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Ultraintense Lasers Applied to Laser Fusion Material Testing: Production of Ions, X rays and Neutrons

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***Abstract*::** *The ability of ultraintese lasers to create short pulses of energetic particles and high fluences is addressed as a solution to reproduce ion and X-ray ICF bursts for the characterization and validation of plasma facing components. The possibility of using a laser neutron source for material testing will also be discussed.*

1. Introduction

One of the challenges to tackle in Laser Inertial Fusion is the design of materials and reactor chambers capable of withstanding the harsh environment of the fusion reactor working 24/7.

In each laser fusion reaction, short bursts of very energetic ions (mostly H isotopes, He, C and some High Z elements), X-rays and neutrons are generated which, if not mitigated by some protection scheme, reach the chamber walls and threaten their functionality [1,2]. Together with the "typical" thermo-mechanical effects, there are atomistic damages which accumulate and evolve in time: lattice structure disruption, physical sputtering, color centers in dielectrics, diffusion and aggregation of defects, nanocavities of He and H isotopes at very high pressures,... all leading to swelling, exfoliation of the material and worsening of its mechanical (and optical) properties.

This already complex combination of noxious factors requires also the consideration of synergetic effects between the implanted species and their role in the mentioned phenomena. Thus, reactions between carbon and H isotope atoms, non linear high radiation flux effects (plasma facing materials are exposed to fluxes $>10^{20}/cm^2/s$), changes in the physical and chemical properties of the materials and their influence in the diffusion of defects need to be taken into account [3].

Unsurprisingly, all these effects are extremely hard to simulate accurately with computational calculations and a solid and reliable behavior of plasma facing components requires empirical investigations. Paradoxically, the difficulty to reproduce the plasma environment of a laser fusion reactor (short pulses, high fluences and high energy spectral ranges of X-rays and ions) has made those studies very scarce. From those available studies, we have to mention the repetitive thermal loads investigated by lasers, the X-ray effects simulated using Z-pinch machines [4,5], the ion effects modeled by RHEPP I at the Sandia National Laboratory [6] or by the inertial electrostatic confinement device at the University of Wisconsin-Madison [7]. It is noteworthy that the studies of plasma facing components by the magnetic fusion community are only partially extensible to laser fusion material due to the intrinsically different plasma conditions [8].

With the advent of ultraintense lasers ($>10^{18}W/cm^2$), in particular "table top" systems in the last decade, this lack of experimental studies can dramatically change. As it will be described, Laser triggered Target Normal Sheath Acceleration mechanism, TNSA, allows for the production and acceleration of proton and heavier ion beams with high fluxes ($>10^{20}p/cm^2/s$) and broad energy spectra [9-11]. Also, ultrashort and bright X-ray pulses with fluences larger than10^{13} photons/sr or even moderated neutron beams (10^{10} neutrons/shot) can be generated [12] with ultraintense laser systems. Moreover, this source of particles is pulsed (with a higher or lower repetition rate depending on the laser system) much in the same fashion as bursts are created in the laser fusion reactors.

In this work, the authors highlight the possibilities of ultraintense laser systems as adequate tools to reproduce the ion and X-ray bursts that take place in a laser fusion reactors and, thus, to use them for the validation of plasma facing components.

2. Laser induced ions

A review of the literature on the generation and characteristics of laser driven ion pulses, in particular for the species relevant to laser fusion, shows that current ultraintense laser systems are capable of reproducing ion fusion bursts by means of Target Normal Shealth Acceleration mechanism, TNSA [13]. In fact, the authors have generated a laser proton beam fairly similar to that of a 48 MJ shock ignition target (see figure 1).

Much in the same way, TNSA allows the generation of Deuteron [14], Carbon [15] and High Z [10] ion pulses and only He ion beams should be generated by other means as Coulomb explosion of laser ionized clusters [16].

Fig. 1. In black, proton beam generated by the authors at the Kansai JAEA facility in Japan. In red, the proton beam generated in a laser fusion reactor (48MJ target) for comparison.

3. Laser induced X-rays

Likewise, the potentiality of ultraintense lasers to generate X-ray pulses which can reproduce those of laser fusion appears plausible. Pulses of of X-rays with durations of hundreds of ps, high photon energies and elevated repetition rates can be generated by several laser induced processes: blackbody radiation, synchrotron radiation, betatron radiation, bremsstrahlung and atomic lines. In particular the last two already yield X-ray fluences similar to those of laser fusion [17 and references therein].

4. Laser induced neutrons

Ultraintense lasers may play an important role as a convenient neutron source for validation of fusion materials as it was already highlighted in the year 2000 [18]. Nowadays, the mentioned laser system would be too costly if even feasible due to the pulse energy and repetition rate requirements, however this might change in the near future with the construction of Diode Pumped Solid State Lasers, DPSSL.

Nevertheless, there are several research groups working on laser neutron sources which start to get close to the neutron fluences of laser fusion devices. The reader is referred to the reviews in [12] and [14]. One inconvenient of these approaches is that the generated neutrons are of low energy (<3 MeV). However, very recent experiments based on ^{7}Li(d,xn) reactions, have shown that high energy neutrons (up to 18MeV and more alike to the ones generated in D-T fusion reactors) can be generated in a fair amount (8*10^{8}/sr), opening the possibility of tests with high energy neutrons [19].

7. Conclusions

The authors have identified ultraintense lasers as a unique tool to validate materials for laser fusion since they can reproduce the pulsed harsh radiation environments and long exposure times of a laser fusion reactor.

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