Combined Nd:YAG - CO_2 Laser Produced Plasma EUV Source Examination with the Code Z*

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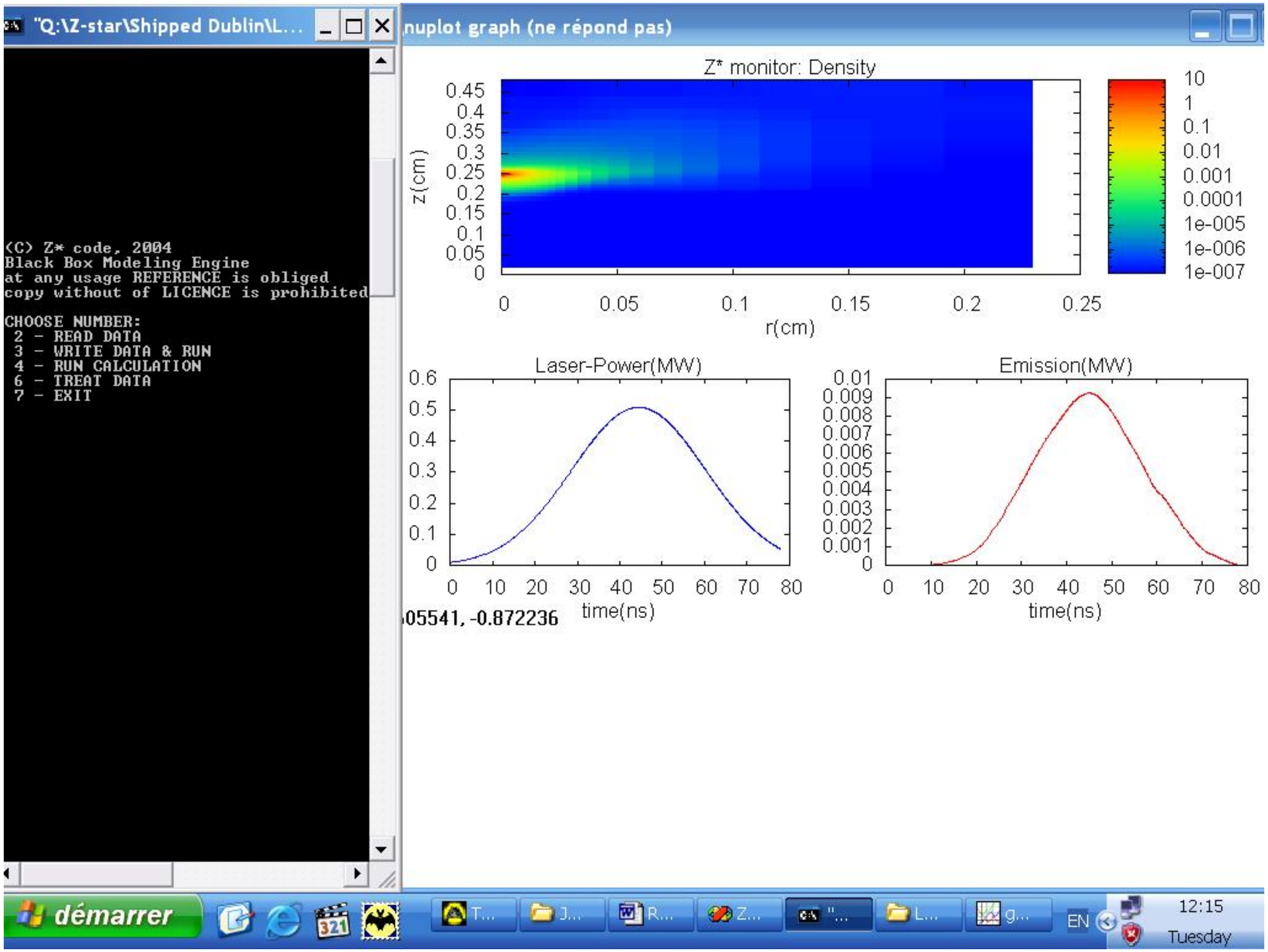
Abstract

The RMHD code Z* has been adopted to specifically model certain key issues in LPP EUV plasma sources with double pulse combined laser. The EUV source is based on droplet targets irradiated with a short pre-pulse Nd:YAG laser and a high power, high repetition rate CO_2 laser system. The Nd:YAG laser just prepares the plasma from the droplet target for the CO_2 laser.

