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Neutron Generation with Repetitive High Intensity Laser Induced Protons
レーザー駆動陽子線による中性子発生

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We estimate a neutron number and an energy spectrum which obtained using laser driven proton spectra with maximum energy of 40 MeV. The 10^8/shot neutrons are estimated. This pulsed neutrons may be used for neutron radiography.

Neutron generation from solid target irradiated with short pulse, repetitive high-intensity laser is one of the areas of experimental research which has been very active[1]. One of the generating method is a method of using a dual target. Ions or protons generated from the rear surface of the first target are incident on the second target. Second target is placed behind the first target. Neutrons are generated in the nuclear reaction in the second target which play a ions-neutron converter. An angular distribution and an energy spectrum of the neutrons, depends on the material of the converter and energy and ion species. This powerful neutron source may be used in neutron radiography, material testing of a nuclear fusion reactor, and the study of transmutation and fast neutrons in the nucleus generation process.

In previous experiment, a 40 MeV proton acceleration was obtained from μm-scale thick metal foils with repetitive compact laser system[2]. In this paper, a neutron number and an neutron energy spectrum is estimated using a neutron convertor target of beryllium and the laser driven protons with maximum energy of 40 MeV.

Acceleration of protons to high kinetic energy in plasmas induced by high intensity laser pulses has been investigated for more than 3 decades [3]. The maximum ion energy was found to increase with the laser focused intensity, with a decade-standing record of ~60 MeV protons from hundred mm foils irradiated by 400 J sub-ps laser pulses of the first PW chirped-pulse amplification (CPA) laser system. A high temporal contrast (10^{10}:1) of laser pulses [4] suppresses ps- and ns-scale amplified spontaneous emission (ASE) enabling irradiation of thin (few μm) targets from which ~24 MeV protons were demonstrated with 10 J 100 fs pulse at the intensity of 10^{20} W/cm^2[4]. To date the highest published proton energy observation is 67.5 MeV which was obtained with an 80 J sub-ps high-contrast (>10^9) pulse Nd:Glass CPA laser and a copper flat-top cone target.

This is substantiated by favorable proton energy scaling corresponding to various regimes of acceleration. For thick (hundred μm) solid density targets and long (hundred fs) TW-PW laser pulses, protons are accelerated by the target normal sheath. For thinner (μm down to nm scale) targets and high contrast laser pulses with intensity <10^{22} W/cm^2, acceleration occurs in the regime of strong charge separation or Coulomb explosion, where the maximum proton energy depends on laser power as $E_p \approx \eta\, 230$ MeV (P [PW])$^{1/2}$ for optimum targets; here η is the portion of electrons expelled from the target by the laser pulse. With higher intensity the radiation pressure dominates in acceleration. Achieving high-quality energetic ion beams with accessible targets and relatively small laser pulse energy by using a compact laser system with a high repetition rate is the purpose of our investigation.

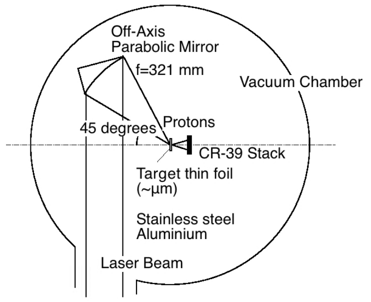

Fig.1. Experimental apparatus

We obtained the 40 MeV proton acceleration from μm-scale thick metal foils irradiated by 7.5 J, 40 fs, 800 nm laser pulses with the temporal contrast of 10^{10}:1 focused to the intensity of 1×10^{21} W/cm^2. This is the highest proton energy for laser pulses with the energy of <10 J .

In this experiment we used the J-KAREN 200 TW OPCPA/Ti:sapphire hybrid laser system at the Kansai Photon Science Institute of JAEA. We focused the p-polarized laser pulse to the intensity of up to 1×10^{21} W/cm^2 at the incidence angle of 45° as shown in Fig.1. No plasma mirror was used to obtain the 10^{10} contrast achieved with a saturable absorber inserted between the high-energy CPA oscillator and stretcher.

Energy-resolved spatial distributions of proton fluence along the target normal were determined using nuclear track detection with CR39 plates stack which is sensitive to ions but not x-rays and electrons. Tracks formed by impinging protons are revealed by etching each plate with a KOH solution. This gives the ion energy and angular distribution since the ion energy determines the penetration range. Protons originate from the water and hydrocarbon contaminants which are always present on a target surface.

The proton energy spectrum is exemplified in Fig. 2 for protons emitted within unit solid angle of 1 msr from rear surface of a 0.8mm thick the Al foil. It is obtained by counting the total number of protons (etched pits) at each CR-39 plate.

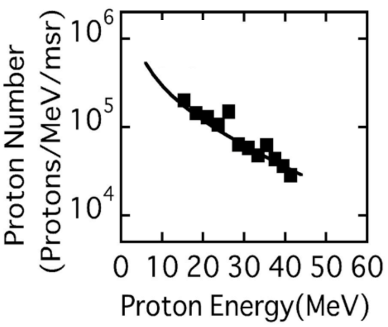

Fig. 2. Proton energy spectrum

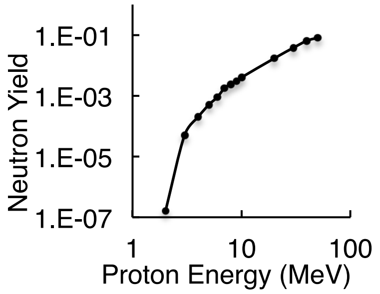

Fig.3. Neutron yield in beryllium

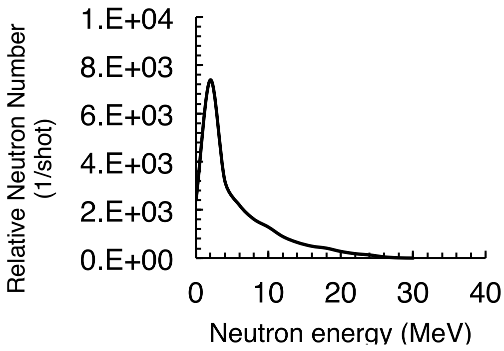

Fig. 4. Neutron energy spectrum

The neutron yield is shown in Fig.3 at a thick beryllium target as a function of incident proton energy. The neutron number N_n generated with laser produced protons and thick beryllium target is described by the equation of

$$N_n = \iint n_p(E,\Omega)\cdot Y_n(E)\, dEd\Omega \quad . \qquad (1)$$

n_p is laser produce proton spectrum, Y_n is neutron yield of beryllium target. Using this equation with integrating for proton distribution solid angle Ω from 0 to 100 msr, one can obtain the neutron number of ~10^8.

An energy distribution of neutrons generated with beryllium thick target and laser produced protons is estimated using the Monte Carlo particle transport simulation code Geant4. The result is shown in Figure 4 as a function of neutron energy. The maximum neutron number is obtained at the neutron energy of about 5 MeV.

We estimated the neutron number and the energy spectrum which obtained using the repetitive high intensity laser driven protons with maximum energy of 40 MeV. This pulsed neutrons may be used for neutron radiography *et al.*

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