# Laser produced X-ray source in the 10-60 keV range at 1 kHz. Modified irradiation schemes in order to reach medical imaging quality

Albert, F; Sjogren, A; Wahlström, Claes-Göran; Svanberg, Sune; Olsson, C; Merdji, H

*Published in:*
Journal de Physique IV

*DOI:*
10.1051/jp4:2001283

2001

*Citation for published version (APA):*
Albert, F., Sjogren, A., Wahlström, C.-G., Svanberg, S., Olsson, C., & Merdji, H. (2001). Laser produced X-ray source in the 10-60 keV range at 1 kHz. Modified irradiation schemes in order to reach medical imaging quality. *Journal de Physique IV*, *11*(PR2), 429-432. https://doi.org/10.1051/jp4:2001283

*Total number of authors:*
6

# Laser produced x-ray source in the 10-60 keV range at 1 kHz
# Modified irradiation schemes in order to reach medical imaging quality

F. Albert[a], A. Sjögren[a], C.-G. Wahlström[a], S. Svanberg[a], C. Olsson[b], H. Merdji[c]
[a] : Lund Institute of Technology, Atomic Physics Division, Box 118, S-221 00 Lund, Sweden,
[b] : Department of Diagnostic Radiology, Lund University Hospital, S-222 85 Lund, Sweden,
[c] : CEA-DSM, DRECAM-SPAM, F-91 191 Gif-sur-Yvette, France

**Abstract.** By tightly focusing ultra-short pulses from a Ti:sapphire terawatt laser onto a high-Z metallic target, hard x-ray pulses of short duration are produced. In most of our previous work concerning x-rays, a 150 mJ laser pulse with a 110 fs duration has been used. Using mostly tin and tantalum targets, hard x-rays in the 10-60 keV range have been produced and used in differential absorption imaging around the $K_\alpha$ absorption edge of a contrast agent and also in imaging employing gated viewing for suppression of scattered radiation. In order to increase the x-ray yield (shortening the acquisition time) an increase in the laser repetition rate is desirable while still staying in the $K_\alpha$ energy regime. We have used a 1 kHz repetition-rate laser delivering 35 fs pulses in order to work towards these goals. We have clear evidence of hard x-ray generation above 30 keV, even for low laser pulse energies. We also studied the effect of a fs prepulse. The medical imaging capability of the source was explored. The use of a prepulse has been optimized in order to improve the image quality as well as the overall x-ray generation yield.

## 1. INTRODUCTION

The generation of hard x-ray pulses from a plasma, through the interaction of a terawatt laser beam with a slab target of high nuclear charge Z, is nowadays well known and widely spread in as various fields as solid state physics, chemistry and medical science. Reducing the dose of x-rays in medical imaging is a challenge. In conventional medical imaging, the image plates record all the photons (generated in an hundred of fs for plasma x-rays) that have gone through the sample, the unscattered (also called ballistic photons) and the scattered ones. A temporal study of the exposure dynamics in laser x-ray imaging reveals that the ballistic photons arrive in a bunch of a few tens of ps, and the scattered ones spread in a sub-ns time regime [1]. Thus, using time-gating it is possible to record an image of better contrast by supressing most of the scattered photons that blur the image. Then for the same image quality (contrast, luminosity, bluring) as for conventionnal x-ray tube source, a lower dose is needed.

Previously, medical X-ray imaging sources in the 10-60 keV range have been achieved at the Lund Laser Center focusing on solid targets 150 mJ laser pulse energy with pulse duration of 110 fs. Along with the main pulses, delivered at 10 Hz, this laser system also produces prepulses (with a contrast of $10^{-3}$-$10^{-4}$), which create a pre-plasma for the main pulse to interact with. To characterize the process, the x-ray spectra have been studied through crystal spectroscopy [2] and photon counting techniques [3]. The imaging capability has also been investigated mainly using conventional medical image plates or streak cameras [1]. Computed tomography on a small object [4] with time gating has also been achieved.

In order to reduce the acquisition time for practical medical applications, the average x-ray yield has to be increased. A first approach consists in increasing the IR intensity on the target. There are clear difficulties and cost concerns in such an improvement, and the physics of the processes also changes, since higher-energy electrons are generated and the spectrum is shifted towards higher energies. Another way is to increase the repetition rate of the IR laser. Then one has to cope with two main problems, the first one is the resulting reduction of the IR energy available in the individual pulses and the second one concerns the probable increase of the debris of the target material with repetition rate, at similar fluence.