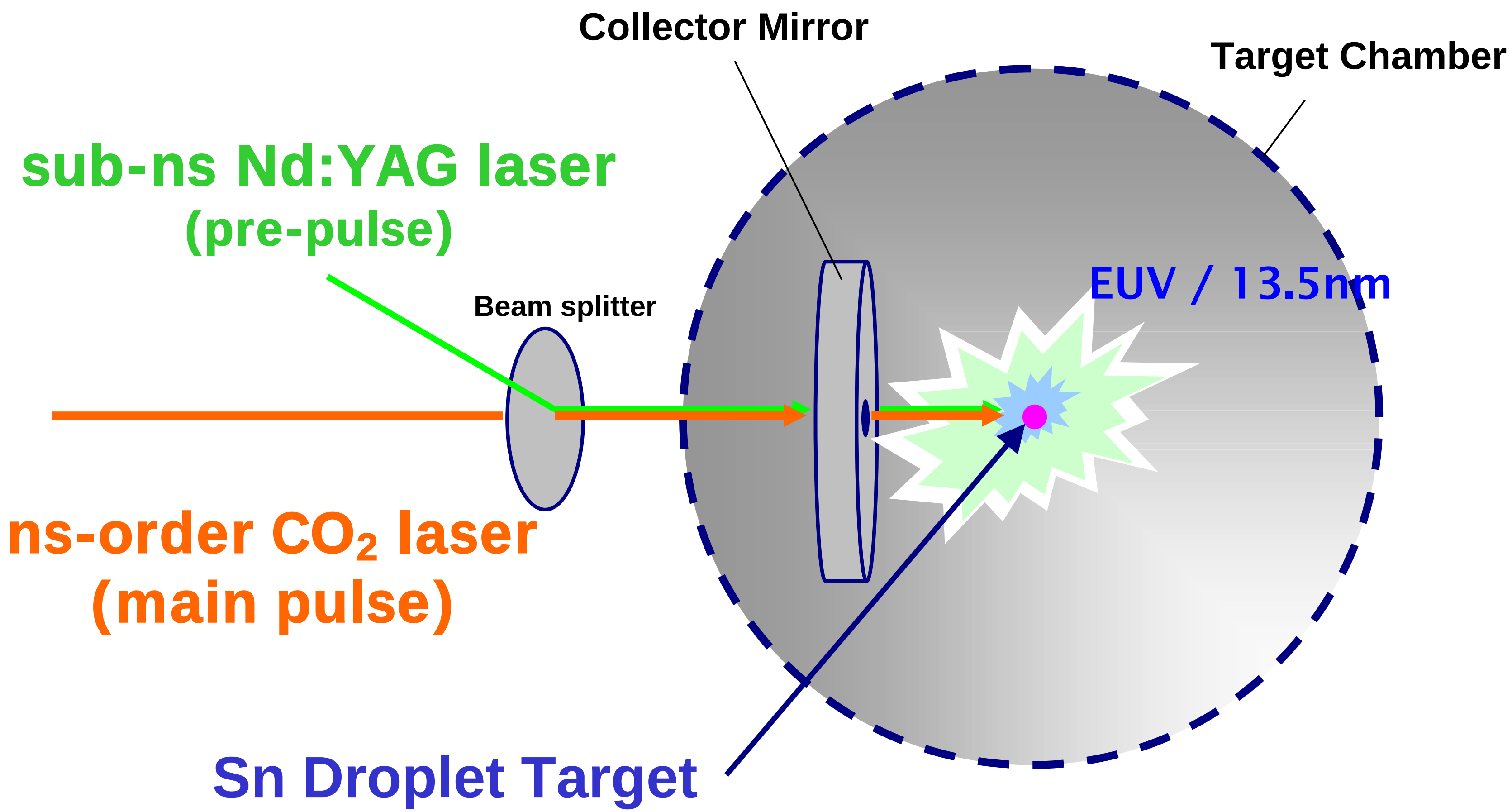
There are two main goals of the approach/simulations: the first one is to increase the EUV emission efficiency by lower reabsorption of EUV radiation due to the 100 times lower density in case of a CO_2 laser with respect to a Nd:YAG laser as the main pulse; the second one is to reduce the debris using a small-size, i.e. low-mass, target. Optimizations of many parameters like the energy of the pre-pulse and main pulse, pulse durations and delay times between pulses are carried out

