INNOVATIVE LOW-ENERGY ULTRA-FAST ELECTRON DIFFRACTION (UED) SYSTEM*

E. Threlkeld, L. Faillace#, S. Boucher, RadiaBeam Technologies, Santa Monica, CA 90404, USA
P. Musumeci, University of California, Los Angeles, CA 90095, USA

Abstract

RadiaBeam, in collaboration with UCLA, is developing an innovative, inexpensive, low-energy ultra-fast electron diffraction (UED) system which allows us to reconstruct a single ultrafast event with a single pulse of electrons. Time resolved measurement of atomic motion is one of the frontiers of modern science, and advancements in this area will greatly improve our understanding of the basic processes in materials science, chemistry and biology. The high-frequency (GHz), high voltage, phase-locked RF field in the deflector allows temporal resolution as fine as sub-100 fs. In this paper, we show the complete design of the UED system based on this concept, including initial beam measurements.

INTRODUCTION

Time resolved measurement of atomic motion is one of the frontiers of modern science, and advancements in this area will greatly improve our understanding of the basic processes in materials science, chemistry and biology. One technique under active development in this area is ultrafast electron diffraction (UED), which has several distinct advantages over X-ray diffraction for certain applications. UED utilizes a less expensive source; the electrons are less damaging to the specimen (at comparable energies); the scattering length of electrons better matches the penetration depth of the probe laser; UED is more suitable for gas phase samples; and it allows direct measurement of atomic positions, since the electron scatter mostly from nuclei. UED has already been used to study solid-state phase transitions [1, 2], gas phase reactions [3, 4], strongly coupled systems [5, 6] and surface dynamics [7]. In light of these results, researchers are demanding ever-shorter electron bunches in order to improve the resolution of their UED measurements. However producing intense sub-ps pulses of electrons in the desired energy range (30 - 100 kV) is challenging, due to space-charged induced longitudinal spreading. To date, efforts in this area have concentrated on either minimizing the bunch charge, which reduces the signal-to-noise ratio (SNR), or on using higher-energy electron beams, which reduces the diffraction angle and increases the size and the cost of the system. RadiaBeam, in collaboration with UCLA, is developing an innovative, inexpensive, low to moderate energy UED system which allows to reconstruct a single ultrafast event with a single pulse of moderate energy electrons (100 keV). By implementing a fast Radio-Frequency (RF) deflecting cavity immediately after

the sample, the diffracted electron beam can be "streaked," transforming the temporal evolution of the diffraction pattern into a transverse image (see Figure 1). The high-frequency (GHz), high voltage, phase-locked RF field in the deflector allows temporal resolution as fine as 100-fs and below, while the probe electron beam can remain comparatively long (10's of ps), and contain a large number of electrons ($\sim 10^8$).
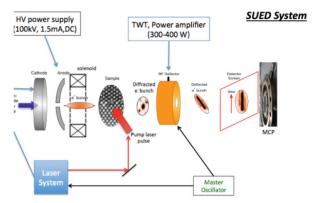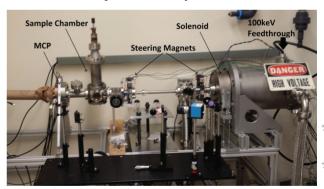

Figure 1: "streaked"- Ultra Electron Diffraction System.

ENGINEERING OF THE UED SYSTEM

The current setup of the UED system:

Figure 2: Current setup of the UED system.

The cathode location is set as z=0m. The solenoid is positioned at about z=6cm allowing a beam focusing point anywhere between the MCP (z=1m) and z=70cm. The sample is located at z=74cm and there is room for a second solenoid at z=40cm. Eventually the deflector can be put at z=50cm, just after the sample chamber to match previous resolution calculations.

PHOTOELECTRON GUN

The design of the 100 kV photocathode electron gun has been carried out by means of the 2D RF/Static simulation code SuperFish and the 2D gun design code

EGUN2. As a starting point, we chose the 100 kV electron gun developed at Eindhoven University of Technology [8].

The main issue, when dealing with high DC field values, is represented by the transition between air and vacuum (vacuum feed-through) as well as the vacuum level inside the gun vessel. Both issues, addressed in the present section, can be the cause of overvoltage and high risk of breakdowns.

Special attention must be put on the feed-through design. A safe configuration would be to lay a high-insulating material around the inner conductor that will be electrically attached to the aluminum cathode holder. Also the interface geometry (such as an exponential cup filled with a dielectric) will be necessary.

