Ultrafast acoustic phonon pulse generation in transition metals

T. Saito, O. Matsuda, and O. B. Wright

Department of Applied Physics, Faculty of Engineering, Hokkaido University, Sapporo 060-8628, Japan

Coherent acoustic phonon pulses excited in thin metal films with ultrashort laser pulses can be used to study the propagation of phonons typically in the ~100 GHz range and also the evolution of nonequilibrium electron distributions[1-3]. The acoustic phonon pulse shape and frequency spectrum depends in general on both thermal and electron diffusion. Nonequilibrium acoustic phonon pulse generation mechanisms using ultrashort optical pulses have been investigated extensively in the noble metals and aluminium[1-3], but no such quantitative studies including the effect of electron diffusion have been made in transition metals. Here we study the optical generation of picosecond acoustic phonon pulses in nickel and chromium.

Pump optical pulses of wavelength 415 nm and duration ~500 fs are used to excite the acoustic phonon pulses, and are focused with an incident fluence of ~0.01 $mJcm^{-2}$. The reflectance and phase changes caused by the phonon pulses bouncing back and forth inside the film are measured using probe optical pulses of wavelength 830 nm, as a function of the pump–probe delay time, by use of modified Sagnac interferometer[4]. Fig. 1 shows the reflectance and phase changes of a polycrystalline Ni film of thickness 210 nm on a Si (100) substrate. Two acoustic echoes are superimposed on a slower background decay caused by the film surface temperature decrease.

In order to model these echoes including the effects of thermal and electron diffusion we assume that the electrons and the lattice are thermalised separately, according to the coupled differential equations of the two–temperature model[2-4]. We have chosen the fluence in experiment to be sufficiently small to limit the maximum changes in electron temperature to ~100 K, so that we can ignore the dependence of electron heat capacity and thermal conductivity on electron temperature and use a linear approximation to the equations[3]. These can be solved analytically in the frequency domain[3]. Comparision with experiment includes the broadening effect on the echoes due to ultrasonic attenuation, measured by comparing the Fourier transform of the 1st and 2nd echoes measured at higher fluences. The echo shapes in both amplitude and phase give reasonable agreement with experiment (not shown).

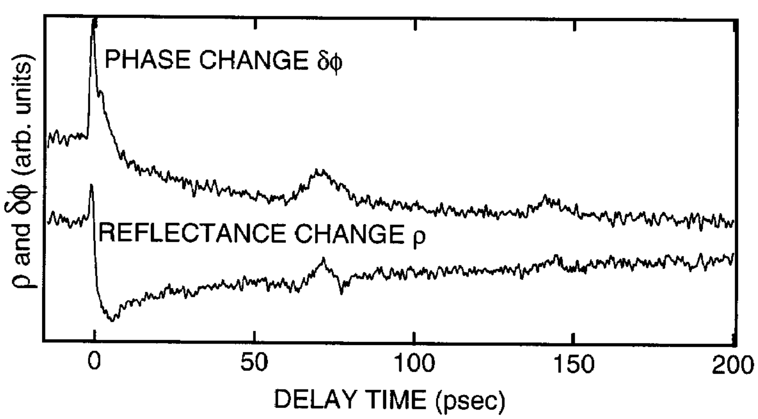

Figure 1: The reflectance and phase changes for a 210 nm film of Ni on Si(100) substrate.

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