Z* Blackbox Modeling Engine from EPPRA sas

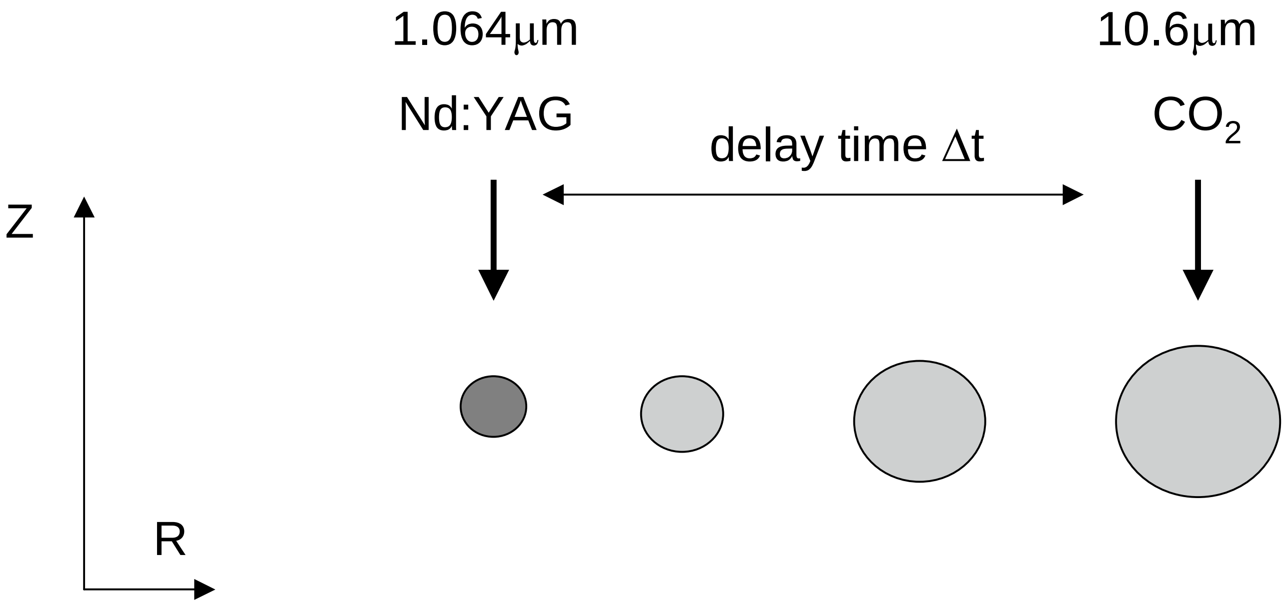
Z* Black-box Modelling Engine (Z*BME) is a system tool based on the adaptation of the Radiation-Magneto-Hydro-Dynamic code Z* to facilitate numerical modelling by non numerical specialists. This tool is integrated into a specific computation environment to provide a turn-key simulation instrument without specialist knowledge in numerical computation.



Nd:YAG-CO_2 laser based EUV system



System layout



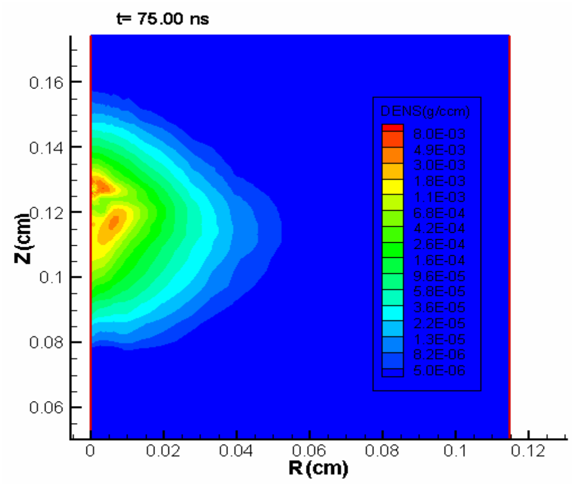
100 times lower density in case of a CO_2 laser with respect to a Nd:YAG laser as the main pulse gives a chance

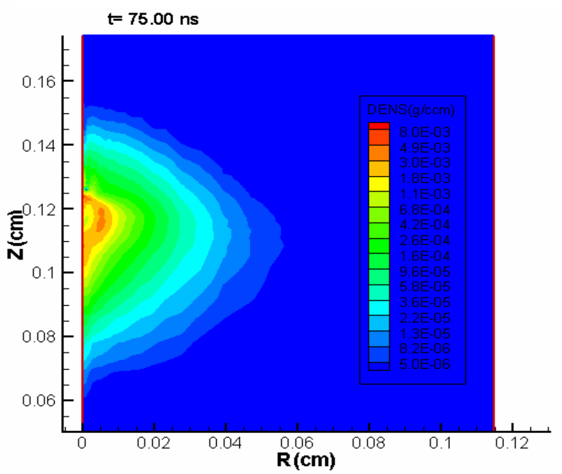
- to increase the EUV emission efficiency by lower reabsorption of EUV radiation
- to reduce debris using a small-size, i.e. low-mass, target

