Femtosecond Electron Diffraction Using Pump/Probe Technique

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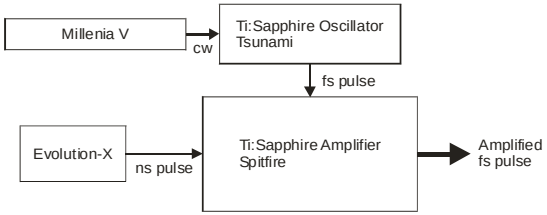
Experiment setup

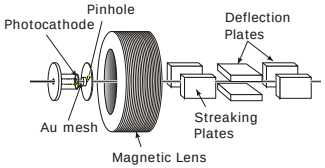
Laser System

There are four components to the laser system:
Millennia V Nd:YLF Continuous Wave Laser
Tsunami Ti:Sapphire Oscillator (fs)
Evolution X Nd:YLF Pulsed (ns) Laser
Spitfire Ti:Sapphire Amplifier
These four components generate the femtosecond laser pulse, that will ultimately be used to perform the experiment. The input energy for the Tsunami comes from Millennia V, the Tsunami is a mode locked Ti:Sapphire femtosecond laser, providing below 50 fs laser pulses, with a peak wavelength of 800 nm and an output energy of 400 mw. The pulse coming from Tsunami is dumped into Spitfire which with the aid of Evolution X amplifies the pulse power to approximately 500 mw. The beam then enters the optical array.



Electron Gun

After the beam enters the optical array the first thing it encounters is the beam splitter, 90% of the beam will be used to pump the sample, the remaining 10% will be delivered to the electron gun. The electron gun pulse first encounters a frequency tripler which brings the beam to a frequency of 266 nm. This frequency provides sufficient energy for the excitation of electrons from the surface of the Ag photo cathode. Once liberated these electrons are accelerated to an energy of 90 keV in an ultra high field. Now the electrons are on their way to the sample. A magnetic lens is used to collimate the beam.
Maintaining fs temporal resolution is very difficult because the beam tends to spread due to what is called the space charge effect; the space charge effect is due to coulomb repulsion of the electrons. Temporal resolution is generally decreased with higher numbers of electrons, because of the greater space charge effect. However, more electrons per pulse gives better signal to noise ratio. To optimize between these counteracting effects the right number of electrons at the correct energy must be found. For our experiment roughly 2000 electrons at 90 keV is optimal.



Diffraction Imaging System

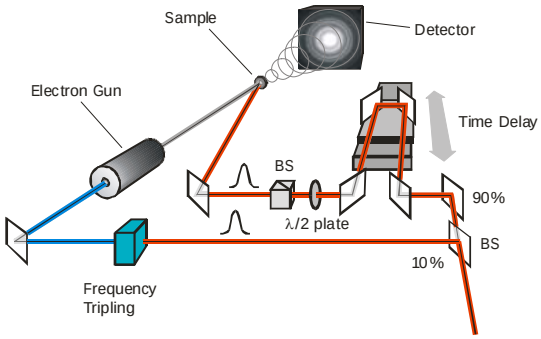
Our imaging system must have a device capable of detecting single electron events, due to the low number of electrons used per pulse. To accomplish this we use a high gain micro channel plate (mcp), to amplify a single electron event. The mcp is essentially an array of thin tubes which have a voltage placed across them. When one electron goes into one of these tubes it liberates roughly two more electrons from the inner surface of the tube. These two electrons are accelerated by the voltage and then strike the wall; each liberating two more electrons. The process continues through multiple iterations such that on the backside of the tube the single electron event has created about one million electrons. Then this bunch of electrons strikes a phosphorous screen, making photons that will be recorded by CCD camera.

Pump/Probe Technique – Experiment

The purpose of our study is to understand the nature of thermal expansion in thin metal films. First, our pump laser delivers energy to the thin metal film whence the electrons in the material are rapidly heated to a temperature much higher than that of the surrounding lattice sites. This happens because the electrons react instantly to the electric field of the incoming laser pulse whereas the lattice sites can not. Thus we can define two temperatures for the materials when in this non equilibrium state, the lattice temperature and then the electron temperature. If we consider the lattice and the heated electrons as thermally coupled, the second law of thermodynamics mandates a process by which the two 'materials' come to have the *same* temperature. We are interested in exactly how this thermally non equilibrium state is resolved, into an equilibrium state by electron-phonon coupling (electron thermal energy transferred into lattice motion energy).

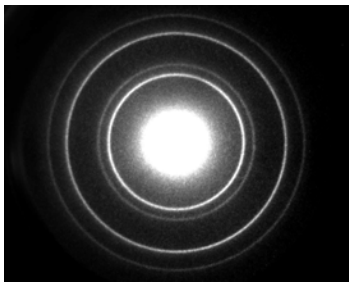
After some variable time delay, we probe the material using the high energy electron pulse for the purpose of diffraction imaging of the sample. By varying the time delay between the pump pulse and the probe pulse one can essentially create a series of frames which represent the dynamic changes in the positions of the atoms in the lattice after initial heating. By observing changes in the diffraction patterns at different delay times, one can infer the motion of the lattice. By analogy, each diffraction image represents a 'frame' in a 'movie' of the changes of the lattice. By analyzing this movie, we can learn exactly how energy is transferred between the electrons and the lattice.

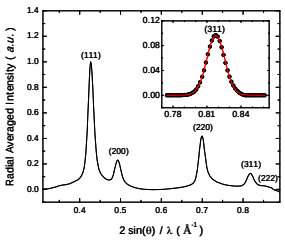
The parameter which relates change in volume to change in temperature is called the Gruneisen constant. We purpose that the Gruneisen constant is constitute of an electronic component due to the expansion from electron contribution and a lattice component, due to thermal motion. Further we purpose that the existence of the coherent acoustic waves in the material observed shortly after heating (due to the thermal stress from the electrons and the lattice) is related to the electronic component.



Diffraction Patterns

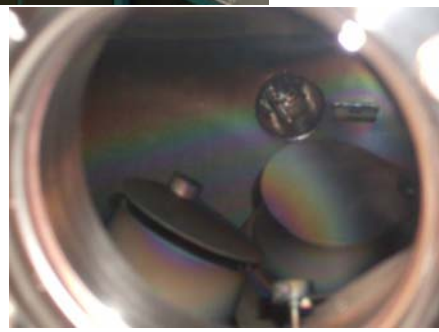
In order to observe the structural dynamics of thin metal films, one can observe the diffraction pattern of those films at various time delays. For polycrystalline materials theory of Bragg diffraction predicts concentric ring diffraction patterns. By analyzing properties of these ring structures such as changing the radius of a given ring or changing intensity of a given ring, one can infer properties of the metal relating to lattice spacing and long range order. These changes are the main interest of our data analysis procedure.





Sample Preparation

We begin with prepared NaCl single crystal substrate, then the metal of choice is thermally evaporated in a vacuum chamber. This process is continued until the desired thickness is reached. The thickness of thin metal film is carefully controlled and is approximately 20 nm thick. The film is composed of micro crystals of the metal and is very pure. This property of the film is what is used to generate the diffraction patterns. Once we have our sample we need to prepare it for use in our experiment. First the substrate is cleaved into smaller pieces about 1mm^2, the sample is then placed into distilled water where the substrate is dissolved. The sample floats on the surface of the water and is then removed using a fine copper grid. Once dry the sample is ready to be placed into the ultra high vacuum chamber.



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References

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