Femtosecond heterodyne pump-probe set-up: characterization of the anisotropic propagation of surface elastic waves in tilted columnar thin films

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This paper presents the possibilities of acoustic characterization given by a femtosecond heterodyne pump-probe set-up [1]. With a spatial resolution better than 1 μm and a time resolution around 1 ps, this set-up allows the visualization of surface acoustic waves and the calculation of their dispersions. The anisotropic propagation of surface acoustic waves in highly inclined columnar tungsten thin films is demonstrated.

The set-up consists of two femtosecond lasers (λ = 515 nm) electronically synchronized with a small difference in their repetition rate (Δf = 700 Hz). The pulse of the first laser (pump) is absorbed by the metallic sample, generating elastic waves. The frequency range of the excited SAWs (Surface Acoustic Wave) typically lies in the gigahertz range. The second laser (probe) measures the reflectivity variations of the sample's surface, which are linked to the temperature and acoustic changes. Due to the Δf difference, the probe laser hits the sample with an incremental delay compared to the pump pulse, leading to a stroboscopic-like measurement. This allows the time scanning over the full repetition period of the laser (T = 20.8 ns), with a resolution of around 1 ps. Thanks to a lens mounted on a translation stage, the pump-probe distance can also be scanned. The radii ($1/e^2$) of the pump and probe spots are typically around 1 μm.

The GLAD (Glancing Angle Deposition) technique [2] is used to deposit tungsten on silicon substrates with two different incident angles of the particles flow: α = 0° (conventional sputtering) and 80° (GLAD). This leads to the creation of thin films presenting a columnar architecture with angles to the normal respectively equal to β = 0° and 43°. These two samples are characterized with the heterodyne pump-probe set-up. A summary of the results is shown in Table 1, which shows for the two different samples, the group velocities of the pseudo-Rayleigh wave at their maximum of energy at $k/2\pi = 3\times10^5$ m^{-1} along x and y axes. The speed anisotropy of the SAW is noted for the GLAD sample, whereas the propagation is isotropic for the conventional sample. Moreover, the group velocities are strongly reduced for the GLAD sample. These two observations are linked with the microstructure of the GLAD sample, which is composed of inclined tungsten columns with elliptical patterns linked by voided regions. The voided regions are responsible for the general drop of group velocities whereas their structural anisotropy leads to a substantial variation of the pseudo-Rayleigh wave propagation.

Sample	v_x (m.s^{-1})	v_y (m.s^{-1})
Conventional (α = 0°, β = 0°)	2220 ± 50	2200 ± 50
GLAD (α = 80°, β = 43°)	870 ± 50	1600 ± 50

Table 1: Group velocities of pseudo-Rayleigh waves at $k/2\pi = 3\times10^5$ m^{-1} along x and y axes in tungsten thin films deposited by conventional sputtering and the GLAD technique.

The heterodyne pump-probe set-up was used to demonstrate the anisotropic propagation of SAWs in tilted columnar thin film deposited by GLAD. This set-up can also be used to perform thermal characterization.

References

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