Sn mass density distribution after pre-pulse

left figure 2.5mJ
laser pre-pulse energy

right figure 5mJ
laser pre-pulse energy



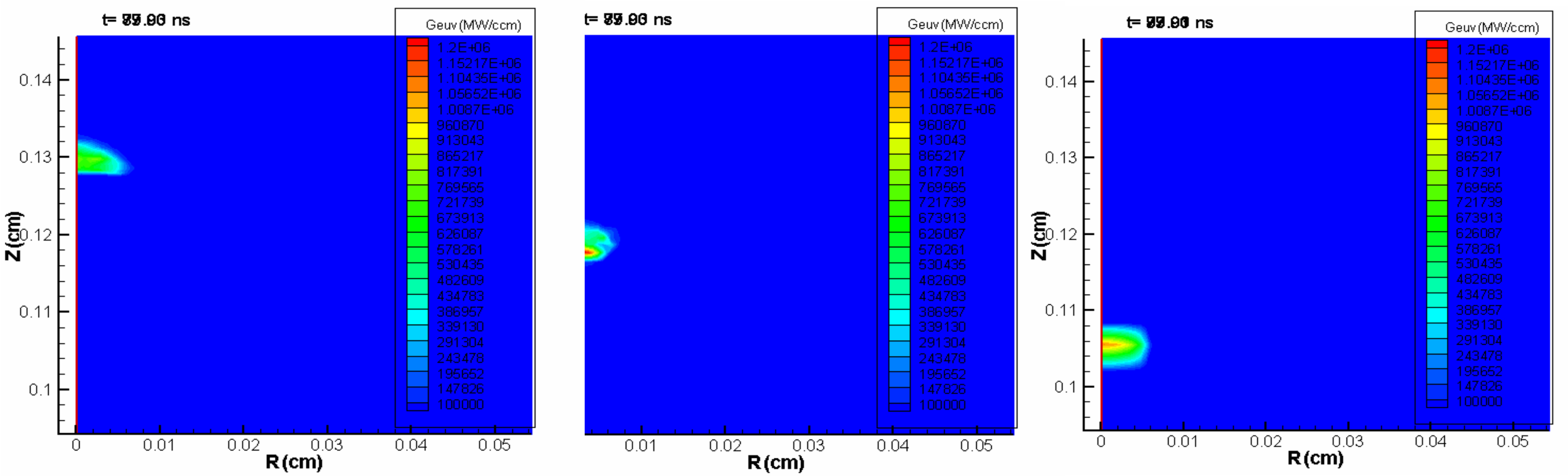


Sn droplet of initially 20 μm diameter.
Mass density distribution 63ns after the peak of the Nd:YAG laser pre-pulse

Laser pulse length10ns fwhm. Initial droplet center position at R=0cm, Z=0.125cm.

EUV emission during main CO_2 laser pulse

2.5mJ laser pre-pulse energy



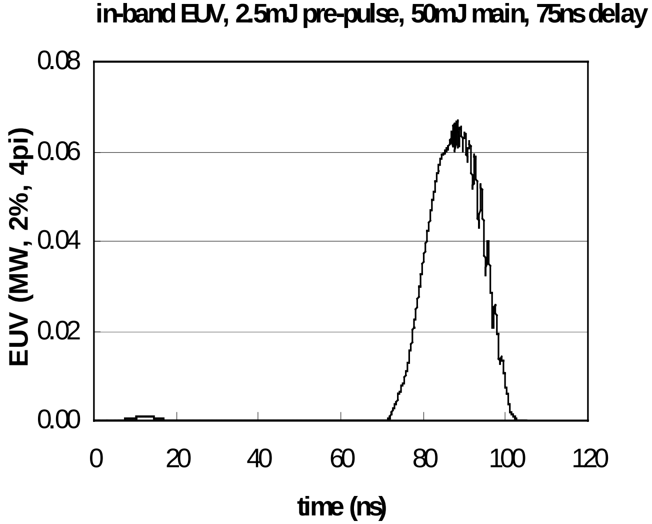
In-band EUV emission at 68, 75 and 82ns after the maximum (left to right).
Main laser pulse: CO_2, 50mJ, 15ns, 100 μm fwhm spot size.

The delay time between laser pulses is 75ns, i.e., the center figure shows the EUV emission at the max. of the main laser pulse.