We have investigated both problems using a 1 kHz repetition-rate laser delivering 35 fs pulses with an energy up to 2.7 mJ per pulse. We have also tried to enhance the conversion efficiency using a laser pre-pulse. In order to achieve this, a pre-pulse generator was built on the basis of a Mach-Zehnder interferometer (cf. Fig.3) with polarization beam splitters. Thus, we were able to control independently the delay between both pulses, their relative intensities and polarization. The pre-pulse configuration has been compared to single 35 fs pulse irradiation. The principal diagnostics were analysis of spectra inferred from single-photon imprints on a back-illuminated CCD camera (photon counting) and tests of imaging capability, recording the transmission of different filters on an intensified and gated CCD.

## 2. MEDICAL IMAGING AT 10 Hz

### 2.1 Set up

The x-ray source consists of a stabilized rotating, 50 mm diameter, slab target irradiated by the focussed laser beam via an off-axis parabolic mirror (cf. Fig. 1). The debris problem is solved by using a simple aluminum shielding as shown in the picture. The beam enters via the hole on the front. To complete the protection a 100 μm glass plate is placed in front of that hole, and is automatically changed when absorbing too much due to matter deposition.

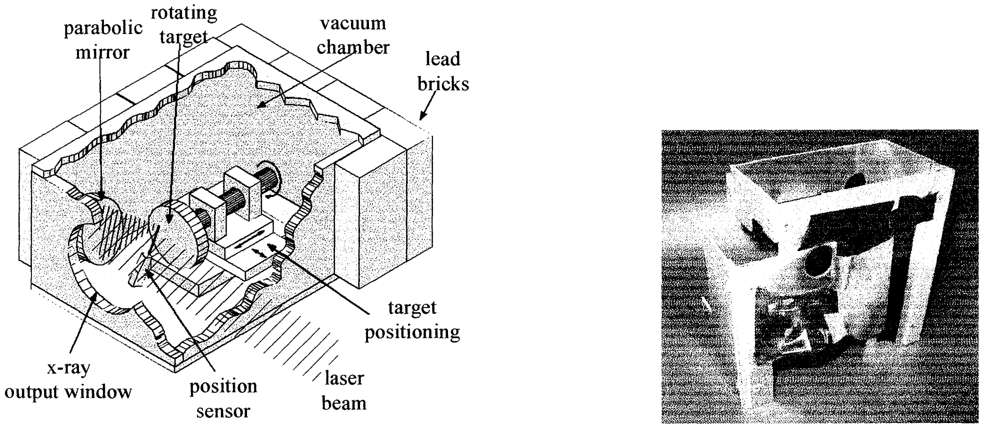

**Figure 1.** Schematic diagram of the interaction chamber. The picture on the right shows the aluminum shielding of the target in order to confine the debris.

This set up works on the 10 Hz, protecting the focussing mirror from debris. Using a very slow transverse translation, the rotating target can last almost a week of experiment time. On the 1 kHz system, it hopefully works the same, without any need to change the rotation and translation speed of the target.

### 2.2 Primary spectra and possible fluorescence

For comparison to our work at 1 kHz, we have recorded reference spectra at 10 Hz on tin (Sn) and tantalum (Ta) targets, employing the photon counting technique.

In order to improve the x-ray yield at 10 Hz, we have found that an increase of the pulse duration up to 500-600 fs was advantageous. The pumping irradiation has also been modified by changing the regenerative amplifier set up, introducing a supplementary prepulse 3.5 ns before the main pulse and at a relative energy of few percents and keeping the usual prepulse train of a typical contrast ratio of $2\text{-}5.10^{-4}$. By such arrangements the integrated power over 30 keV and $2\pi$ sterad is 1.2 mW for a Ta target.

Spectra recorded for Sn and for Ta are shown Fig. 2. The presence of two peaks in the 25 keV region of the Sn spectrum is not fully explained yet. One should be the Sn $K_\alpha$ lines and the other one probably fluorescence of antimony (Sb), used on previous experiments in the same vaccum chamber. It should be noted that one of them also occurs in the Ta spectrum, suggesting Sn fluorescence (or Sb) from a deposit on the shield (cf. Fig. 1). Further experiments should clarify this point. The absence of Ta $K_\alpha$ lines shows that the pumping energy is too low to reach such a regime for heavy elements. However, the Bremsstrahlung emission for Ta is much larger than for Sn while the line radiation intensity is comparable.

