High-Flux Ultrafast Electron Diffraction at LBNL

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The next challenge for future ultrafast scientific instruments is to be able to follow the dynamics of atoms and molecules. This is a particularly difficult task, especially for large, dilute or isolated, non-periodic samples, as their weak interaction with probe pulses produces faint signals of difficult detection. Most important parameters for the next generation of scientific instruments are therefore the beam brightness and the average flux. Beams of electrons and X-rays are both widely used as ultrafast probes: while the X-ray beam brightness can be arbitrarily high, electron beam phase space density is limited by quantum mechanics. On the other hand electron sources are compact and cheap, and electron beams are easy to handle, shape and detect.

At LBNL we have developed an electron source (APEX) \cite{1} producing femtosecond relativistic pulses, capable of running with repetition rates up to 186 MHz, with an average flux in excess of $10^{13}$ electrons per second. The electron source has been designed, built and successfully tested at LBNL and our proposal to build an high repetition rate ultrafast diffraction instrument has been recently funded by DOE-BES, allowing the construction of a dedicated diffraction beamline (HiRES) \cite{2} which is now underway. The enormous electron flux will greatly increase the signal to noise ratio in stroboscopic experiments, while the high peak field at the cathode and relativistic electron energy will produce and maintain a high peak brightness at the sample for single-shot experiments.

The electron diffraction beamline (Fig. 1) is composed by the electron gun, two solenoid magnets for beam focusing, and an rf buncher \cite{3} working at a frequency of 1.3 GHz. Two meters downstream the cathode, an achromatic dogleg (2 dipoles, 3 quadrupoles) switches the beam to a dedicated beamline for electron diffraction. Here the electrons are focused on the experimental chamber, and then collected at the final viewscreen, 1 meter downstream the sample.

The energy dispersion within the dogleg enables energy collimation. Energy spreads of few tens of eV can be achieved, with a nominal energy of 750 keV. Electron energy loss experiments are being currently studied, with resolutions in the 100-eV region.

Short electron beams are produces by the joint use of a femtosecond laser for electron beam production via photoemission, high electric field at the cathode allowing extraction of high electron densities, and an rf-buncher cavity downstream the electron gun, introducing energy-time correlation in the beam and causing time compression in the following drift section. We simulated electron beam pulses down to 50 fs (Fig. 2, right plot) while still keeping high average current at the sample ($10^6$ times the charge/pulse).

High repetition rate operations open the door to the use of high bandwidth feedback systems for noise cancellation. Beam jitters can be greatly mitigated by compensating for phase and amplitude noise in the different subsystems. This is particularly important when pushing the time resolution to 100 fs or below, as at this level the beam time-of-arrival jitter at the sample tends to limit the time resolution. Energy collimation can also be sued to improve the system stability at expenses of average current. Selecting a fixed energy range within the bunch improves the time-of-arrival jitter together with the energy stability.

We report the status of HiRES, the results of beam dynamics simulations including particle-particle...
interactions that limit the minimum bunch length. Beam jitters in energy, time and position are currently being characterized, and a mitigation strategy via fast feedback loops is discussed [5].

References:

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Figure 1. HiRES beamline at APEX. The beamline is currently being installed. An rf bunching cavity is used for electron beam time compression, and energy collimation within the dogleg is used for achieving very small energy spreads and increase the beam stability in energy and time-of-arrival.

Figure 2. Results of simulations using the GPT [4] code. The plots show the trade-off between electron-per-pulse at the sample and emittance, i.e. spatial resolution, (left) and time resolution (right). To get the average current from the charge one has to multiply by $10^6$ in the APEX case.