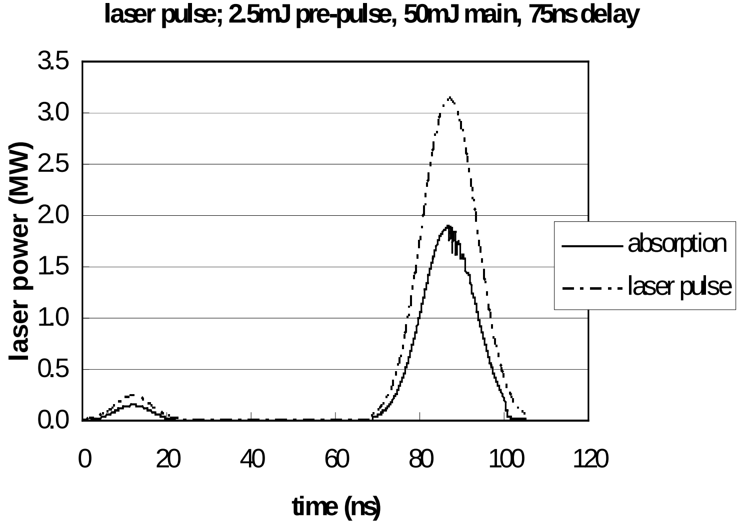
Laser pulse shapes, laser absorption & EUV emission

20 μm Sn-droplet,
2.5mJ Nd:YAG pre-pulse, 10ns fwhm
50mJ CO_2 main-pulse, 15ns fwhm
75ns delay time between both laser pulses

EUV emission



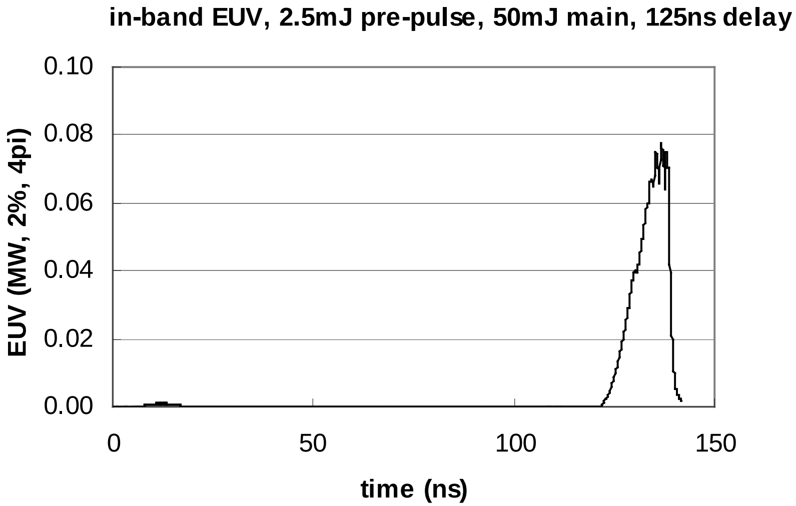
Laser pulse shapes



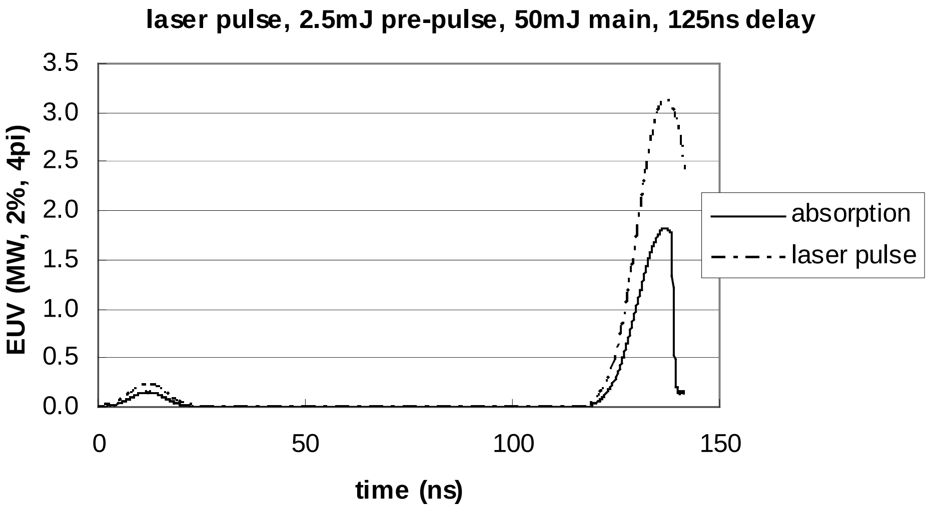
Laser pulse shapes, laser absorption & EUV emission

20 μm Sn-droplet,
2.5mJ Nd:YAG pre-pulse, 10ns fwhm
50mJ CO_2 main-pulse, 15ns fwhm
125ns delay time between both laser pulses

