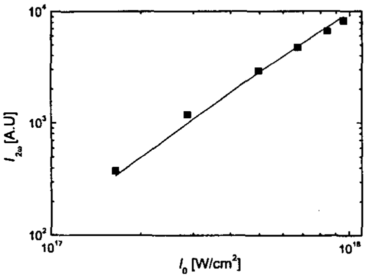

CTuC3 Fig. 3. The second harmonic intensity versus laser intensity of the pump pulse.

the second harmonic intensity are shown, respectively. The second harmonic intensity was proportional to the square of n_e. But it was not proportional to the square of I_0, although it is two photon process in low intensity regime. The intensity of the second harmonic was measured to be proportional to I_0 with the power of 1.7. This difference is thought to be caused by the relativistic effect. The second harmonic generation from the relativistic plasma can be described by $I_{2\omega} \propto a_0^4/(1 + a_0^2/2)^{3/2} \cdot n_e^2$ from Ref. 2. We plotted this theoretical curve in Fig. 3. They are in good agreement with each other.

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CTuC4 9:00 am

kHz femtosecond laser plasma x-ray and ion source

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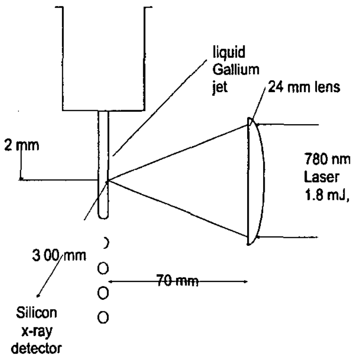
X-ray Source

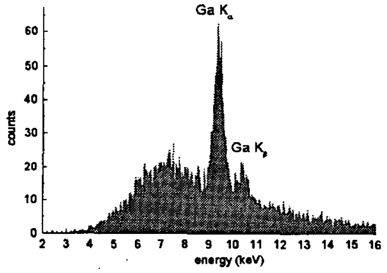
Femtosecond laser plasmas have attracted much interest in recent years as intense short pulses x-ray sources in the keV range for a variety of applications, such as lattice dynamics of semiconductor materials.[1,2] There would be many advantages to having high repetition rate (kHz) version of this source, but for this, the laser must be able to provide sufficient intensity, and it must be integrated with a debris-free, continuous target. High repetition rate femtosecond lasers based on chirped pulse amplification now possess excellent shot to shot stability[4] up to frequencies of 10kHz. In addition, however, it is well known that laser pulses with focused intensities $> 10^{16}$W/cm^2 are needed to generate x-rays above 1keV[5] with high photon numbers. Practically this then requires lasers with kHz repetition rates with pulses shorter than 100 fs and energies above 1mJ. Compared to moving wires,[1] liquid jets[3,7] have many advantages as laser plasma targets. With liquid jet flow velocities of 10–100 m s^{-1} a new intact and unperturbed liquid filament surface is exposed to subsequent laser pulses even at elevated repetition rates of up to 100 kHz. The small size of the jet, with diameters as small as 10 μm allows a near perfect match of the spatial extension of the of the target to the laser focus, minimizes plasma debris and the self-absorption of the emerging X-rays. In addition, the narrow spatial confinement of the radiation source could be favorable for the generation of very short x-ray bursts in the 100fs time range.

In this paper we describe the first demonstration of a kHz femtosecond laser plasma source produced from a liquid metal jet target. With a 30 μm diameter liquid Ga jet, this source produces photon numbers of up to 5×10^8 photons/sec in 4π sterad using a kHz Ti:Sapphire laser producing 50fs-pulses with an energy of 1.8 mJ at a repetition rate of 1kHz.

The experimental setup for both experiments is shown on Fig. 1. The fs-laser delivers 3W of average power at a repetition rate of 1 kHz. The compressed pulse has a bandwidth of ~ 25nm and the measured pulsewidth was 50fs. For the experiments described here average powers of 1.8 W were used. The laser beam was focused with a thin plano-convex quartz lens of focal length 7 cm to generate intensities of 3×10^{16} W/cm^2 onto the Ga jet target in a vacuum chamber with micron precision. The x-ray emission was diagnosed with a Si-photodiode-based energy dispersive x-ray detector (AMPTEK, XR-100CR) located 300 mm from the x-ray source. An x-ray spectrum from the plasma generated with the Ga jet is shown in Fig. 2. The spectrum consists of a broad continuum and two narrow peaks at 9.3 keV and 10.3 keV corresponding to the characteristic Ga K_a and -K_b lines. We interpret the broad continuum as bremsstrahlung emission and secondary emission (fluorescence) from the walls of the vacuum chamber. Details of the source will be described, as well as it's scaling with higher laser intensities beyond 10^{17} W/cm^2.