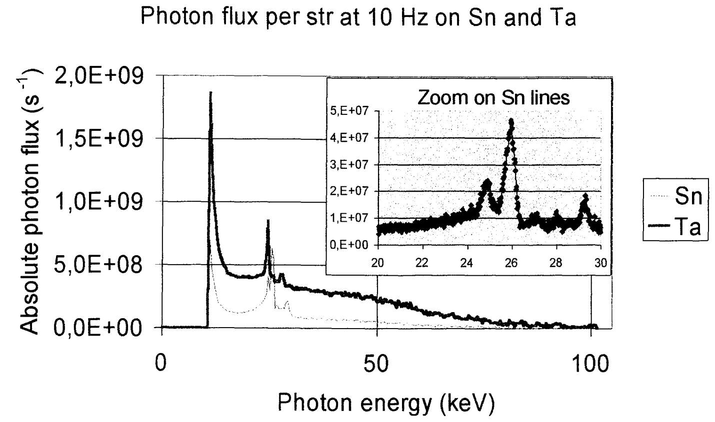

**Figure 2.** Comparison of the x-ray yield from a Ta target and from a Sn target.

## 3. TESTS AT 1 kHz

### 3.1 Set up of the prepulse generator

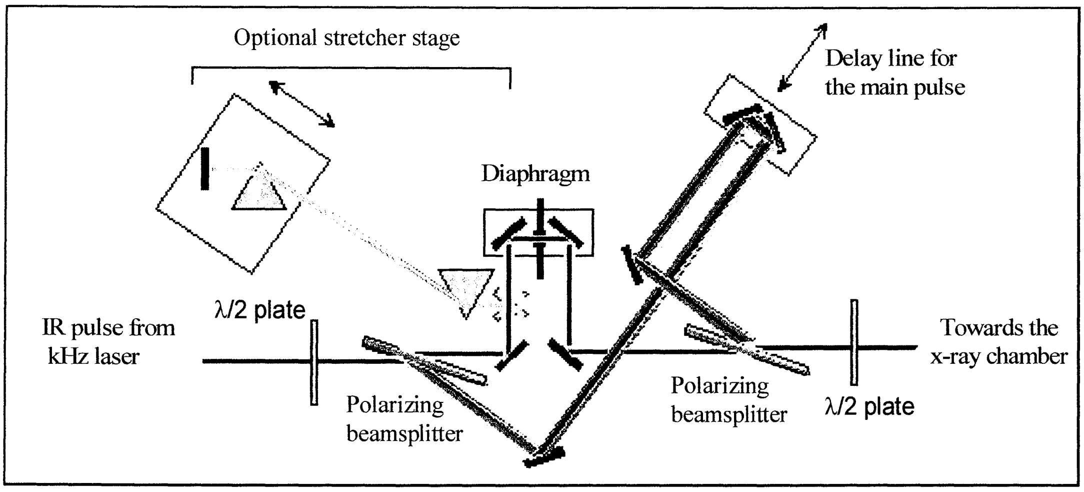

**Figure 3.** Schematic representation of the prepulse generator.

The aim of the design of our prepulse generator (cf. Fig. 3) is to be able to study independently the effects of a prepulse on the x-ray yield. The first half-wave plate enables control of the balance of energy between the two pulses, giving different polarizations on each pulse. An optional stretcher stage not used this time allows to stretch the prepulse up to 40 ps. The diaphragm enables us to superimpose easily the two quasi-collinear pulses in the focus region by having a bigger focal spot for prepulse than for main pulses. The best x-ray yield was obtained for P-polarized main pulses and S-polarized prepulses, after testing different polarization conditions by means of the second half-wave plate.

### 3.2 Spectral and imaging results

We have tested several delays between prepulses and main pulses in the 0.75 ns to 12 ns range. For each setting we have found an optimum in the prepulse ratio. A maximum for the x-ray yield was found at 2.4 ns separation with an optimum prepulse to main pulse ratio of 10%. A filter transmission image for this situation is shown in figure 4.

