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Optimisation of Narrow Band Extreme UV Conversion Efficiency of Picosecond Laser Plasma Sources

TMR Large-Scale Facilities Access Programme

F Bijkerk et al

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Optimisation of the Narrow Band Extreme UV Conversion Efficiency of Picosecond Laser Plasma Sources

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F Bijkerk, R Stuik, L A Shmaenok

FOM – Institute for Plasma Physics Rijnhuizen, PO Box 1207, 3430 BE Nieuwegein,

The Netherlands

A A Sorokin

Ioffe Physical Technical Institute, St Petersburg 194021, Russia

I C E Turcu, W Shaikh, N Spencer

(A Hall in report preparation)

CLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX.

SUMMARY

This report describes the experiment entitled 'Optimisation of the Narrow Band Extreme UV Conversion efficiency of Picosecond Laser Plasma Sources'; carried out at the Central Laser Facility (CLF) from the 5th May to the 2nd June 1997. The experiment, funded by the Framework IV Large-Scale Facilities Access Scheme, was proposed by Dr. F Bijkerk, FOM-Institute for Plasma Physics Rijnhuizen, Nieuwegein, The Netherlands, and carried out by visiting researchers from the Institute. They were supported by researchers from Ioffe Physical Technical Institute, Russia and the Central Laser Facility, Rutherford Appleton Laboratory.

Experimental Results

- Evaluated the importance of a high energy picosecond source for 13nm Extreme UV lithography applications

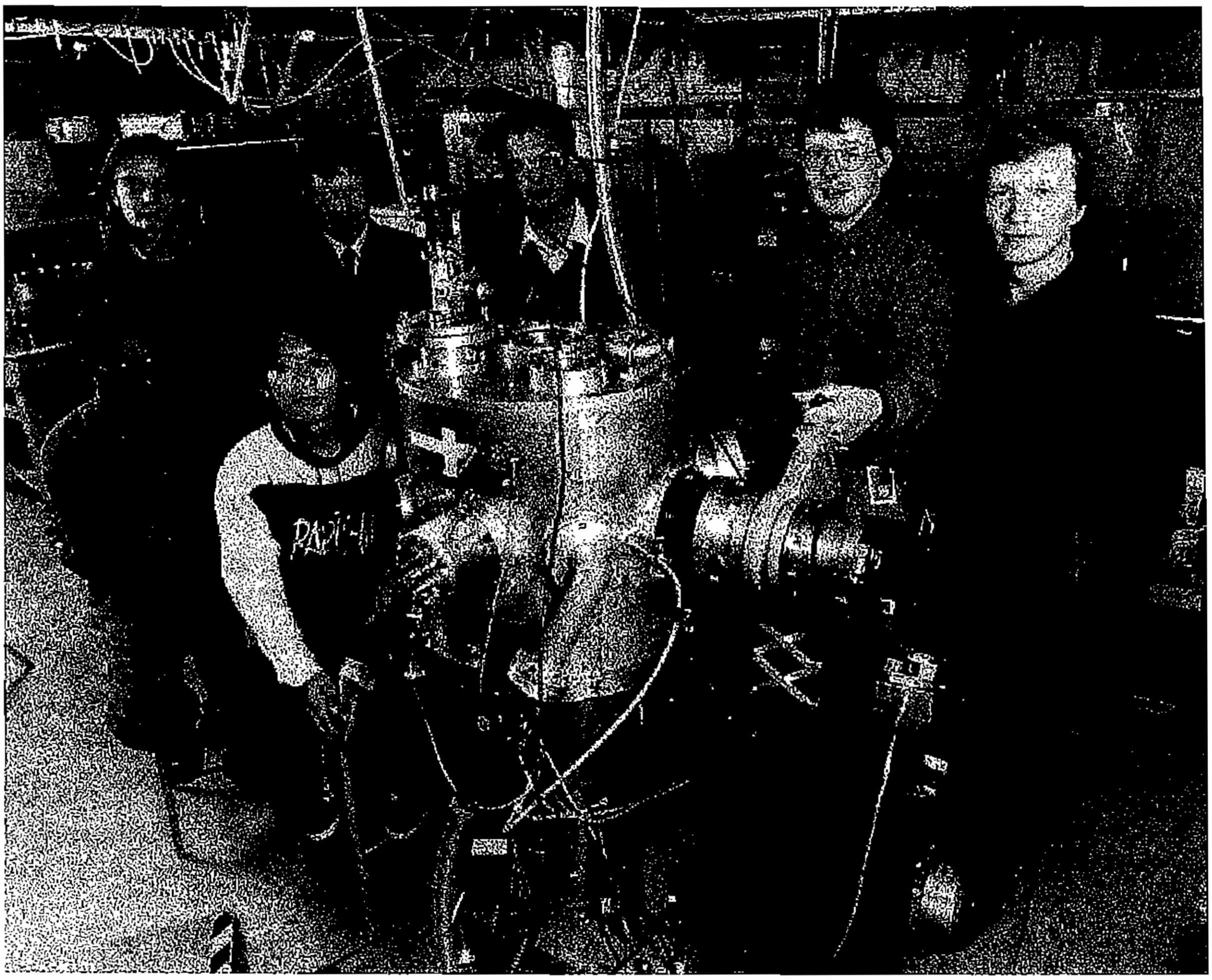
- A variable length picosecond oscillator and various focusing conditions were used to produce different irradiation conditions on various solid targets