CTuC4 Fig. 1. Experimental set up: Laser (1.8mJ, 50fs, 1kHz); F-thin plano-convex lens f = 7cm; Jet- 30μm-thick Ga-jet; Si- x-ray detector: Amptec energy resolving detector. For proton acceleration a 10μm water jet has been used.

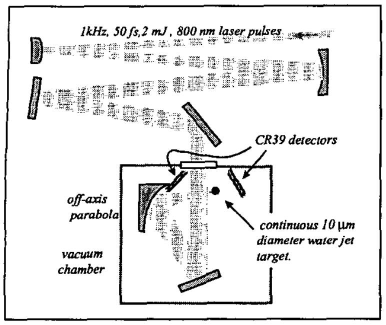


CTuC4 Fig. 2. Hard x-ray spectrum detected for Gallium using the XR100CR-detector. The accumulation time was 600 s.

Ion Source

Recent experiments with large, single-shot, sub-picosecond, multi-TeraWatt laser facilities focused to intensities in the range of $3 \times 10^{18} - 3 \times 10^{20}$ W/cm^2 on massive planar targets have demonstrated efficient conversion of the absorbed laser light into forward-going beams of high energy protons and fast ions.[8-10] Most of this work has been directed towards their potential for creating nuclear reactions, driving the front end of a high-energy particle accelerator or initiating nuclear fusion by fast ignition. The observation of fast ions from laser plasmas is not new, MeV ions being observed from plasmas produced by focused laser beams with values of $I\lambda^2$ in excess of 10^{14} W.μm^2/cm^2 as early as the mid-80's.[12] Fast ions have also been observed more recently in a number of picosecond high intensity laser interaction experiments with solid targets,[13,14] gas jets[15,16] and cluster targets.[17,18] The latest experiments on fast ion generation which show large fluxes of collimated, forward-going ions or protons, accelerated by electron acceleration of ions off the rear surface of the target,[9,10] by 'Coulomb explosions',[9] or by direct acceleration of the ions through the target from its front side,[8] opens up new applications in a variety of areas. These include various medical applications such as proton tomography and cancer therapy. However for these lofty objectives to be realized, these sources must be configured as compact facilities capable of operating routinely at high repetition rates. The pathway towards this capability will be through the progressive development of table-top, high repetition rate (kHz) femtosecond lasers[11] capable of producing the required focused intensity levels, (≥2 × 10^{17} W/cm^2) and high average powers integrated with a laser illumination system and a renewable target system that is both damage and debris free.

In our first experiments in this direction the same kHz-laser system is used as for the x-ray generation to produce high energy forward-going protons and fast ions from a fine continuous liquid water jet target with a diameter of 10μm. The output beam is expanded to a diameter of ~30 mm with the aid of a reflective telescope, and focused to intensities of ~2×10^{17} W/cm^2 by a 60 degree, 50 mm focal length off-axis parabola, (Fig. 3). This target geometry not only preserves the focusing optics from particulate debris emanating from the plasma region, but it also allows close, open access to the plasma radiation source. The <10 μm focused spot of the laser can be positioned onto the target with an accuracy of a few microns. Fast ions and protons are detected with CR39 nuclear emulsion detectors and radiographic plates. Ion emission is observed in both the forward and backward directions. The majority of the fast particles are observed in the for-



CTuC4 Fig. 3. Experimental setup for ion generation.

ward direction. The directionality and energy distribution of the proton emission is now under study, and dependence of the proton emission on laser intensity and focus parameters, and target geometry will be described.

