Experimental study of the interaction of sub-nanosecond and nanosecond duration laser pulses with solid targets at different laser energies.

Ragava Lokasani[1,2], Elaine Long[1], Oisin Maguire[1], Domagoj Kos[1] Patrick Hayden[1],Fergal O'Reilly[1], Paul Sheridan[1], Emma Sokell[1], Padraig Dunne[1] ,Jiri Limpouch[2], Akira Endo[3] &Gerry O'Sullivan[1]

1)UCD School of Physics, University College Dublin, Belfield, Dublin 4, Ireland

2) Czech Technical University,Prague,Czech republic

3) HiLASE Project, Prague, Czech republic

1.Abstract

XUV emission is produced when high intensity pulsed laser irradiate solid targets. The emitted XUV radiation can be suitable for different applications that include nanolithography and biological imaging. XUV emission from slab targets of the elements from yttrium (Z=39) to palladium (Z=46) irradiated by Nd:YAG laser pulses with durations of 170ps and 7ns respectively were investigated systematically. The XUV emission was recorded with flat field grazing incidence spectrometer equipped with a variable groove spaced grating. The atomic structure code developed by Cowan[1] was used to generate simulated spectra for comparison with experimental results and enabled the identification of a number of new features arising from 3d-4p, 3d-4f and 3p-3d transitions. With increasing Z, transitions along particular isoelectronic sequences shift systematically to shorter wavelength so that while the spectra appear quite similar there is a gradual shift towards higher energy in going from yttrium to palladium. The major effect of laser pulse duration is to alter the ratio of 3d-4p, 3d-4p, and 3p-3d emission which is observed to be greater in the case of sub-nanosecond irradiation.