- Using copper, the optimum power density using 248nm irradiation was 2×10^{14}W/cm^2, producing a conversion efficiency of 0.22%/% BW at 13.7nm

- Various pulse separations were used to investigate the influence of a prepulse

- In line with other investigations, gold targets produce the highest conversion efficiency

The CLF makes beam time at its facilities available to European Researchers with funding from DG-XII, CEC under the Large-Scale Facilities Access Scheme. For further information contact Dr. Chris Edwards at the CLF. Tel: (0)1235 445582, e-mail: c.b.edwards@rl.ac.uk



The EU researchers with collaborators and RAL support staff.

From left to right:

Top row: N Spencer, F Bijkerk, ICE Turcu, R Stuik, AA Sorokin
Bottom Row: W Shaikh, N Takeyasu

Optimisation of the Narrow Band Extreme UV Conversion Efficiency of Picosecond Laser Plasma Sources

INTRODUCTION

Extreme Ultra Violet lithography is considered a likely successor of the current deep-UV lithographic techniques in semiconductor industry. For this application a bright source of monochromatic light with a wavelength in the range between 10 and 20 nm is needed. An appropriate candidate is the laser plasma; a very bright point source, also in this wavelength range. Optimisation of yield of a laser plasma is needed in order to use this source as efficient as possible. Much research has been done on this subject at longer pulse lengths (5-25 ns), e.g. [1,2]. So far, shorter pulses, usually resulting in high temperature plasmas, have not often been studied. In this work, several experiments have been carried out with the FOM Institute for Plasma Physics Rijnhuizen (Nieuwegein, The Netherlands), to provide a characterisation of the RAL picosecond laser plasma source[3] in the EUV band. A calibrated diagnostic unit for detection of radiation at 13.7 nm wavelength was employed.

MATERIAL AND METHODS

The characterisation of the picosecond plasmas was done at 13.7 nm, in the wavelength band that will be used in future EUVL applications. The laser plasma was generated using the RAL picosecond laser system. A pulse train of 6 picosecond pulses of 20 mJ laser light of 248 nm generated a laser plasma with temperatures of a few hundred eV. These temperatures obtained with the high electromagnetic radiation levels of the laser are sufficient to generate x-rays with energies of several tens of eVs up to several keVs. A small energy band ($E/\Delta E \sim 25$) centred at 90 eV (13.7 nm) was selected using a multilayer mirror. The mirror consisted of 40 bi-layers of Mo/Si on a spherical substrate with 32 cm radius of curvature. The plasma was imaged on a PIN diode by this multilayer mirror. The diode was covered with a filter consisting of 50 nm Si_3N_4 and 100 nm Nb. This filter suppresses visible/UV by a factor of 10^4. All elements (mirror, filter and detector) were absolutely calibrated for the wavelength under observation at

the PTB beam line at Bessy (Berlin) and the Institute for Physics of Microstructures (Nizhny Novgorod).

