Electron Pulse Length Broadening Due to Space Charge

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Introduction

Ultrafast electron diffraction (UED) is a rapid advancing technique that holds a great promise to reveal the atomic-detail structural dynamics in real time [1]. The UED relies on the short and intense electron pulses. However, an electron pulse broadens its temporal duration as it is propagating from source to sample due to the space charge (SC) effect. Here we present a study of the SC effect on electron pulse broadening on the sub-picosecond timescale.

Results and Discussion

The ultrashort electron pulses are generated by our 2nd generation 60 kV femtosecond electron gun [1]. The pulse temporal duration as a function of electron numbers per pulse was measured by a customized deflection-type streak camera and employing a dual-sweep design to double the streaking velocity [2]. The experimental data are summarized in Fig. 1. It is clearly seen that pulse broadening depends heavily on number of electron per pulse. Particularly, in order to keep a sub-ps temporal resolution, the total number of electrons per pulse has to be set less than 2000. We have also conducted a pulse width measurement using an alternative approach, by probing a transient process of the ultrafast lattice heating of Al thin film with UED. The rising edge of the lattice temperature recorded with UED is set by the convolution of intrinsic electron-phonon coupling time ($\tau_{e\text{-}ph}$) and the probe electron pulse width. Given $\tau_{e\text{-}ph}$, the electron pulse width can be calculated by the de-convolution of the elongated rising edge. The data obtained by this de-convolution are also plotted in Fig. 1. In the overlapped region, they agree well with the data obtained in streaking measurements.

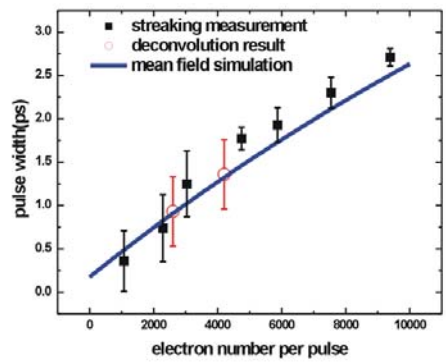

Fig.1 Temporal width of electron pulse as a function of electron number per pulse.

We also conduct a mean-field theory calculation of SC broadening effect [2], shown as the solid line in Fig. 1. The simulation agrees very well with the streaking data. This indicates that among several competing broadening mechanisms, such as the space charge effect and broadenings due to electron energy dispersion and different trajectories, the space charge effect is the dominant factor to determine the final electron pulse. In order to keep a sub-picosecond resolution while maintaining sufficient beam intensity to conduct sub-picosecond diffraction measurements, the drifting time of the electron pulse must be minimized either by shortening the distance from the source to the sample and/or increasing the electron kinetic energy. Our measurements also show experimental evidence that, as the intensity of electron beam increases, the space charge effect can also effectively change the shape of the longitudinal intensity profile, resulting in a top-hat shape [2]. The evolution of the longitudinal intensity profile to a top-hat shape is usually correlated with a quasi-linear velocity chirp, which has been theoretically predicted.

Acknowledgements

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References

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[2] Wang, X., *et al.*, Rev. Sci. Instr., in press (2008).