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Karl Schmid

Laser Wakefield Electron Acceleration

A Novel Approach Employing Supersonic Microjets and Few-Cycle Laser Pulses

Doctoral Thesis accepted by
Max Planck Institute for Quantum Optics
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Author
Dr. Karl Schmid
Max Planck Institute for Quantum Optics
Hans-Kopfermann-Str. 1
85748 Garching
Germany
e-mail: karl.schmid@gmx.eu

Supervisor
Prof. Ferenc Krausz
Max Planck Institute for Quantum Optics
Hans-Kopfermann-Str. 1
85748 Garching
Germany
e-mail: ferenc.krausz@mpg.de

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Supervisor's Foreword

Particle accelerators play an indispensable role in several branches of modern research such as, inter alia, physical, biological and materials research or medicine. In many of these applications and using current particle accelerator technology, these devices are very large and costly thereby impeding installation at small and medium-scale research institutes or universities. The alternative approach of laser-driven electron acceleration, which is the object of research of the present thesis, holds the promise of reducing the size and cost of conventional accelerators by many orders of magnitude thereby making this indispensable scientific tool available to a much broader range of users. Additionally, laser driven electron acceleration offers the advantage of generating electron pulses which are significantly shorter than those produced by conventional technology. This unique property has the potential of enabling ground-breaking research of certain ultra-fast processes with unprecedented temporal resolution.

In the present thesis two separate topics are investigated, with both relating to electron acceleration facilitated by the strongly relativistic interaction of an ultra-intense laser pulse with a fully ionized helium plasma. Firstly, microscopic supersonic gas jets necessary for the experimental realization of the acceleration process are explored. Detailed theoretical analysis, design and characterization of nozzles producing microscopic supersonic gas jets are presented in part one of this thesis. These investigations lead to the generation of the smallest tailored gas targets ever used in the context of laser-plasma research.

Secondly, the generation of ultra-short, relativistic electron bunches is investigated. The generation, precise optimization and characterization of the accelerated electron bunches are the main topics of part two of this thesis. Stable monoenergetic electron beams were produced in a complex experimental setup including a high degree of freedom in the relevant parameter ranges and with a unique laser system producing ultra-short and ultra intense pulses.

In order to characterize the properties of the electron bunches, several electron beam diagnostics were designed and used for detailed studies of various properties of the electron bunches such as energy spectrum, angular distribution, divergence and charge. The acceleration experiments are performed with high repetition rate and deliver a pulsed electron beam with an electron energy spectrum free of low-energetic background. Careful parameter scans using a large number of samples yielded the optimal experimental parameters and valuable information about the physics of the laser-plasma interaction.

The knowledge gained from this work is a solid basis of forthcoming research. One of these directions is the development of a novel injector placing electrons into the accelerating plasma wave thereby further stabilizing the acceleration process. Another outcome is new characterization techniques of unexplored electron beam properties such as normalized transverse emittance, electron bunch duration or the structure of the electron plasma wave accelerating the particles. Therefore, this work is not only a detailed universal description of supersonic nozzles for a broad field of applications but also a pioneering investigation on plasma based laser-driven electron acceleration.

Garching, January 2011 Ferenc Krausz

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