For a few experiments, also a streak camera was used to investigate the time structure of the plasma at the wavelength of 13.7 nm. The scheme used was analogous to the absolute calibration measurements, with the cathode of the streak camera replacing the PIN diode. This way, a time resolution of a few tens of picoseconds could be obtained.

The power density on target was varied using different methods of illumination:

- *Beam attenuation*: by inserting different quartz plates, the laser beam was attenuated over more than an order of magnitude while keeping the spot size constant. A second method to attenuate consisted of positioning a diaphragm in the beam, which changed somewhat the focal spot size.
- *Pulse duration*: Changing the oscillator cavity, a range in pulse duration's between 3 and 21 ps per pulse could be obtained. Since the energy per pulse did not change significantly over this range, almost an order of magnitude in pulse duration could be investigated.
- *Different lenses and lens defocusing*: Changing the spot size was achieved in two ways: By varying the focal distance of the lens and by defocusing the lens. It is noted that the error in the power density is somewhat larger due to imperfectness of the lens and a non-linear shape of the beam waste.

Moreover, two other parameters of importance to the CE have been studied:

- *Pulse to pulse separation*: Previous measurements have shown [4], that a pre-pulse can influence the conversion efficiency of the main pulse. In a pulse train this situation may occur for every pulse, except the first. The influence of pulse-to-pulse separation has been investigated for discrete values of 1.8, 3.6 and 7.2 ns.
- *Target material*: Different target materials have different electron configuration and therefore different excitation and emission energies, giving different levels of radiation at the investigated wavelength.