EUV emission

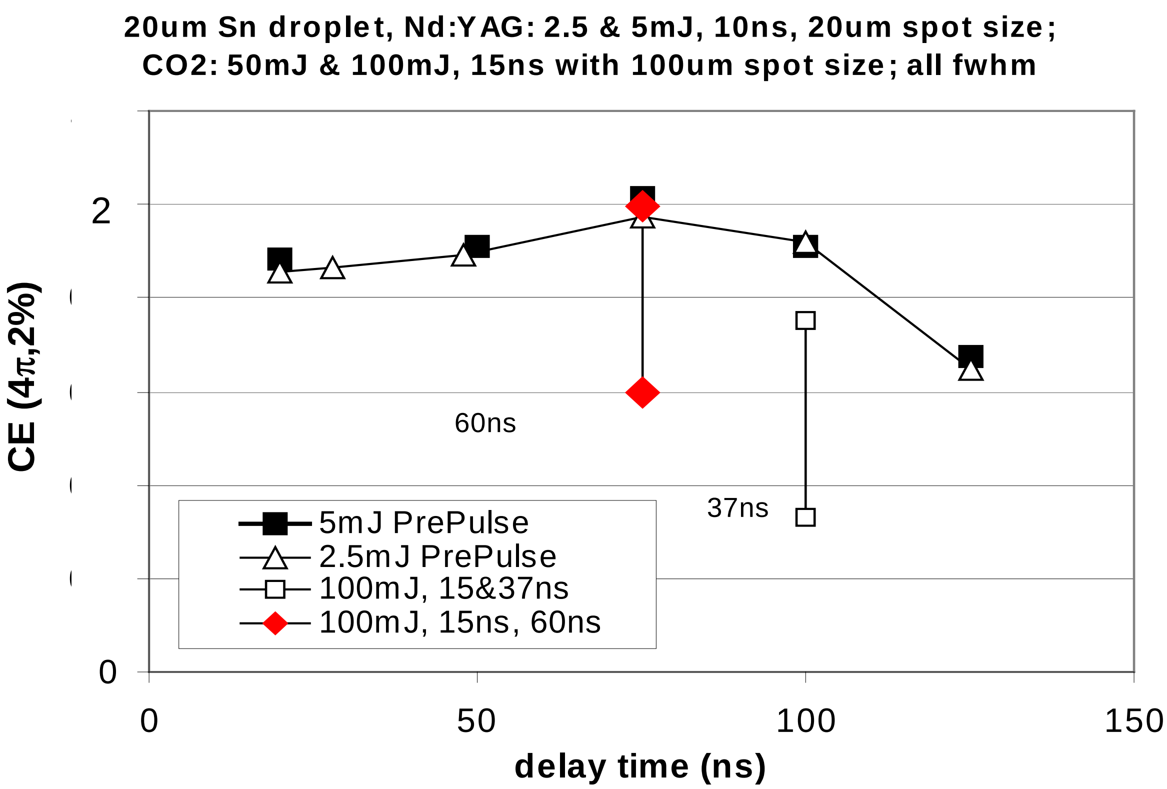


Laser pulse shapes

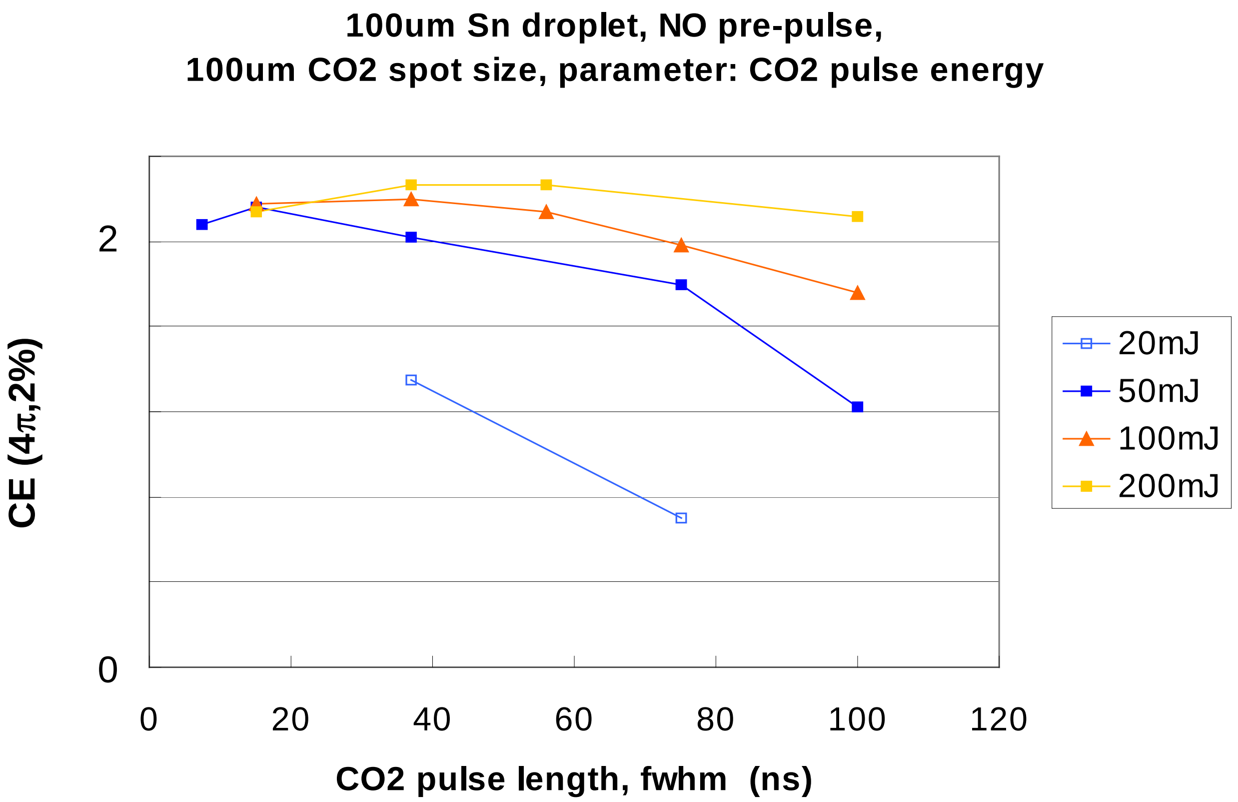


CE vs. delay time between pre-pulse & main pulse laser

