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Ultrafast electron-phonon dynamics in gold/cobalt structures

Investigation of the electronic and acoustic response in thin metal layers irradiated by ultrashort laser pulses became a classical topic in ultrafast science [1-4]. Studies in metallic multilayer samples stimulate allow for understanding the mechanisms of energy transport across metal-metal interfaces [5-6]. Here we report the experimental and theoretical results of heat transport in gold-cobalt bilayers grown on sapphire [6]. The optical penetration (skin) depth of laser light in gold is only about 15nm. However, the superdiffusive hot electrons can propagate hundreds of nanometers before transferring their energy to the lattice [2-5]. The situation becomes particularly interesting if in the process of ultrafast diffusion these hot electrons cross the metal-metal interface. The two temperature model (TTM) [4] is well suited to describe the electron diffusion in bi-metallic structures. In a 240nm Au/30nm Co/sapphire structure the dynamics of electronic temperature, assuming its continuity at the gold-cobalt interface, demonstrates the ultrafast hot electron diffusion across the 240nm thick gold layer on a sub-picosecond time scale (Fig. 1a). Due to the 23 times larger electron-phonon coupling constant the lattice temperature in cobalt grows much faster than in gold (Fig.1b). As a result, the lattice temperature in Co side becomes 15 times bigger than in gold. This strongly inhomogeneous spatial distribution of lattice temperature inside the gold-cobalt structure leads to the generation of complex acoustic transients, which we observe in femtosecond time-resolved pump-probe experiments (Fig. 1c,d). Generation of a short acoustic pulse form the overheated cobalt layer is observed in all sample with gold thickness in the range between 50 and 500 nm. In all cases the pump-probe signals represent the sum of thermal dynamics and photoacoustic signal in cobalt layer. Using the initial conditions for the spatial distribution of lattice temperature and applying the concept of the thermal boundary (Kapitza) resistance for Au/Co and Co/Sapphire interfaces, we were able to simultaneously fit the experimental data by solutions of heat diffusion equation obtained with COMSOL (red curve on Fig. 1d) and acoustic wave equation (red curve in Fig. 1e).

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Figures:

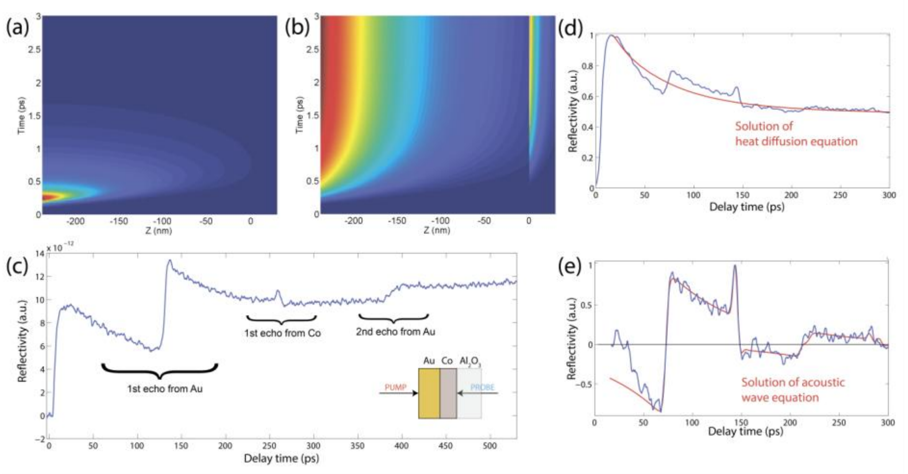

Figure 1: TTM simulations of ultrafast dynamics of (a) electronic temperature (b) lattice temperature in a 240nm Au/30nm Co/sapphire structure. (c) Time-resolved reflectivity measurements in 420nm Au/30nm Co/sapphire structure. Reflectivity measurement in 240nm Au/30nm Co/sapphire structure can be well approximated by a solution of heat diffusion equation (d) superimposed with the photoelastic term determined by the solution of the acoustic wave equation (e).