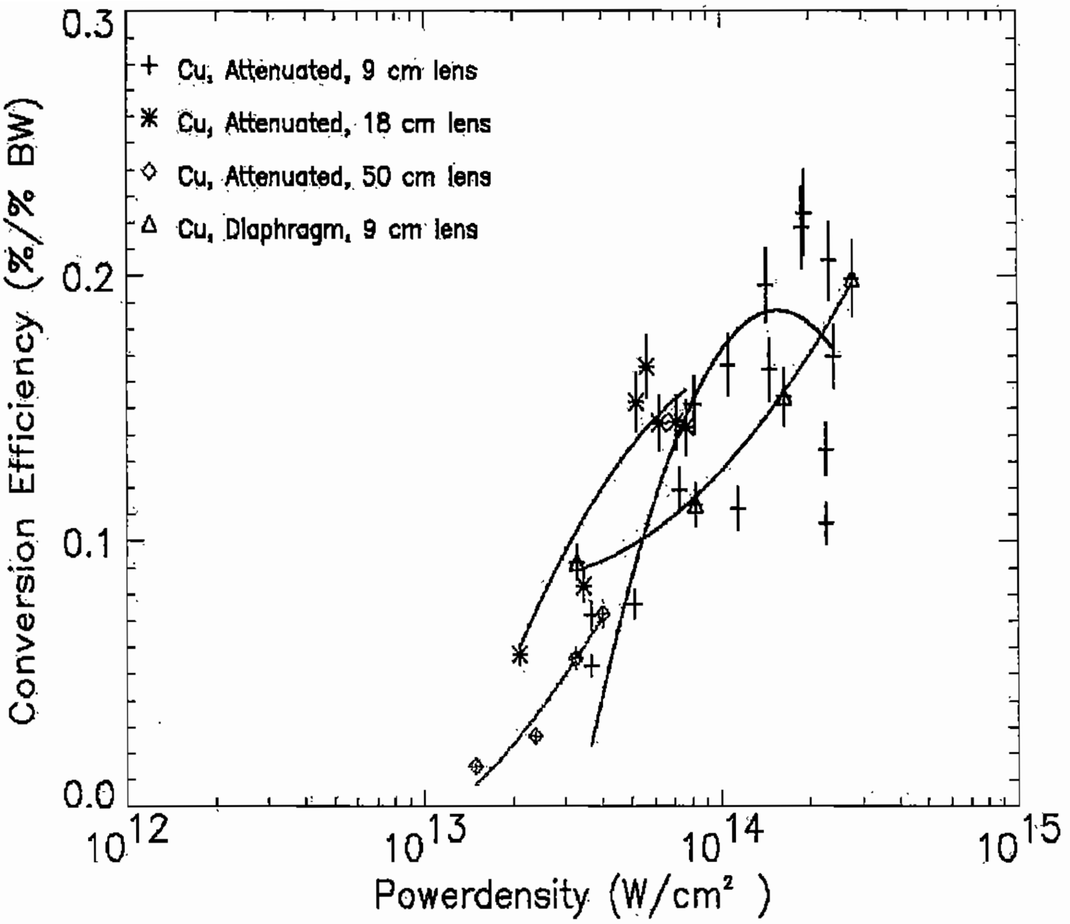


Figure 1. Dependence of the CE on power density for various lenses and beam attenuation schemes

For all these cases, the absolute conversion efficiency (CE) was determined. Also the time structure was investigated using the streak camera. The target material was Cu tape, unless indicated otherwise.

RESULTS

Figure 1 shows the dependence of the conversion efficiency on the power density as varied by attenuation of the beam for each of the three focal lengths used. All curves show a similar behaviour: The conversion efficiency increases with the power density, but above 10^{14} W/cm^2 the curves seem to top off. This could be an indication of a local optimum power density, but verification required an energy in the laser pulse beyond that of the current experimental

conditions. The range of power densities of the 9 and 18 cm lens overlap, indicating that both lenses gave an approximately equal focal spot size. The range for the 50 cm lens is somewhat smaller due to high noise levels at the lower end of the power density range. As all lenses follow the general curve, the conversion efficiency seems to be only dependent on the power density. Larger spots with higher energy result in similar CE values as smaller spots with low energy.

Using shorter pulses a higher power density can be investigated, up to almost 10^{15} W/cm^2 (Figure 2). The plot shows an initial increase of the conversion efficiency with increasing power density, followed by a drop of the CE for even higher power densities. Combining figure 1 and 2, a local optimum is found at $2\mathrm{x}10^{14}$ W/cm^2.

The conversion efficiency varies only slightly with the pulse-to-pulse separation, as shown in figure 3. Due to the small number of points combined with the relatively large errors on the data, the dependence of the conversion efficiency is not yet clear. There seems to be a slight increase in CE for longer pulse separations.

The material dependence is shown in figure 4. Four materials for three different lenses could be measured and a clear dependence of the conversion efficiency on the material and power density can be seen. For figure 4 only comparable conditions are used, explaining the lower maximum value for the copper target. From the materials investigated, gold shows the highest conversion efficiency. These results should be compared with results found in ref. [2], where longer pulses with lower power densities were used. They observed increased emission where a K, L or M shell transition was close to the wavelength under investigation.

DISCUSSION

From the different schemes of scanning the power density on the target (attenuation, duration, lens focal distance and lens defocusing) coherent data could be obtained about the behaviour of the conversion efficiency on the power density. Combining figure 1 and 2 shows an optimum power density of $2\mathrm{x}10^{14}$ W/cm^2 for copper targets. The conversion efficiency obtained at this value is 0.22%/% BW.

