Aneutronic Nuclear Fusion Experiments by Laser-Plasma Energetic Particles

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Abstract

Abstract. Protons at energies up to a few 100keV have been accelerated, by irradiating thin Al foils with an intense, fs laser pulses. The produced energetic protons, directed on a massive natural B sample, induced p+^{11}B fusion reactions accompanied by alpha particles emission, detected by a CR39 plate.

Introduction

The main interest in the aneutronic nuclear fusion reactions for energy production concerns the possibility of greatly reducing the problems associated with neutron activation (as for example in D+T or D+D fusion reactions) and related requirements for biological shielding, remote handling, and safety [1]. Among the so called "advanced fusion fuels" the proton-Boron fusion reaction seems to be the most attainable from an experimental point of view, due to the relatively high cross section of the process exhibited at the centre of mass kinetic energy of 148 keV and 580 keV respectively. However, the very high temperature required to activate the fusion reaction makes unrealistic the conventional fusion approaches. The advent of the Chirped Pulse Amplification (CPA) [2] and the development of the new Laser Plasma Acceleration techniques [3], based on super-intense and ultra-short laser pulses, allowed to investigate different approaches and schemes [4, 5]. In particular in the case of the proton-Boron fusion reaction, instead of trying to achieve in the fusionistic plasma the unrealistic temperature 600 keV, required to maximize the fusion cross-section for the process, one can think to direct the accelerated protons at energies of hundreds of keV on the Boron or plasma Boron [6]. To this purpose an experiment has been performed at CELIA in which a multi-TeraWatt Ti:Sapphire laser interacted at fairly relativistic intensities with different solid targets to produce energetic protons to be addressed to a Boron target. Several diagnostics were activated to monitor the effectiveness of the laser-target interaction, the energy spectrum of the accelerated particles and the release of charged particles related to the activated fusion processes.

The experimental apparatus.

The experiment was performed at "Centre Lasers Intenses et Applications" (CELIA) using

the ECLIPSE laser. ECLIPSE is a Ti:Sapphire (λ=812nm) laser delivering at 10Hz up to 170mJ in 40fs, with a temporal contrast of $4x10^{-9}$ at 12ns and 10^{-7} at ASE level, energy stability 5% rms shot to shot. The laser beam was focused on target with a 25cm off axis parabola at an intensity of $2x10^{18}$ W/cm^2.
The main particle diagnostics activated in the experiment were the Time Of Flight (TOF) measurement, Thomson Parabola and CR39 plates.

The laser-plasma accelerated protons.

The laser beam focused on a thin 6µm Al foil produced a few 100eV plasma, in which the fast escape from the target of energetic electrons produced the acceleration of protons (present on the oil impurities deposited on the target surface) in the forward direction [7] with energies up to a few 100keV. In FIGURE 1 the oscilloscope trace, related to the proton Time Of Flight (TOF) measurements performed with a monocrystalline diamond detector manufactured by Università di Tor Vergata [8, 9, 10], is reported in the top. In the bottom the corresponding energy values of the accelerated protons, taking in consideration the distance of the detector from the laser-target interaction point, is reported. The trace reported in figure is typical of the many other obtained in the same experimental condition, indicating the good repeatability of the phenomenon.

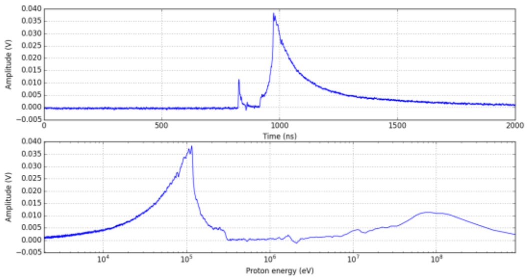

FIGURE 1. 6µm Al foil, I=$2x10^{18}$ W/cm^2 .

The proton-Boron interaction and the alpha particles detection.

As shown in FIGURE 1, the spectrum of the laser-plasma accelerated protons includes one of two energies at which the cross-section of the Proton-Boron reaction exhibits its maxima, i.e. at 148 keV and 580 keV respectively. The main channel of the reaction involves the production of three alpha particles for a total kinetic energy of 8.7 MeV [11]:

$$p + {}^{11}B \rightarrow 3\ {}^{4}H_{e}\ (8.7 MeV)$$

In the FIGURE 2 the set-up we used to detect the alpha particles produced during the a-neutronic reaction is reported. The blue arrows indicate the particles accelerated in the forward direction during the laser-target interaction, while red arrows represent particles emitted from the surface of the Boron or reflected by it.

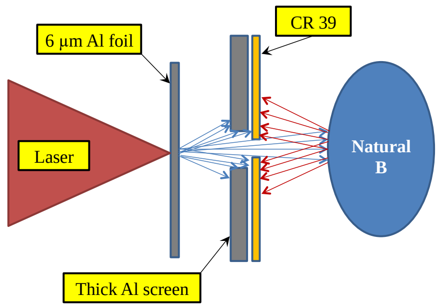

FIGURE 2. CR39 set-up.

The laser pulse was focused on the thin Al foil in the same conditions in which we produced the few 100 keV protons, as reported above. The energetic protons, passing through a narrow hole made on an aluminium thick foil, impinge on a thick natural B sample, inducing the aneutronic fusion reaction. The produced alpha particles coming out from the natural B sample surface hit the CR39, that will be afterwards analysed.
The results of such analysis are still in progress. However, as for now we can say that a clear dependence of the number of

counts versus the diameter of the craters formed after the action of the etching is apparent. The distribution shows a very large number of counts at 2-3μm crater diameter, probably due to low energy protons (less than 200keV) and very few counts at 20-30 μm, attributable to 3-4 MeV alpha particles, according to reference [12]. The 20-30 μm diameter tracks are compatible with the impact of the alpha particles from the P-B fusion reaction. The CR39 surfaces was etched for 7 hours in a solution of NaOH at 70^0C temperature. The CR39 surface towards the B sample shows a number of 20-30 μm diameter tracks about ten times the ones detected on the CR39 surface towards the laser. The number of counts on the CR39 surface towards the laser is comparable to the one we detected also on the surfaces of a non exposed CR39 plate. Most likely the tracks on non exposed CR39 slab are due to the alpha particles produced in the Radon decay.

Conclusions

In this experiment we were able to produce protons during the interaction of an ultra-intense laser pulse with a thin Al target and to direct them on a solid Boron target, so inducing aneutronic fusion reactions. The onset of the P-B fusion reaction was evidenced by the detection of alpha particles, whose energies were compatible with the ones expected for such reaction.

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