2.Experimental setup

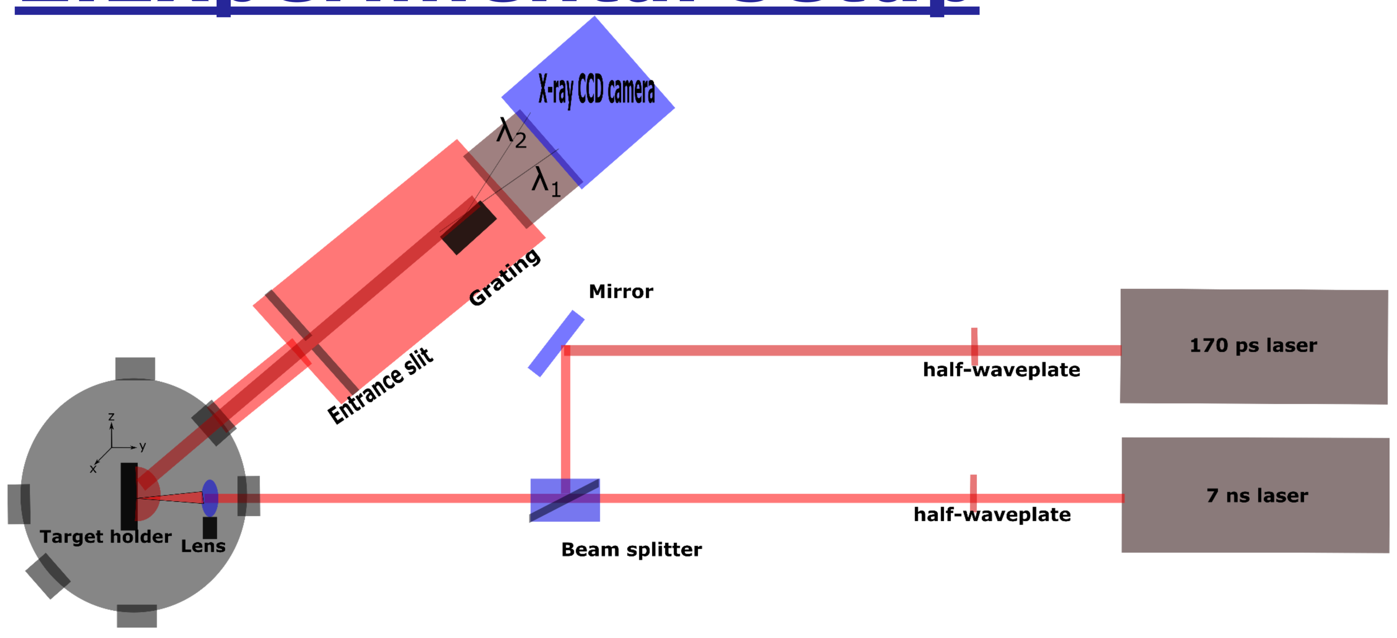


Figure 1: Experimental setup & Schematic of the experiment. Pulses from an Ekspla SL312P 150 picosecond and a Surelite 7ns Nd:YAG laser were focused on solid targets of Y, Zr,Nb,Mo, Ru, Rh and Pd.

Laser Parameters Used

Parameter	ns laser	ps laser
Model	Contuniuum surelite III	EKSPLA
Maxium pulse energy (mJ)	600mJ	230mJ
Pulse length ,FWHM	7ns	170ps
Maximum power density (W/cm^2)	2.2X10^12	3.4X10^13