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CTuC5 **9:30 am**

Measurement of 3/2-harmonic radiation in high-intensity femtosecond laser-solid interaction

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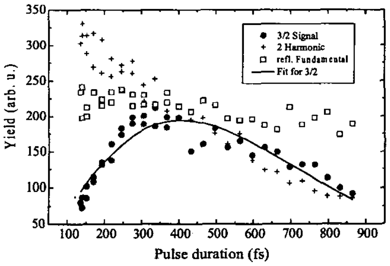
High intensity femtosecond laser produced plasmas are an important research topic relevant to X-ray lasers, laser initiated nuclear reactions, and relativistic effects in laser-plasmas. Parametric instabilities are invoked in the plasma which may lead to 3ω/2 generation. 3/2-harmonics have been extensively studied experimentally and theoretically with laser pulses of nanosecond and several hundred picosecond duration.[1] The observation of green light in fs-Ti:sapphire laser-solid interaction is reported[2] which was attributed to 3ω/2 generation.

We report, to our knowledge the first experiments and pulse duration dependence of high intensity fs-laser generated 3/2-harmonic radiation in inhomogeneous plasmas and the comparison of this effect to theory.

P-polarized 150-fs, 790-nm Ti:sa laser pulses with an energy of 200 mJ were focused under an angle of incidence of 45° to an intensity of 2×10^{17} W/cm^2 onto a polished aluminum target inside a vacuum chamber. The generated 3/2-radiation was collimated in the specular direction. A conversion efficiency of 5×10^{-7} was measured ($\Delta\Omega \approx 2 \times 10^{-3}$ sr solid angle) which is comparable to results with nanosecond laser pulses.[3]

Figure 1 shows the measured fundamental (open squares), the second harmonic (crosses), and the 3/2-harmonic radiation (filled circles) as a function of the incident Ti:Sa laser pulse duration between 150 and 900 fs. The position of the compressor gratings were varied and the measurement shows both directions from the optimal position indicating that the generation process does not depend on the sign of the chirp. Since the energy and the size of the focus were kept constant, the intensity is inversely proportional to the pulse length. The ω-signal stayed almost constant, so the reflectivity was constant in the applied intensity range. The 2ω-radiation increased with shorter pulses, i.e., with higher intensity, while in contrast, the 3ω/2-yield shows a maximum at 350 ± 50 fs.

The 3/2-generation is due to the coupling of plasmons of ω/2 frequency, which are generated by the two-plasmon decay in the vicinity of the quarter-critical density (1/4 n_c), and incoming laser photons. It is expected that the 3/2-intensity is proportional to the intensity of the laser beam at 1/4 n_c and to the amplitude of the produced plasma waves. The plasma wave amplitude is growing exponentially in time since the instability provides an amplification of the density fluctuation. This holds when saturation effects can be neglected, which is fulfilled for the short times considered here. The interaction time is assumed to be equal to the laser pulse duration. This is supported by measurements of the 3/2-emission time. For describing the result we take the maximum growth rate in an inhomogeneous plasma[1] which than provides a theoretical curve used to fit the 3ω/2-yield. A good agreement between measurement and theory is obtained.



CTuC5 Fig. 1. 3ω/2-, 2ω-, and reflected ω-signal as a function of the pulse duration. The solid curve represents a fit for the 3/2-harmonic based on two-plasmon decay instability in an inhomogeneous plasma.

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CTuD

8:00 am–9:45 am
Room 324/326

Novel Lasers and Sensors

Dmitrii Stepanov, *Redfern Optical Components Pty, Ltd., Australia, Presider*

CTuD1 **(Invited)** **8:00 am**

Highly efficient hybrid fiber taper coupled microsphere laser

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1. Introduction

High Q dielectric microcavities, in which light is trapped internally as whispering gallery mode (WGM) resonances, have attracted interest in applications as diverse as quantum optics and optical communications.[1-5] Among these, rare-earth doped glass microsphere lasers have been demonstrated as potentially compact laser sources. We recently presented a fiber-taper coupled microsphere laser in the 1550-nm band, which exhibited efficient fiber to sphere coupling and the advantages of fiber compatibility.[5] In this paper, we propose a novel hybrid-fiber-taper based laser coupling configuration, in which the microsphere is coupled using a single fiber taper that is a combination of 980-nm single mode fiber (SMF) and 1550-nm SMF. The pump source and the laser emission are then both guided in single mode fiber, to or from the taper region. This structure has greatly improved the coupling of the fundamental pump mode to WGMs of the microsphere. In addition, the measured laser output power of 112-µW is over an order of magnitude larger than our previous result. The differential quantum efficiency has been measured to be 12%.

2. Hybrid fiber taper coupling to microsphere

A 1550-nm band fiber-coupled microsphere laser is formed by placing a tapered fiber in contact