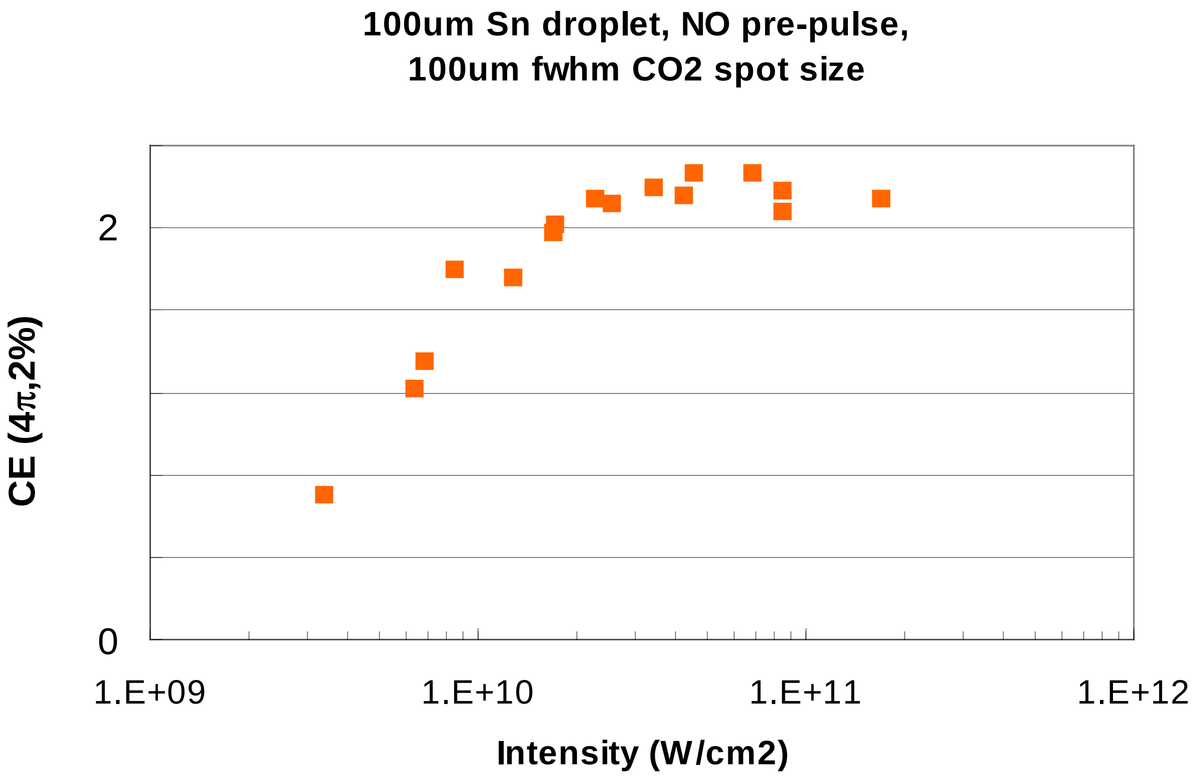
Target: 20μm diameter Sn droplet
Pre-pulse laser: Nd:YAG, 10ns fwhm, 20μm spot size, pulse energy 2.5 & 5mJ
Main pulse: CO_2-laser, 15, 37 and 60ns fwhm, 100μm spot size