3.Results

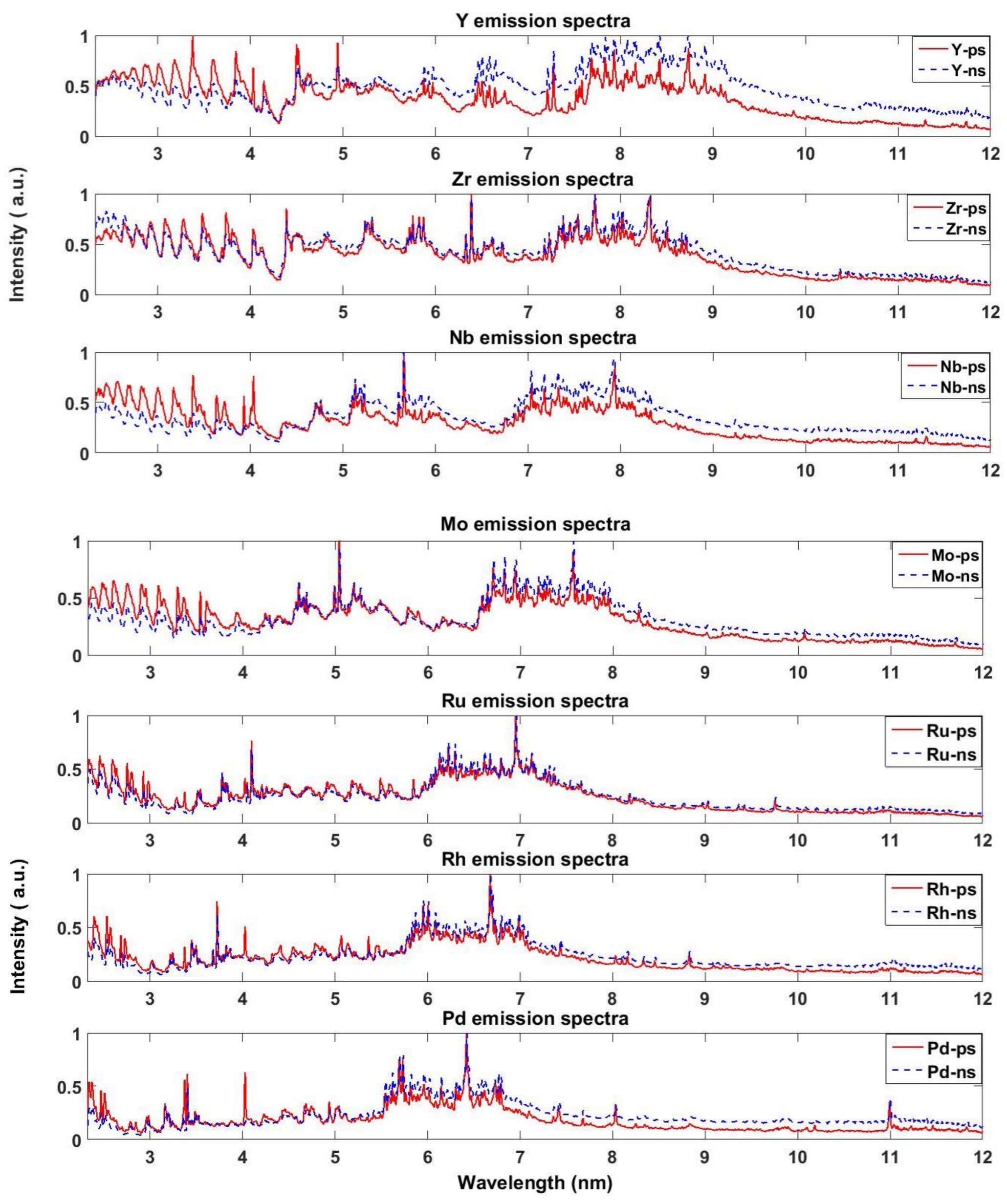
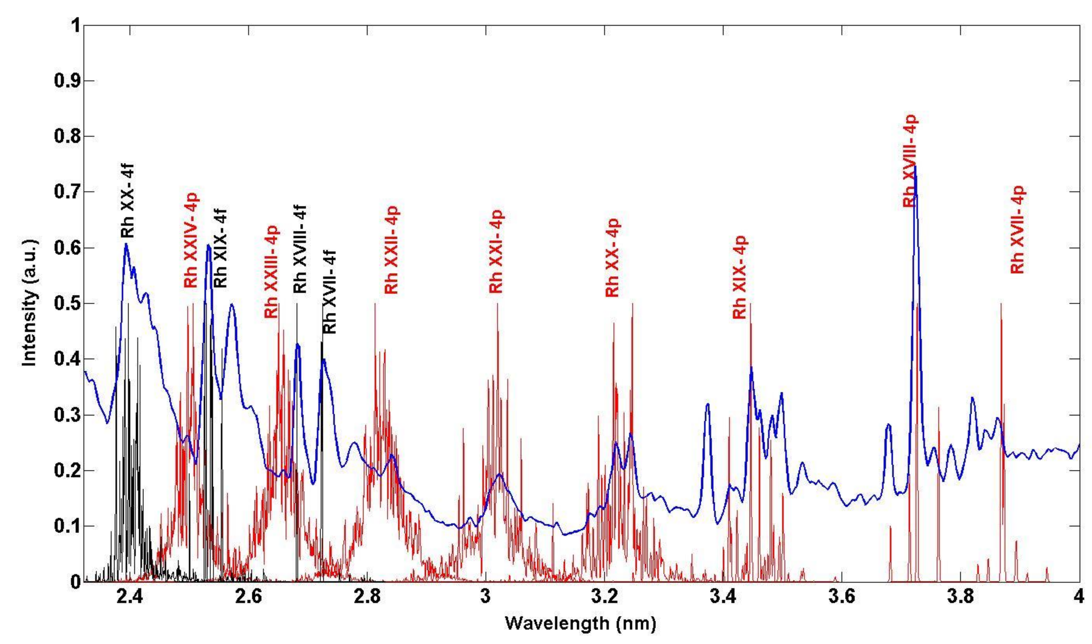


Figure2: nano(blue) and pico(red) second laser spectra from laser produced plasmas of Y, Zr, Nb,Mo, Ru, Rh and Pd. The high intensity peak is arising from $3p^n$-$3p^{n-1}$ $3d^{n+1}$ transitions.