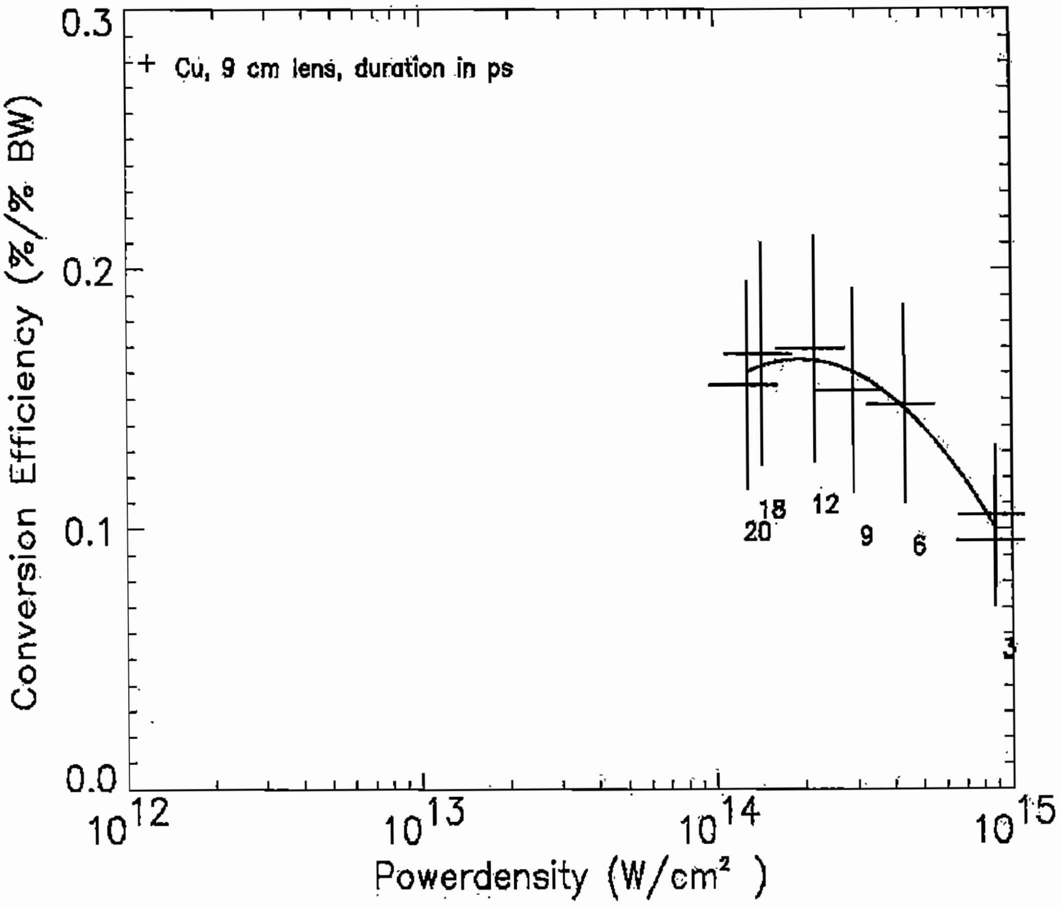


Figure 2. Dependence of CE on power density for different pulse duration's (annotated)

A certain trend can be seen in the conversion efficiency versus pulse-to-pulse separation plot (Figure 3). For somewhat longer separation, the conversion efficiency seems to increase. Even at separations of more than 7 ns, some influence of the pre-pulse is visible (At infinite separation the CE should drop to the level of a single pulse). For different materials the conversion efficiency follows the general trend already found in previous research at lower power density [2]. Gold has the highest conversion efficiency (0.22%/% BW at 2.5×10^{14} W/cm^2) under similar conditions, but the lack of variation of materials in this investigation leaves room for further material optimisation at these power densities (like Ge and Re for 10^{12} W/cm^2, see figure 4).

