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Ion acceleration by the interaction between the high peak power femtosecond laser pulses and the solid density targets
高強度フェムト秒レーザーによる固体薄膜ターゲットからのイオン加速

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Ultra-high intensity laser interaction with a solid target can produce energetic ions whose energies up to several tens of MeV. Related to this interesting observation, many experimental as well as theoretical investigations have been carried out in all over the world in the past 10 years. Particle acceleration based on this technique has achieved high quality particle beams that compare favorably with conventional acceleration techniques in terms of emittance, brightness, pulse duration and compact source size. However, for the actual applications, we need to overcome some issues, for example, relatively small maximum energies of protons for some applications, the reduction of beam density according to the beam transport, and so on. Introduction of the intensive investigations to overcome those issues in many institutes are reported as well as the recent related activities at JAEA Kansai is also introduced.

More than 10 years have been passed since the discovery of the energetic ions from the interaction between the high peak power laser and the target materials [1]. Laser-driven ions attract many research fields, especially because those are accelerated from a small spatial size acceleration field of the order of ~μm with the extremely high field gradient of ~TV/m, which will be never achieved by other method. Therefore, the downsizing of the conventional accelerator is achievable. Adding to the previous peculiar characteristic, those laser-driven protons exhibit small transverse emittance of ~10^{-4} π mm mrad [2], which is two orders of magnitude better value than that of the beam from the usual conventional accelerator. More than 10^{13} protons are emitted from a small source region within a pico-second bunch duration at a source [3], thus high peak current is achieved to be ~ GA, which is again, amazingly high value.

Due to their quality, laser-driven ion sources can serve many applications, which include proton radiography [4], injectors for conventional accelerators [5], and the potential for development of compact facilities for laser-driven ion beam radiotherapy [6], producing high energy density matter (warm density matter) by inhibiting hydrodynamic expansion (isochoric heating)[7], fast ignition [8].

However, since the proof of principle of the laser-driven proton acceleration experiment, the maximum energy of the proton of ~60 MeV, which is obtained with single shot based ~kJ class laser pulse interaction with the thin-foil target is not updated significantly. At least more than 80 MeV energy protons should be repetitively obtained for the medical use [9]. It means that such high energy proton beams should be produced by compact laser system (e.g. sub-PW class) which enables us to supply repetitively the laser pulses.

A number of mechanisms of ion acceleration are discussed for further understanding of this mechanism especially to know the most interesting and important issue, 'energy scaling'. Many theoretical models are proposed. The information of the achievable maximum energy with given laser intensity (or energy) is essential for the feasibility study of the proposed applications.

When the initial laser pulses have sufficiently intense (for example, ≳ 10^{22} Wcm^{-2}) so that electrons in the plasmas are stripped away completely, the acceleration mechanisms take place are coulomb explosion (CE) mechanism [10] or Radiation Pressure Acceleration (RPA) mechanism [11]. At this moment only a few experiments appear [12], whose acceleration mechanisms are dominated by such efficient acceleration mechanisms. Because the achieved laser intensity on target is just increase up to ~10^{22}Wcm^{-2}[13].

In most of the experimental results reported in the past 10 years the dominant acceleration occurs therefore at charge separation field established at the rear side of the target. Among the models, which explain this physical picture, including interaction with underdense plasmas [14], two of them are quite well known; one of them is based on the scheme, 'plasma expansion into vacuum' [15], which is also known as Target Normal Sheath Acceleration mechanisms. Ions are accelerated by the charge separation field in a narrow layer at the front of the plasma, which is formed between the electrons and ion expanding into vacuum. On the whole, the plasma is electrically neutral. The other model is based on the physical picture, 'strong charge separation field' at the rear side of the target between the electrons with certain temperature distribution and the immobile ion sheet in the target [16].

The detail of the attempts to increase the maximum proton energies in all over the world will be introduced in the presentation. The energy scaling of those models and the comparison with the data taken in many institutes will be reported in the presentation. The resent experimental results at JAEA where we succeed in accelerating protons up to 40MeV energy with 250 TW, 40 fs, 8J laser pulse interaction with the thin foil metal target is also reported.

Another important issue to overcome is density decrease in the ion pulse followed by the beam transport. In contrast to conventional ion accelerators currently used in medicine, ion acceleration from flat foils typically produces divergent proton beams with a broad energy spread (~100%) resulting in a potentially significant decrease in number of particles delivered for therapy. In order to achieve the same level of the beam divergence and energy spread as in the conventional accelerators, it is desired that the laser-driven beam at the source point (or at least at the injection point which is near the source) should have a quality comparable to what is given by conventional accelerators.

Many attempts to overcome this issues carried out in all over the world in many ways are introduced, for example, using tailored target, combining the conventional beam optics with the laser-driven proton source, applying plasma optics to the laser-driven proton source, and so on. Detail of those attempts will be presented in the talk as well as the recent experimental investigations carried out at JAEA where we achieve to obtain the monochromatize and collimated proton beam from the thin foil target by using sophisticated target holder will be shown in the presentation.

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