1 Introduction

The last decades have seen an enormous progress in the generation and application of ultrastrong laser pulses. Initially, there were the large scale facilities designed for laser based plasma and fusion research. There, huge systems based on CO_2- or solid-state lasers were used to create intensities of up to about 10^{16} W/cm² [JC95]. This changed dramatically in the mid 1980s when the method of chirped pulse amplification (CPA) was introduced [SM85]. The basic idea of CPA is to ‘stretch’ a laser pulse before amplification, thereby increasing its duration by a factor of 10^4 or more and reducing its peak power correspondingly. Accordingly, saturation and damage problems during amplification were reduced which allowed for the generation of much stronger pulses. After recompression of such pulses focused intensities of up to 10^{21} W/cm² and a peak power of 1.5 Terawatt (10^{12} W) [PPS99] were achieved.

CPA together with the development of solid-state laser media with broadband emission band [PM92] and the discovery of Kerr-lens mode-locking [SKS91] resulted in a remarkable change in small laser laboratories as well. The laser oscillators became smaller, much more reliable and the pulse length was pushed down to a few femtoseconds. The combination of such oscillators with chirped pulse amplification resulted in laser systems with Terawatt pulse power fitting on a table (and into the university budget). With such systems it became possible for a much larger community to take part in, e.g., laser plasma research. That, of course, boosted the number of applications. As an example, laser-based generation of X-rays pulses became an entirely new method for a number of different fields of physics. Such pulses are created typically when a strong laser pulse is focused onto a (preferably solid) target. The target emits characteristic line radiation with energies of a few keV (wavelengths of 0.1…1 nm) within a time that is governed by the laser pulse duration. Such a source of ultrashort energetic photons may play an important role in next generation micro-lithography [ELT01], but it can also extend the diffraction methods in solid state physics, chemistry or biology to a new – temporal – dimension. Within the last decade diffraction experiments with such sub-ps X-ray were successfully conducted and gave a breakthrough in the observation of rapid dynamics of structural changes [HER97].

While the large scale facilities are mostly designed for a single shot regime, the table-top Terawatt systems usually work at 10 Hz repetition rate. New pump lasers for ultrafast amplifiers are available now with repetition rates of >1 kHz and enable researchers to increase the repetition rate of the whole amplification scheme by a factor of 100. The progress of the laser systems to higher repetition rates generates new requirements to the targets for X-ray generation: They have not only to be stable within a few microns, but also replaceable within less than a millisecond. It was the major objective of this work to develop a complete system for laser based X-ray generation at kilo-Hertz repetition rates including a new target scheme that meets the respective requirements. In Chapter 3 of this thesis the laser system producing focused intensities of up to 5×10^{16} W/cm² at 1 kHz repetition rate as well as the new target based on a microscopic liquid jet is presented. Stability of the target is a very important requirement for the generation of X-rays and will be discussed by means of jet-photography with ns-resolution. Chapter 4 contains the characterization of the X-ray emission for different targets and repetition rates of 1 and 10 kHz, respectively. X-ray generation processes will be discussed based on energetic electrons from the laser-produced plasma (LPP) that impinge into the cold target material. Investigations of the broadband bremsstrahlung emission of different targets will complete this chapter. The application of the X-rays from a liquid-gallium target in a diffraction experiment will be shown in Chapter 5. The question, whether the photon budget of the whole system is sufficient for time resolved precision experiments will be addressed.

Chapter 6, where particle acceleration effects in the LPP is investigated, has to be seen in strong connection to the theoretical introduction given in Chapter 2: Since the plasma processes take place on very short time scales under almost exotic conditions of field strength and pressure a diagnostics are not easy. Chapter 2 explains the laser plasma basics, and in Chapter 6 a number of experiments are shown which give insights into the basic processes in the LPP, such as the generation and propagation of a critical density surface, interactions between photons and plasma waves and, finally, the acceleration of charged ions out of the plasma. For this purpose a direct measurement of collimated electrons as well as spectroscopic examination of the visible radiation from the plasma will be presented. A careful analysis of these experiments together with the results from Chapter 4 delivers a general picture of the underlying plasma processes. Chapter 6 closes with measurement and discussion of accelerated protons. Finally, the main results and the future prospects of this work are summarized in Chapter 7.