High-Coherence Electron and Ion Bunches from Laser-Cooled Atoms

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Biography
Robert Scholten is a Professor of Physics at The University of Melbourne, where he leads the Ultracold Plasma high-brightness electron source Project of the ARC Centre of Excellence in Coherent X-ray Science. His research career began with studying electron collisions from laser-excited atoms, where laser polarisation was used to control the quantum state of the target atoms. His interest in laser-atom interactions formed the basis of later research, for example using atom-optics techniques for nanofabrication as a Fulbright Postdoctoral Research Fellow at NIST in the USA. He has also developed novel approaches to optical imaging of cold atoms, is currently working on quantum sensing using colour centres in diamond, and has created a high-tech start-up company (MOGLabs) based on lasers and laser electronics.

Abstract
Cold atom electron and ion sources based on photoionisation of laser cooled atoms offer a new approach to generating high brightness and high coherence charged particle beams for applications including ultrafast electron diffractive imaging of dynamic processes at the nanoscale. The effective brightness of electron sources has been limited by non-linear divergence caused by repulsive interactions between the electrons, known as the Coulomb explosion. It has been shown that electron bunches with ellipsoidal shape and uniform density distribution have linear internal Coulomb fields [1], allowing reversal of the Coulomb explosion using conventional optics. A cold atom electron source can create bunches shaped in three dimensions and in principle achieve the transverse spatial coherence and brightness needed for picosecond diffractive imaging with nanometre resolution.

We have demonstrated [2] arbitrary shaping of the cold atom cloud (Fig. 1), and hence of the extracted electron bunches, and used the shaping capability to allow detailed measurement of the spatial coherence properties of the cold electron source [3]. We also show remarkable ion bunch shape formation and evolution, with direct visualisation made possible by the very low (milliKelvin) temperature of the ions. Using a counter-intuitive two-step femtosecond excitation

Figure 1: (a) A bunch of electrons (left) has been produced with a complex spatial distribution, and because of the low electron temperature (10 K) the bunch has retained its shape after propagating 24cm. (b) Images of propagated ion bunches (right) show two adjacent expanding ion bunches; excitation laser beam intensity profile for an array of miniature ion-bunches, and far right, complex
and nanosecond ionisation scheme, we have generated electron bunches with durations of a few hundred picoseconds [4]. Diffraction experiments of simple crystalline materials are currently in progress, to demonstrate application of the high coherence of the novel source. Future development of the cold atom electron source will increase the bunch charge and charge density, demonstrate reversal of Coulomb explosion and picosecond pulse durations, and ultimately, ultrafast coherent electron diffractive imaging.

References