INVESTIGATION OF ELECTRON-PHONON INTERACTIONS USING FEMTOSECOND ELECTRON DIFFRACTION

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Introduction

Coupling between electrons and phonons (e-ph) is key to many important processes in solids, such as superconductivity and laser-induced strucutral phase transitions. Transiently heating the conduction electrons to a temperature well above that of the lattice and monitoring susequent thermalization dynamics provides an unique way to study this e-ph coupling in the time domain using fs opical spectroscopy tools for an indirect measurement of lattice temperature evolution. Here we report the study of e-ph thermalization in Au and Al samples by directly measuring the transient lattice temperature change that is induced by fs optical excitation using femtosecond electron diffraction through the Debye-Waller effect.

Results and Discussion

In metals, the photoexcited electrons first thermalize with the cold bath of electrons below the Fermi level, evolving from an initial non-equilibrium distribution as generated by the photo-excitation to a Fermi-Dirac distribution with electronic temperature T_e, and subsequently lose their energy to the lattice with temperature T_l through electron-phonon scattering. A widely used model describing this electron-phonon thermalization uses a set of coupled nonlinear differential equations:

$$\mathrm{C}_e(T_e)\frac{\partial T_e}{\partial t} = \Delta(\kappa T_e) - g(T_e - T_\ell) + A(\mathbf{r},t)$$
$$\mathrm{C}_\ell\frac{\partial T_\ell}{\partial t} = g(T_e - T_\ell) \qquad (1)$$

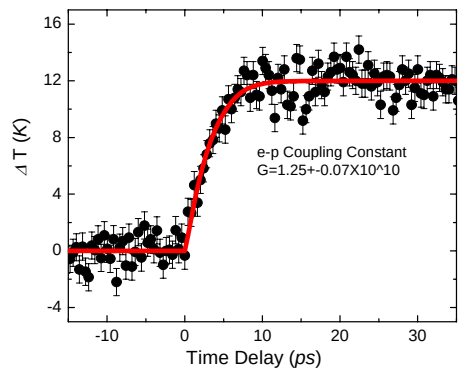

Fig. 1. Temporal evolution of lattice temperature in 20-nm Au film. The solid line is a fit to the data using two temperature model, where g = 1.25 ± 0.07x10^{16} $Wm^{-3}K^{-1}$ is extracted.

where C_e and C_l are the heat capacities of the electrons and lattice, κ is the electron thermal conductivity, and $A(\mathbf{r}, t)$ represents the source term for the absorbed laser energy. The crucial parameter is the electron-phonon coupling constant, g, which determines the rate of energy transfer from electrons to phonons. Figure 1 shows the direct FED measurements of ultrafast heating of 20-nm Au films after optical excitation at 800-nm wavelength. By fitting the data of lattice temperature evolution using Eq. (1), the electron-phonon coupling constant of Au is measured to be: $g = 1.25\pm0.07\times10^{16}$ $Wm^{-3}K^{-1}$. This value lies within the range of g obtained by the indirect optical pump-probe measurements. However, the e-ph thermalization time of 1.8 ps in Al measured with FED is more than five times longer than that is predicted from the Eq. (1) using a well accepted g value [1]. This significant slow heating of the lattice is not due to the finite electronic thermalization time of ~ 200 fs, which tends to slow down the e-ph coupling. The relevent physics of this unexpected slow lattice heating in Al is currently being investigated.

Acknowledgements

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References

[1] H. Park, *et al.*, Solid State Commun., **136**, 559 (2005).