JCCM-Mar06-02

Measurement of the Electronic Gruneisen Constant by Femtosecond Electron Diffraction

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Phys. Rev. Lett. 96, 025901 (2006)

Recommended and Commentary by Albert Migliori, LANL, Los Alamos

Separation of the effects of overlapping physical phenomena is always a good thing. For example, using a magnetic field to turn off superconductivity and then examining heat capacity with field on and with field off provides a superb differencing experiment that accurately reflects the temperature dependence of a BCS gap. Similarly, very low temperatures can freeze out the T^3 component of the specific heat arising from phonons to reveal and separate the underlying linear heat capacity of the conduction electrons. In this article, time is used as the separating variable, while the probed quantities are basically the thermodynamics of the electronic and vibrational subsystems in a good metal at temperatures (presumably ambient, though strangely for such a carefully analyzed measurement, nowhere in the article is the temperature specified) way above those that are normally used to separate these phenomena.

The measurement is another amazing display of the power of time-resolved optical pump-probe studies. The idea is to whack a 20nm-Al film with a light pulse to set it ringing in a standing acoustic wave. Then, using a photocathode and a small piece of the pump beam, an electron burst (1000 or so electrons) is generated and accelerated to 60keV speeds. The electron burst is used as a timeresolved source for an electron diffraction measurement to obtain the lattice parameter as a function of time with 500 fs time resolution, and a few parts in 10^5 spatial resolution. The Debye Waller factor is used to measure temperature.

The standing acoustic wave is of interest in its own right. At these frequencies (1.7×10^{11} Hz), the wave-vector is non-negligible, the corresponding energy is about 8K out of a Debye temperature of 394K for Al. If thinner films could be measured, or higher harmonics observed, it might be possible to map out a substantial portion of the phonon dispersion curve. The acoustic wave is also nominally in the extreme isothermal limit (most sound speeds are reported at the adiabatic limit). The elastic modulus that determines the stiffness

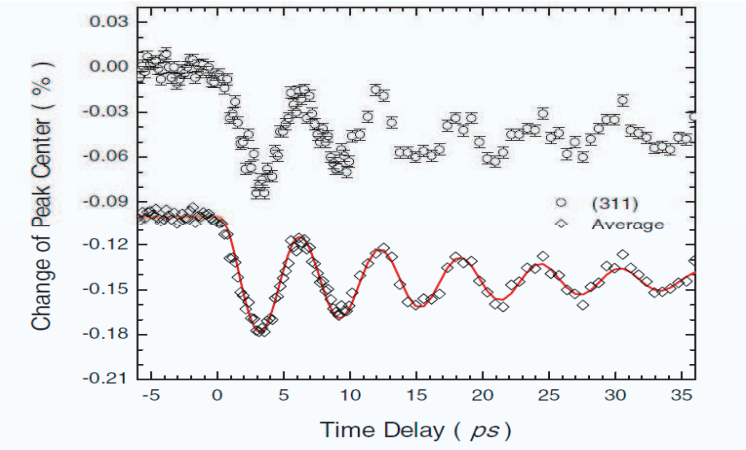

FIG. 1: The ringing of the diffraction pattern due to a standing acoustic wave

is also apparently time dependent as the electronic and vibrational systems are not excited together. Finally, the strain amplitudes are large, of order 0.1, well above the yield strain in bulk pure Al.

The result is seen in Fig. 2 from the paper and reproduced here: In this figure, the acoustic standing wave is measured by a signal-averaged fractional lattice parameter shift versus time. From a fit to these data, the average lattice expansion is determined and then used to separate the electronic and vibrational Gruneisen constants. Most of this part of the experiment is over in about 8 ps, with electron-lattice equilibration time constant of about 2 ps. Thus the important electronic subsystem is bared, and electron-phonon time scales are measured accurately at temperatures an order of magnitude above that where such measurements are traditionally performed.

Of great importance here is that with a little better signal to noise and time resolution, many more interesting effects could be observed, including the pure electronic elastic modulus, the electronic third-order elastic moduli (pressure dependence of the moduli) by changing drive amplitude, and finally, the strain rates here approach 10^7, well into the extreme shock conditions normally approached by laser min-flyer plate studies.