Single Laser Pulse



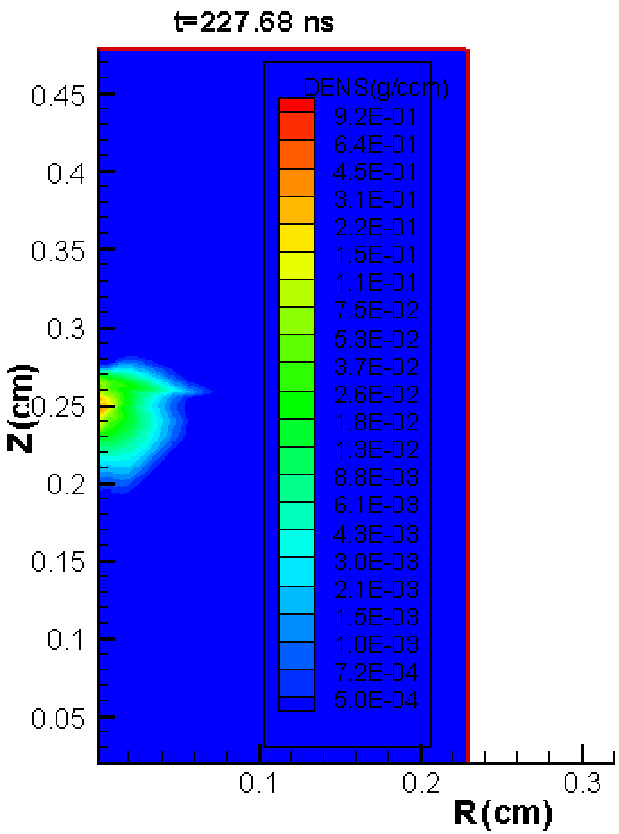
Single Laser Pulse



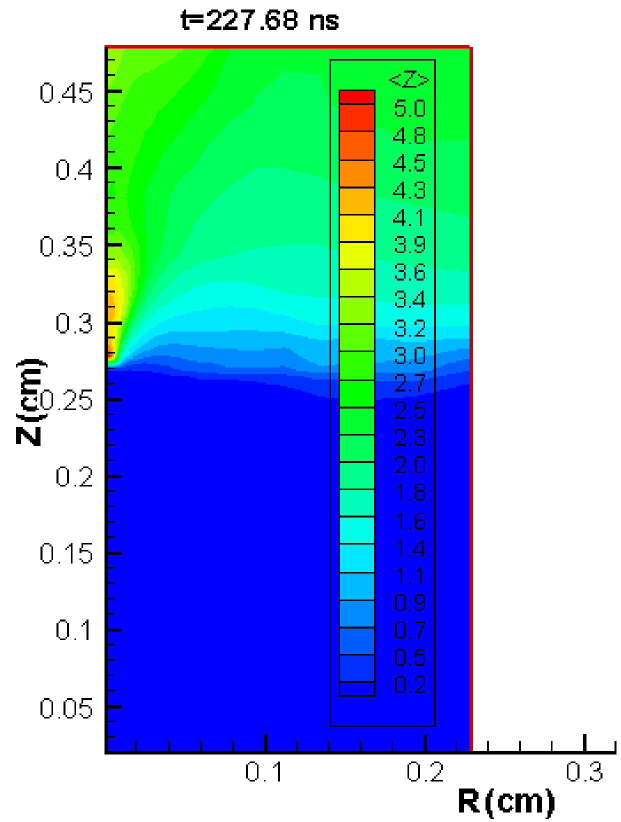
Debris 100μm Sn droplet

50mJ, 100ns CO_2 laser, 100μm fwhm spot size

Mass density



Mean charge state <Z>



Most of initial Sn mass does not form plasma, far from mass limitation.

Summary

Application of a combined Nd:YAG - CO_2 system for LPP EUV source permits to reduce significantly the necessary mass of tin droplets and consequently to reduce debris and tin consumption.

With proper delay time between Nd:YAG pre-pulse and CO_2 main pulse, laser energy and pulse duration the conversion efficiency for the limited mass tin droplet may be kept at the same level as for high mass target.

Simulations of the LPP with Z*****BME allows a fast and easy optimization of multi-parameter combined laser systems.