The 2D profile used in simulations is given in Figure 3. The cathode is a flat disc with a 1 cm diameter. The holder, a hollow cylinder, allows for both back and front illumination and replaceability of the cathode piece itself. In the same figure, the axial electric field distribution is also shown. The field value at the cathode is about 9.8 MV/m. The maximum value is located at the round edge of the holder (11.8 MV/m). The above mentioned values of electric field are safe as far as breakdown is concerned, according to experimental results [9], showing that a high voltage of 250 kV is considered the safety threshold value inside a gap (cathode-anode) of about 1cm.
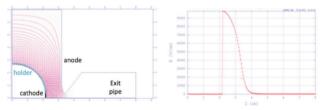

Figure 3: Left, 2D model from SuperFish (equipotential lines and field arrows are also shown); the cathode area is flat (1 cm dia.). Right, axial electric field (9.8 MV/m at the cathode).
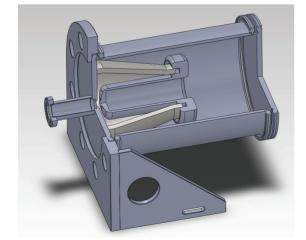

Figure 4: SolidWorks 3D model of the 100kV photo-gun.

A 3D mechanical model of the photo-gun, from SolidWorks, is shown in Figure 4. The replaceable cathode sample is made out of copper. The hollow

cylindrical body that holds the cathode is made out of aluminum while the vacuum vessel, that the anode electrode is attached to, is stainless steel. In order to obtain very high vacuum level inside the gun (up to 10^{-14} mbar), a TMP pump will be used. The high-voltage feed-through and the TMP pump are attached to the vessel. The isolation between cathode and the anode is realized by using an insulating cone made out of Macor® (see: light grey conical piece in Figure 4).

PHOTOCATHODE DRIVE LASER

The laser used for this device is a Titanium-Sapphire 800nm 2GW (50fs pulse) source that goes through two BBO crystals (the first crystal is second harmonic generation while the second crystal is third harmonic generation) and gets converted to 266nm UV beam. This beam is sent to the photocathode using front illumination. A beam splitter is used to create a virtual cathode plane to enable measurement of the laser spot size with a CCD camera. A lens (f=50cm) is used to image onto the cathode an iris that can be used to adjust the spot size (see Figure 5).
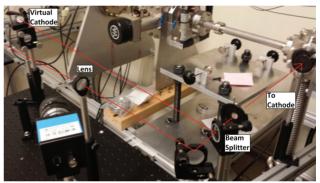

Figure 5: The optics just before the chamber including the imaging lens, beam splitter and virtual cathode.
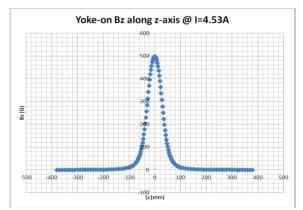
BEAM CONTROL

Figure 6: Plot of solenoid field at the center as a function of z.

Once the beam has been accelerated, it travels through the solenoid for focusing. See Figure 6 for the B vs Z of the solenoid. After, there are two 2-axis steering magnets for aiming and fine-tuning the position of the beam.

06 Accelerator Systems

T02 - Electron Sources and Injectors

DETECTOR SYSTEM

The micro channel plate (MCP) detector that will be used to image the beam is shown in Figure 7. The MCP basically works as an electron amplifier in which the incoming electrons generate secondary electrons. In this case, the incoming electrons enter channels in which they are accelerated by an electric field and generate the secondary electrons.
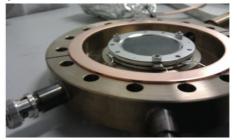

Figure 7: Multi Channel Plate Detector

The MCP is equipped with a phosphor screen that is imaged 1:1 onto the CCD camera, allowing a spatial resolution of 50 μm. The relation between the bunch duration and the length of the streak on the phosphor screen is obtained by integrating the Lorentz force that is acting on the electron bunch during its travel along the axis through the deflecting cavity. The MCP is located at the focusing point of the solenoid, in order to obtain a sharper diffraction pattern.
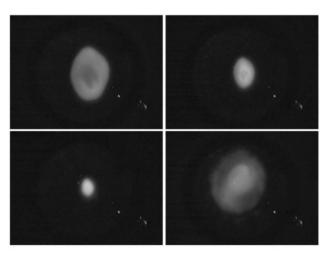
MEASUREMENTS

Figure 8: Beam images at different solenoid currents in order from top left to bottom right: 2.373A, 2.486A, 2.566A, 2.738A. The recurring white spots are dead pixels in the CCD camera.

In order to commission the system a solenoid scan was performed to compare the results with simulation and obtain first estimates on the beam parameters. We show in Fig. 8 a few representative images from the solenoid scan (Fig. 9). The minimum spot size at the MCP plane is obtained for a current of 2.566A. For these measurements the gun voltage was set at 40kV.
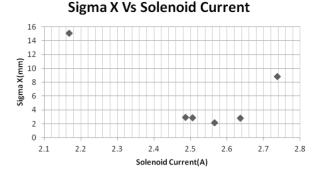
Sigma X Vs Solenoid Current

Figure 9: Measured Sigma X on the MCP as a function of solenoid current.

CONCLUSIONS

The UED technique has already been used to produce groundbreaking results in a number of areas of materials science and chemistry. It has been described as providing the capability to "make a movie" of events occurring on the atomic scale. Clearly, such a technology has the potential to enable new discoveries. The SUED system we are developing, with improved resolution and SNR, would enable even further breakthroughs in the understanding of ultrafast phenomena, stimulating new innovations in material science, chemistry and biology.

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