. Phys. 110, 124908 (2011).

[6] <u>O. Matsuda et al., J. Opt. Soc. Am. B, 30, 1911(2013).</u>

[7] <u>S. Danworaphong, M. Tomoda, O. Matsuda, ..., Appl. Phys. Lett. 106, 163701 (2015).</u>

[8] F. Pérez-Cota, R. J. Smith, E. Moradi, L. Marques, K. F. Webb, M. Clark, Appl. Optics 54, 8388 (2015).

[9] S. M. Nikitin et al., *Sci. Rep.* 5, 9352 (2015).

[10] M. Kuriakose et al., Ultrasonics, 69, 201 (2016).