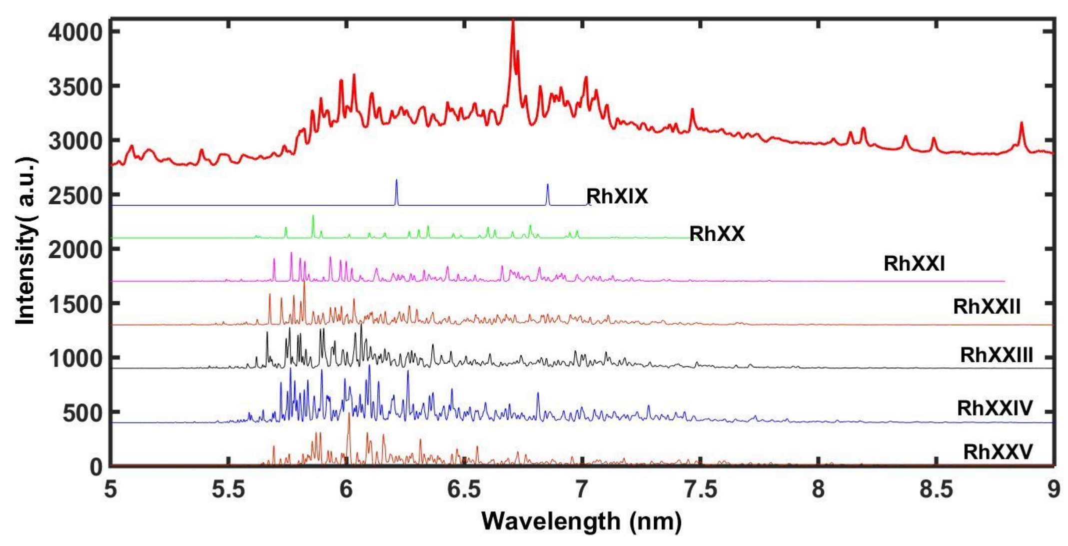


Figure 2 (a),(b) : Comparison of the experimental spectrum of Rh plasmas showing with Ion 3d-4p,3d-4f (top) 3p-3d (bottom) transitions along with Cowan synthetic spectra of each ion stage.

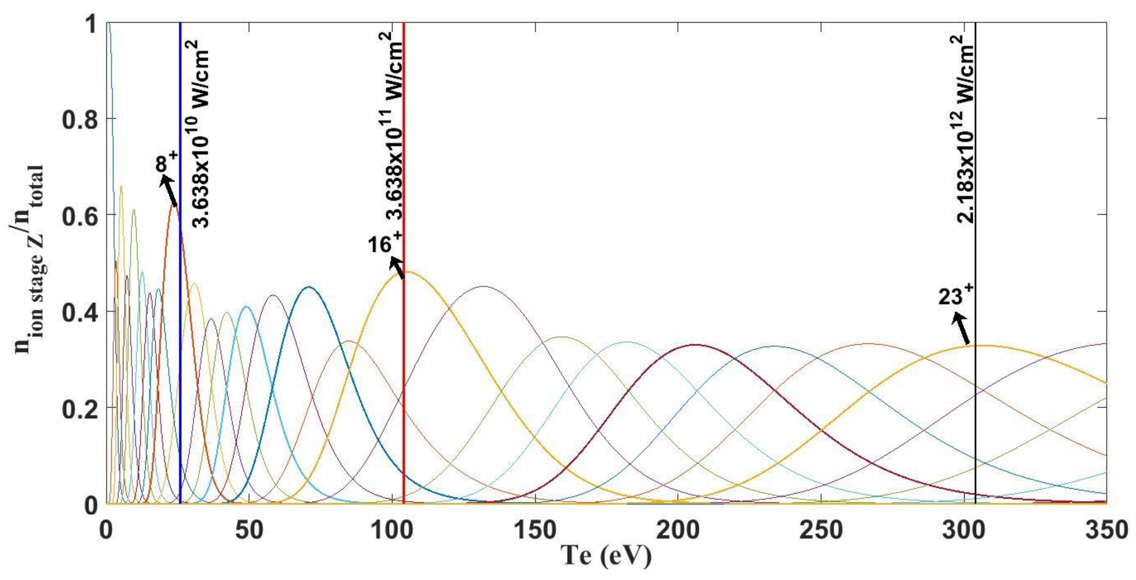


Figure 3: Ion fraction of Rh as function of electron temperature showing the dominate ionization stages at the different power densities.

