Electron-Phonon Coupling in Ni Thin Film

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Background

The dynamics of electron phonon-coupling is studied with ultrafast optical excitation in Ni thin film using femtosecond electron diffraction.

Electron gun

The electron- gun consists of a photoelectric material that releases electrons into a large potential difference. The electrons are accelerated to high energies that make contact with the sample creating a diffraction pattern. Currently, the electron gun operates at a potential difference of 80 KV. Higher voltages allow for shorter pulse widths, greater electron density and the ability to study thicker samples.

Sample

The sample used in this investigation is a 20nm nickel particle prepared using the sputtering process. The sample was sputtered on a sodium chloride (NaCl) substrate. The prepared sample was immersed in water in order to separate it from the substrate. This thin film of nickel was removed and placed on a copper grid which is then placed in the vacuum chamber.

Crystal structure

Many materials have crystalline structure which consist of an arrangement of repeated structural units. These structural units are held together by forces which can be thought of as tiny springs. These springs carry quantized vibrations known as phonons. Electrons passing through the lattice interact with these vibrations, this is called electron-phonon coupling.

Phenomena in the lattice can be observed with electron diffraction. Diffraction is a property of wave motion in which waves spread and bend as they pass around barriers. High energy electrons colliding with the lattice can diffract, producing a diffraction pattern as seen in fig. 3. Changes in the lattice can easily be seen as changes in the diffraction pattern, such as the spacing and intensity of the bright rings, "Bragg peaks".

Electron Lattice Interaction

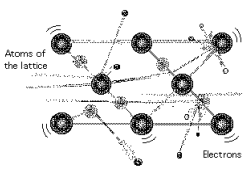

fig. 2

Diffraction Pattern

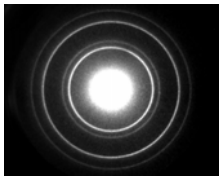

fig. 3

Femtosecond Electron Diffraction Setup

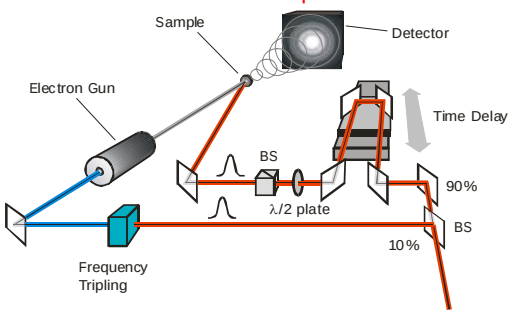

fig. 1

Femtosecond electron diffraction is accomplished by taking laser pulse and first separating them by a beam splitter. 90% of the initial beam is passed through a time delay and then allowed to hit the target. The remaining 10% is used to trigger the electron gun via the photoelectric effect. These high velocity electrons creates the diffraction pattern. The pump beam width is 2mm with a fluence of ~0.83 mJ/cm^2. This is the highest fluence that can be achieved due to possible sample damage. The single pulse temperature jump is ~20K.

Overview

Random thermal phonons are present in crystalline materials. However, through femtosecond laser pulses coherent phonons (vibrations moving in the same direction) can be generated. Such processes involve the interaction between electron, lattice and spin systems and the elastic properties of the material. All these subsystems have contributions in driving the coherent phonon. One example which can be studied in this interaction is the electron-phonon coupling of nickel.

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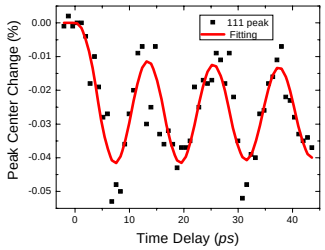


fig.4 Bragg peak oscillation in diffraction pattern.

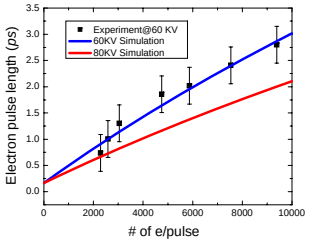


fig.5 Electron pulse length as a function of electron number.

fig. 6

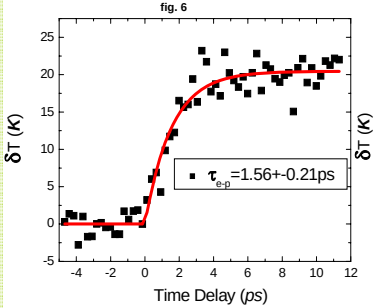
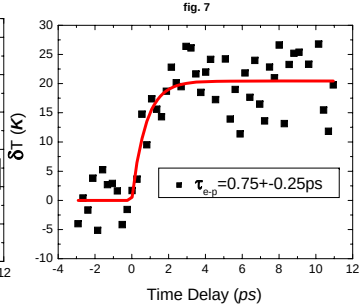


fig. 7



Temperature change as a function of time in 4100 and 1100 electron pulses.

# of e/pulse	Pulse width FWHM	e-p coupling time	Convoluted e-p coupling
1100	0.6 ps	0.7 ps	0.8 ps
2100	0.9 ps	0.7 ps	0.86 ps
4500	1.8 ps	0.7 ps	1.31 ps

fig. 8 e- p coupling data.

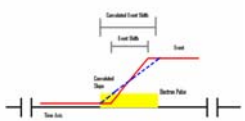


Fig. 9 Example of convoluted data

Discussion

Figure 4 is a plot of the motion of the Bragg peak as a function of time. This is the evidence of a coherent phonon in the nickel thin film.

Figure 5 is a graph of electron pulse length as a function of electron number per pulse. The difference in the two pulses becomes even more significant at higher electron concentrations.

Figures 6 and 7 are measurements of the temperature change in the sample. Figure 6 is a plot using 4500 electrons per pulse, while figure 7 is the same measurement with 1100 electrons per pulse. The effect of the different electron fluxes are visible. Figure 6 shows a good signal to noise ratio but, with a longer time delay while figure 7 displays a shorter time delay with more noise.

Figure 9 is a representation of convoluted data. The length of the electron pulse can affect the perceived length of the event. In this extreme case the length of the pulse covers the entire event, making it appear as if it occurs within the temporal length of the beam.

Figure 8 gives the convoluted electron-phonon coupling time as compared to the "accepted" value. The real electron phonon coupling time constant of 0.7ps is an estimation, which is in good agreement with previous documented measurements. Considering the relative large measurement error bar, 1100e/pulse should have sufficient temporal resolution.

Possible subjects for future studies include measurement of the electronic Grüneisen constant. The electronic Grüneisen constant (γ_e) defines the dimensional changes of a solid in response to the heating of its conduction electrons. Heating of the sample above the curie temperature allows the electron contribution to be measured independently of the magnetic contribution.

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