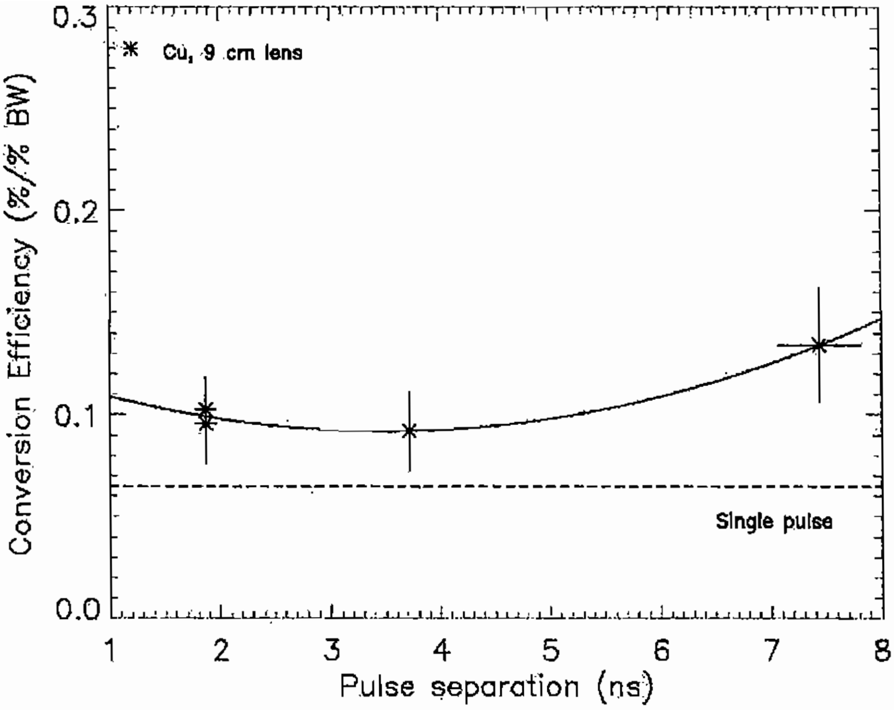


Figure 3. Dependence of conversion efficiency on the pulse-to-pulse separation (Horizontal line is a single pulse)

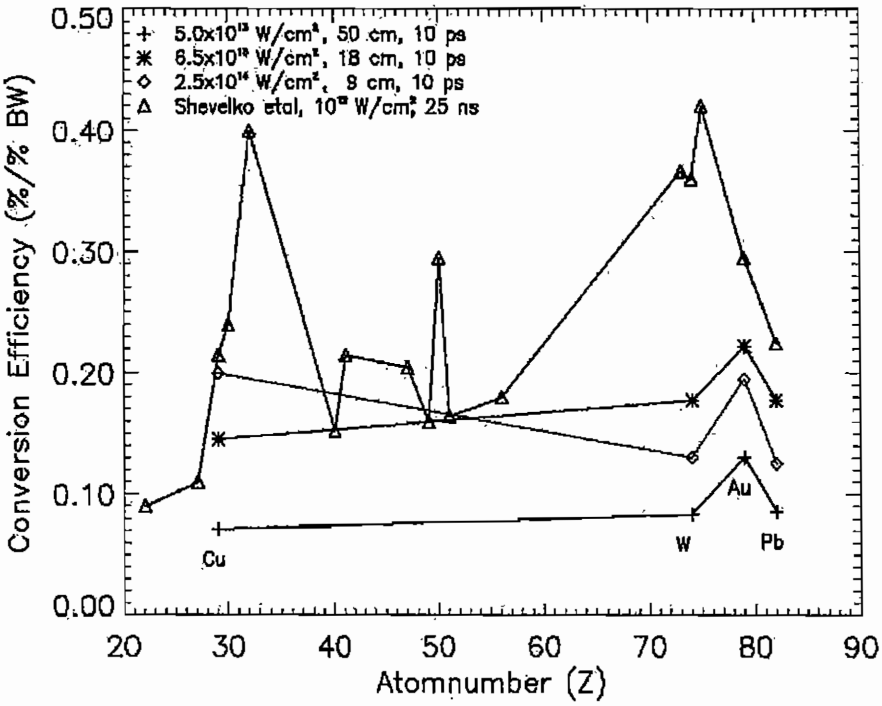


Figure 4. Dependence of the conversion efficiency on material and power density.

Future research could be focused on a better spread of elements in the periodic table, at a larger range of laser energies, pulse repetitions and focal spot sizes. From figure 1 we conclude that a higher pulse energy on target could confirm the optimum power density for these picosecond pulses.

ACKNOWLEDGEMENTS

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