MLM	Wavelength (nm)	Reflectivity (%)
Cr/V	2.42	9
Cr/Ti	2.73	17
TiO_2/ZnO	2.74	29
Cr/Sc	3.14	21
Cr/Sc B_4C	3.15	32.1
Cr/Sc	3.35	10

Table 1: Peak wavelength and percentage of reflectivity of different multilayer mirrors in the water window region

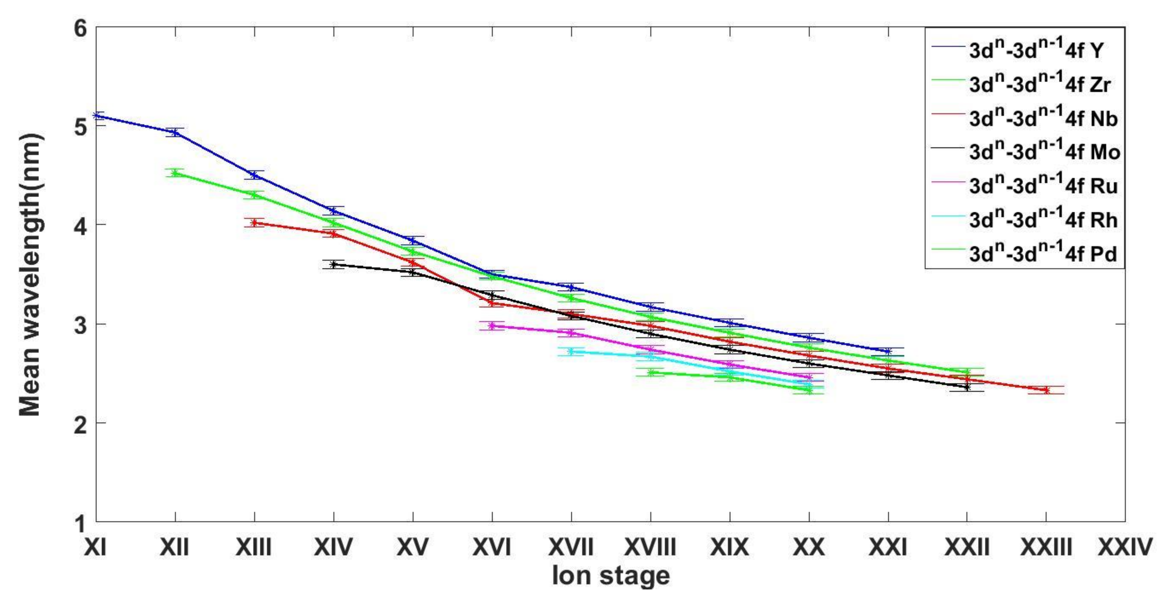


Figure 4: Positions and widths of the 3d-4f unresolved transition arrays (UTA) in the spectra of number of ions of the elements from Y(Z=39) to Pd (Z=46)