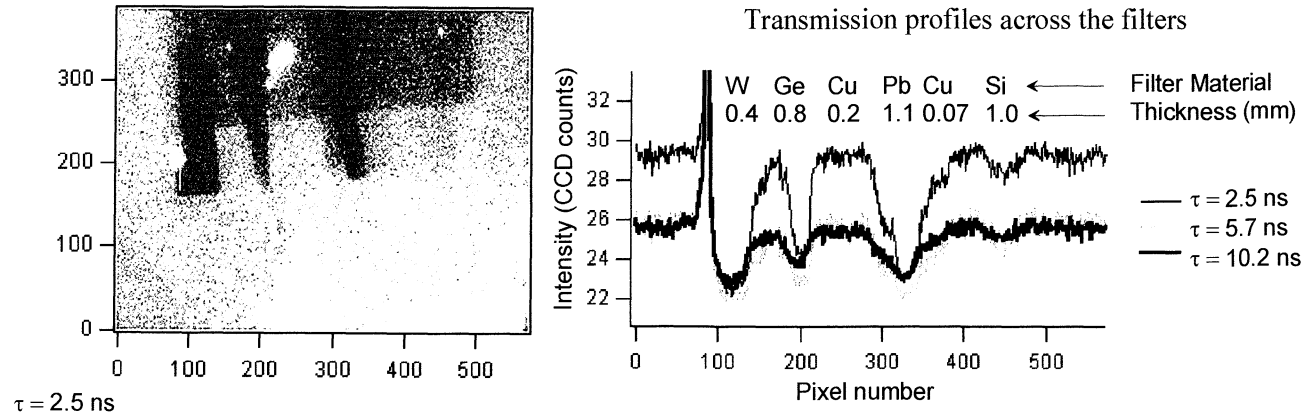

**Figure 4:** Image of different filters with the intensified CCD and Ta illumination. The horizontal intensity profiles are displayed for different prepulse delays on the left. They are averaged over 30 pixels vertically.

A comparison of the ordinary irradiation scheme with only the internal prepulse, of contrast $7.55\ 10^{-3}$ due to the leakage of the Pockels cell polarizer of the regenerative amplifier, and the irradiation with the prepulse set-up shows the good efficiency of the latter despite the losses of the generator. The fluorescence line (integrated over 1 keV) has tripled in intensity and the integrated power in the spectrum above 30 keV increases from 2.6 μW to 11μW.

## 4. CONCLUSIONS

We have demonstrated the possibility of producing x-rays in the 10-60 keV spectral range at 1 kHz with total IR pulse energies as low as 2.1 mJ. With the use of a controllable prepulse t is possible to increase the x-ray yield and to improve the conversion efficiency. It is now important to test the influence of the prepulse duration in the quest for achieving a sufficient amount of x-rays for medical imaging (a further increase of one order of magnitude is required). We will also investigate the role of x-ray fluorescence to clarify the lines observed in the tantalum spectrum.

## Acknowledgements

This work was supported by the Swedish Natural Science Research Council and by the European TMR program on Generation and Application of Short X-Ray Pulses ( contract ERBFMRXCT996-0080 ) .

## References

[1] M. Grätz, A. Pifferi, C.-G. Wahlström and S. Svanberg, "Time-Gated Imaging in Radiology: Theoretical and Experimental Studies", IEEE JSTQE **2** (1996), 1041-1048.

[2] G. Hölzer, E. Förster, M. Grätz, C. Tillman and S. Svanberg, "X-ray Crystal Spectroscopy of Sub-picosecond Laser Produced Plasmas beyond 50 keV", Journal of X-Ray Science & Technology **7** (1997), 50-70.

[3] J. Dunn, B.K. Young, A.D. Conder, and R.E. Stewart, "Detection of 1-100 keV X-Rays from High Intensity 500 fs Laser Produced Plasmas Using CCD", in Solid State Sensor Arrays and CCD Cameras (C. N. Anagnostopoulos, M.M. Blouke, and M.P Lesser (eds.)), Proceedings SPIE **2654** (1996),

[4] M. Grätz, L. Kierman, C.-G. Wahlström, S. Svanberg, K. Herrlin, " Time-Gated X-Ray Tomography", Appl. Phys. Lett. **73** (1998), 2899-2901.