§46. Hot Electron Spectra in hole-cone Shell Targets and a New Proposal of the Target for Fast Ignition in Laser Fusion

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In Fast ignition (FI), an imploded core with a density of several hundred times the solid density is created by an imploding laser. The imploding core is auxiliary heated and ignited by hot electrons. The hot electrons are produced by the interaction between a chirped ultra-short pulse laser (heating laser) and the pre-formed plasma created by the pre-pulse of the heating laser at a tip of a guiding cone. According to the simulation, the maximum coupling efficiency between the core and the hot electrons can be expected at the typical hot electron energy of 2 MeV or less). Usually if the scale length (1/e-hold length) of the plasma density is long, the effective electron temperature T_{eff} (=slope of the electron spectrum) is high and the coupling efficiency is reduced because the electron passes through the core with small energy deposition.

Sunahara et al. proposed an hole cone shell target without the cone tip (hole-cone shell) to resolve these problems. The heating laser directly irradiates the core. The low energy electron, which had been lost in the cone, can be used for core heating. The efficiency reduction due to the divergence of the hot electrons can be also recovered because the distance from the hot-electron generation point to the core can be shorten. It is the most serious problem that the pre-formed plasma may be created because a part of the compressed plasma enters the cone through the hole during the imploding phase. T_{eff} may increase due to the interaction between the heating laser and the plasma.

Direct heating of the imploded core has been performed by using the hole-cone shell target in order to minimize the energy loss of the hot electrons in the cone itself. At the beginning, we had worried about the increase of T_{eff} due to the exploding plasma with long scale length from the hole. However T_{eff} is not so high and high neutron yield can be obtained. This reason may be that the pre-formed plasma is created in the inner side of the imploding shell (because there is no tip of the cone), the pre-formed plasma is shortened by the shell implosion and the scale length remains short because the spouting plasma from the hole is too dense. Actually the LFEX laser can reach the imploded core according to the MIXS image. Although the neutron yield increases, the neutron energy is slightly shifted from 2.45 MeV (thermal DD neutron) because the accelerated deuterium beam is also contained. The beam may be accelerated in the spouted plasma from the imploded core by a ponderomotive force of the LFEX. The effective core heating can be expected because the stopping range of the accelerated deuterium ion is too short.

In the hole-cone shell, higher coupling efficiency can be expected because T_{eff} is not so high and the range of accelerated ions is short. We summarize the results about the hole-cone shell as follows;

(a) T_{eff} in the hole-cone shell is lower than T_{eff} in the standard cone shell.

(b)The neutron yield in the hole-cone shell is larger than that in the standard cone shell. However much neutrons come from beam deuterons are contained.

(c)The neutron yield in the hole-cone shell is less than that in the target proposed by the collaborator of The Graduate School for the Creation of New Photonics Industries (GPI).

(d)High intense neutron yield can be observed even at early LFEX injection timing.

(e)Much x-ray amounts have been observed in Au-(hole)-cone shell rather than in DLC-(hole)-cone shell. They have been obtained at the earlier injection timing of the LFEX laser.

About (b), the ablation plasma contained deuterium ions blows from the hole of the cone. Ions are accelerated by the ponderomotive calculated by Sentoku. The core heating by the energetic ion can be expected because the ranges of ions are much shorter than that of the electrons. Indeed from the neutron measurements, DD neutrons based on the beam deuteron have been observed. However the neutron flux in the hole in shell is smaller than that in GPI target as mentioned in (c). In GPI target, two holes shell without cone was used. LFEX laser was injected to the core created by the irradiation of only two imploding lasers. Ablation plasma was supposed not to be blew to the laser path due to two holes on the shell. However the part of the ablation plasma was invented to the LFEX laser path. In the hole-cone shell, little ablation plasma invents to the laser path only through the hole on the shell. The scale length is short and the acceleration is not enough. Therefore it may be better to prevent the ablation plasma to the laser path in order to utilize the effective ion heating.

When the LFEX laser injection is delayed, the neutron flux can be expected to be enhanced because there is much spouting ablation plasma through the hole. However the neutron flux is enough even at early injection timing in the experiment as mentioned in (d). This means the electron heating is dominant in the hole-cone shell target. X-ray amount in Au-(hole) cone shell target is larger than that in DLC-(hole) cone shell target. This result that much X-rays in high-Z material are generated, is reasonable because X-rays are generated by the interaction between the hot electrons and target. If the LFEX laser injection is delayed, X-rays amount are decreased because the hot electrons are interacted with the spouted CD plasma as mentioned in (e). The most suitable target for FI can be sought by comparison of the spectra between varied targets using an electron spectrometer. We compare T_{eff} in the cone irradiated by the LFEX laser with T_{eff} in the plate. Direct heating of the imploded core has been performed by using the hole-cone shell target. T_{eff} does not become high and high neutron yield can be obtained. The hole-cone shell target is another candidate of FI.

At earlier LFEX injection timing, for example, before the imploding shell is filled by the pre-formed plasma, more effective coupling efficiency may be expected. At that time, the electron deposition is decreased because the density is still low. However almost hot electrons can irradiate the core from inside (cavity) although the beam divergence is large. The relaxation between the electron and the ion is enough although the density is over several g/cm^3. If another hole is drilled in the opposite side of the cone (Fig. 1), T_{eff} may be strongly reduced. The pre-formed plasma cannot be created because the pre-pulse goes through the hole during the imploding phase. If the LFEX laser is injected when the pre-cursor filled the cavity, lower T_{eff} and short interaction distance and effective irradiation efficiency can be expected.

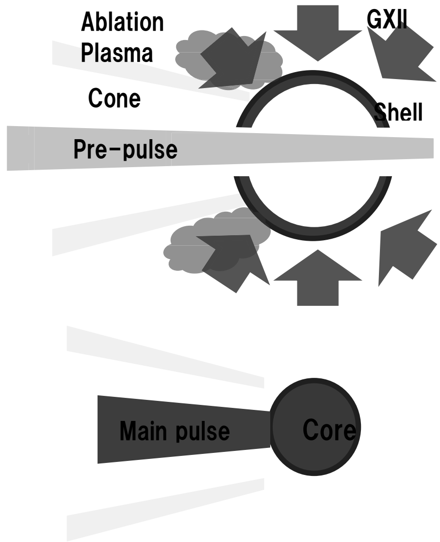

Fig. 1. Hole-cone-hole-shell target.