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Femtosecond heterodyne pump probe platform

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Abstract: We present a femtosecond heterodyne pump probe platform[1] with two electronically synchronized Ytterbium lasers. The main goal of this platform is to provide thermal characterization at short space and time scales on submicrometer-structured samples. Thermal conductivities and thermal interface resistances can be extracted for the different layers in the studied sample by fitting thermal models with experimental data. We show how to measure beams size, which is an important parameter to know to extract with accuracy the thermal parameters. This platform can also be used to observe picoseconds acoustic phenomena and measure for instance acoustic wave velocities.

In our experimental setup, a double cavity Ytterbium laser (wavelength of 1030 nm) designed by AMPLITUDE SYSTEMS is used. The pulse width is about 150 fs. Second Harmonic Generation (SHG) crystals can be added to one or to both lasers beams to obtain a wavelength of 515 nm. In the following results, the wavelength of both beams is 515 nm.

The two lasers are electronically synchronized with a controlled frequency shift generated by a Direct Digital Synthesizer (DDS). The frequency repetition rate of the lasers is about 48 MHz with a frequency shift (f_b=T_b^{-1}) of 700 Hz. This leads to an additional time difference Δt between the pump and the probe *(Eq. (1))* of about 300 ps every pulse (Fig. 1):

$$\Delta t = f_b \,.\, T_s \,.\, T_p \qquad (1)$$

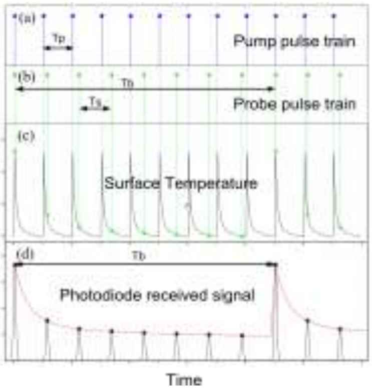

Figure 1 Experimental setup: femtosecond pump probe technique

with T_p^{-1} (respectively T_s^{-1}) the pump (respectively the probe) laser repetition frequency. This stroboscopic technique removes the necessity of a delay-line with mirrors on a translation stage: the acquisition is thus fast and with no fluctuation of the beam pointing and the modification of focused beam diameter.

After filtering and amplifying the photodiode signal, the evolution of the change of reflectivity is obtained with a time dilatation coefficient which depends on T_p and f_b (cf. fig. 1). Fig. 2 presents a simplified scheme of our setup (Beam expander, λ/2 and λ/4 wave plates are not represented).

The coincidence between the "Pump" and the "Probe" is determined thanks to a two-photons (λ = 1030 nm) absorption within a GaAsP photodiode (sensitive to λ = 515 nm). A sharp pulse is then generated. This periodical pulse is the trigger signal of our setup. The jitter of our setup is defined as the jitter of this pulse divided by t_c. The low pass filter (f_c = 15 MHz) and the jitter of the periodic pulse lead to a time resolution of 1 ps.

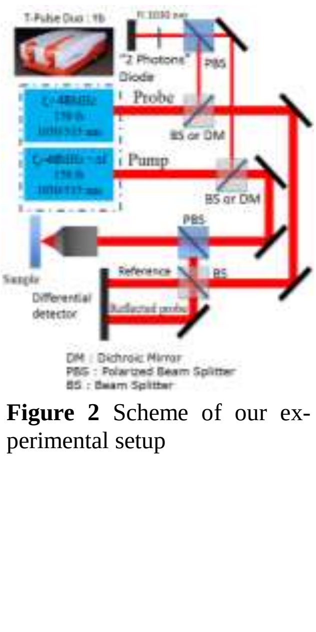

Figure 2 Scheme of our experimental setup

The variation of the relative reflectivity is linked to the variation of the stress and the variation of the temperature. Acoustic waves are created by the brutal thermal dilation caused by the pump. The propagation of the acoustic echoes in the thin tungsten metal layer induces periodical constraints which modifies the surface reflectivity as seen in Fig.3. Sound velocities can be measured if the thicknesses are known. On the other hand, as in Fig. 3, the thickness can be obtained with a known velocity : with a mean period between the echoes of 40.2 ps, and a theoretical sound velocity of 5200 m/s for the tungsten, a thickness layer of 105 nm is calculated. Depending on the sample, Brillouins oscillations (interferences between the probe beam reflected on the surface and on the acoustic wave) can also be observed. Lenses on a X-Y stage enable the scan of the pump beam. This permits the study of surface acoustic waves[2] propagation. Modification of the set-up (scan of the probe beam with interferometric measurements) will soon enable us to also study acoustic waves in phononic cristals as in ref [3].

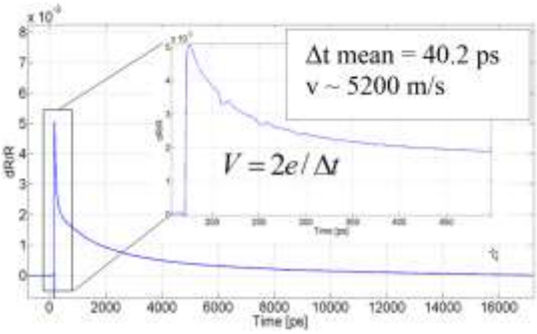

Figure 3 Typical thermoreflectance signal on a silicon substrate with a layer of 105 nm of tungsten

In order to know the thermal evolution, the thermal quadrupole method[4] is employed. Each part of the sample (the transducer, the different layers, the thermal interface resistances and the substrate) are represented by a matrix determined by using equations based on the Fourier and Heat laws in Laplace and Hankel space.

Thanks to this method, we are able to calculate the temperature evolution of the sample's surface depending on parameters such as the thermal conductivity of the different layers and substrate, and the thermal interface resistances.

Accurate determination of the laser spot size is essential to extract with high accuracy the thermal properties of the studied sample. By convolving the probe beam with the variation of reflectivity induced by the pump[5,6], we can deduce the beam size on the studied sample.

Figure 4 presents an example of an experimental curve obtained on a sample of Si substrate with a layer of 105 nm of tungsten. By fitting the normalized experimental data with the theoretical model, we can obtain some of the parameters (fixing others). We can thus extract the thermal conductivity of the substrate (142 $W.m^{-1}.K^{-1}$) and the thermal interface resistance (2.85 10^{-9} $m^2.KW^{-1}$), which are in good agreement with the literature. Figure 5 shows the difference obtained between the experimental and the simulated data, denoting a good fit.

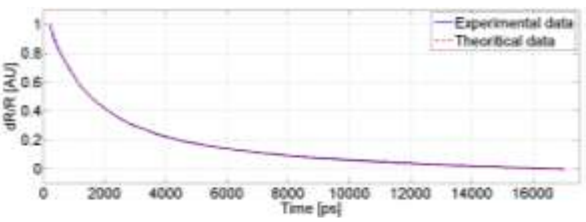

Figure 4 Fit between the normalized experimental data of a sample of silicon substrate with a layer of 105 nm of tungsten and the normalized simulated data

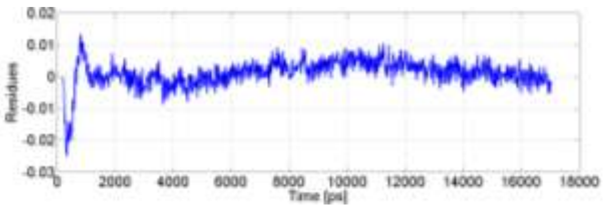

Figure 5 Residues of the fit between the experimental and the simulated data

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