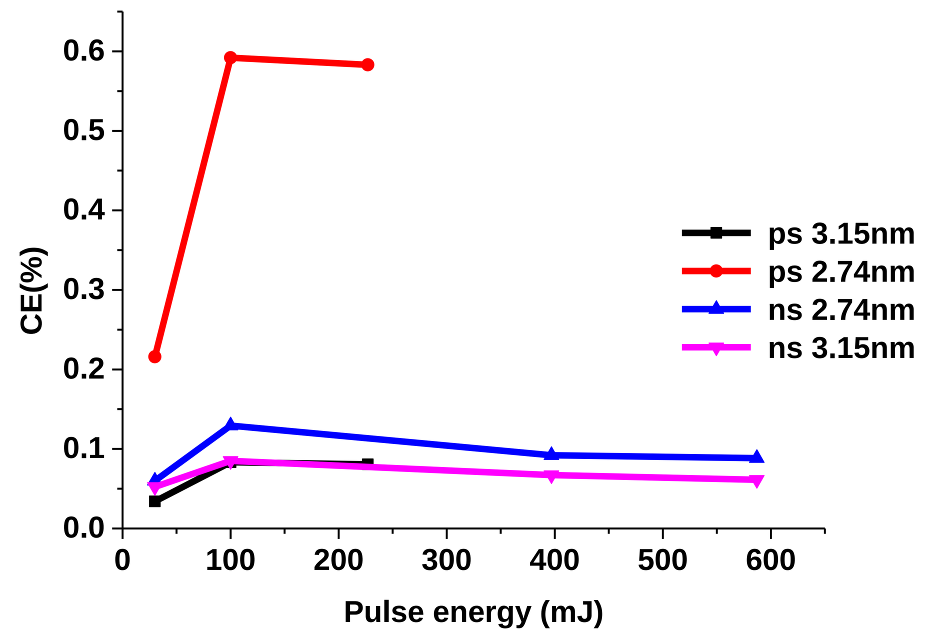


Figure 5: Conversion efficiency of Mo (Z=42) at different wavelengths

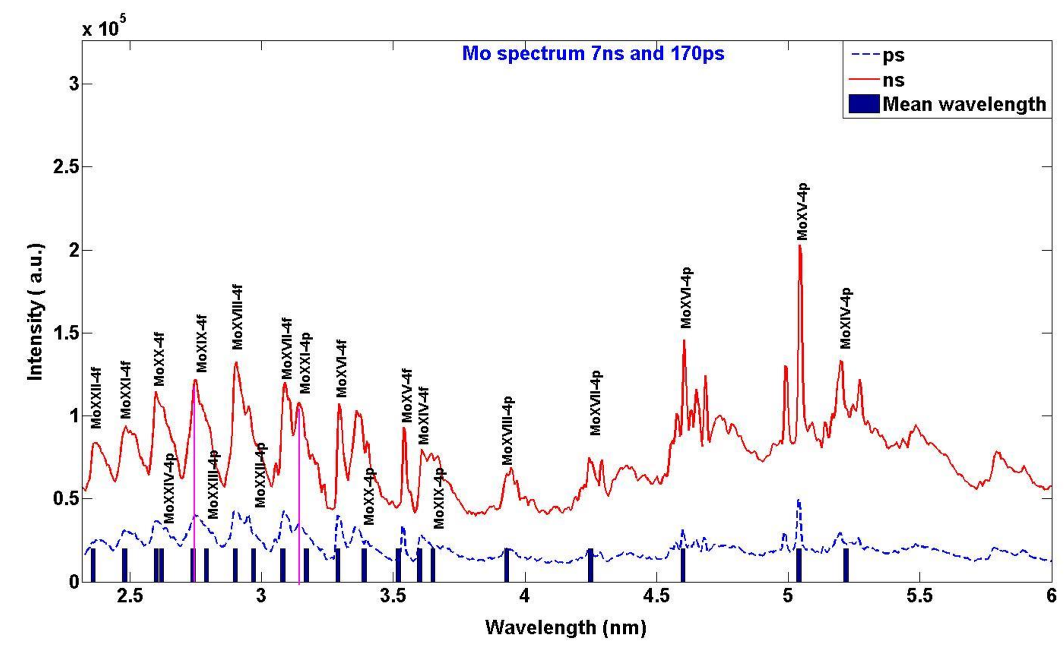


Figure 6: Mo experimental spectrum with 3d-4p,4f mean wavelengths and multilayer mirror matching in the spectrum

4.Conclusion

- Theoretical spectra were calculated using Hartree-Fock configuration-interaction numerical method and compared with experimental spectra and identified ion stages of 3d-4p.3d-4f transition arrays for Y, Zr, Nb, Mo, Ru, Rh and Pd
- 3d-4f transitions in the 2nd transition row are produced at lower plasma temperatures and are promising sources for water window imaging
- A comparison of spectral emission around the "water window" (2.4 nm to 4.3 nm) which is useful for bioimaging suggests that Mo is the strongest emitter.
- A comparison of emission in the 6.x nm spectral region, which has potential applications in future nano-patterning for lithography, suggests that the best emitters are Ru and Rh.

Ref: [1] R. D. Cowan, The Theory of Atomic Structure and Spectra (University of California Press, Berkeley, CA, 1981).
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[3] J. Bauche, C. Bauche-Arnoult and M. Klapisch Adv. At. Mol. Phys. 27, 131 (1987)

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