7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Nuclear Fusion Study at GIST

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Rapid heating of matter using high power lasers is an emerging research area in laser-plasma physics. This has been motivated primarily by the interests in the exotic states of matter achieved after heating. In these experiments, the interaction between intense light and matter is sufficiently strong and fast for the atoms to be ionized instantaneously, and the resulting electrons or ions (or both) attain large kinetic energies very quickly. By directly illuminating a small solid target with an intense laser beam, a target temperature on the order of 10^6 K has been demonstrated. Using even smaller targets (~10 nm radius spheres), an ion temperature exceeding 10^8 K has been achieved in the laboratory,[1] which is sufficiently high for deuterium ions to produce nuclear fusion reactions efficiently.

In a laser-cluster-fusion experiment, an intense (>10^{16} W/cm^2) laser beam irradiates ~10 nm radius spheres of solid density deuterium (called deuterium clusters).[2] If the incident laser field is sufficiently strong, the laser-matter interaction leads to an explosion of the individual spheres generating energetic deuterium ions. The resulting deuterium ions are so energetic (> 10 keV) that they generate nuclear fusion reactions as they collide with each other within the plasma or with ions in the background gas. These fusion reactions produce a ~1 ns burst of neutrons and protons.

At GIST, we have studied a scaling law ($Y \sim E^\beta$) of the laser pulse energy (E) for fusion neutron yields (Y) from laser-cluster fusion experiments, as shown in Fig. 1.[3] We find the scaling exponent β approaching 1.0 as the ion temperature increases from 1 keV to 100 keV.

We have also built an experimental platform to study fusion plasmas using high power lasers. We have produced high temperature deuterium fusion plasmas with ion temperatures exceeding 300,000,000 K. We will show that we can control the temperature of fusion plasmas by varying the incident laser intensity. We have measured fusion neutron yields at different plasma temperatures, and preliminary results will be presented.

High power lasers can also be used to produce intense ion sources capable of heating a small sample to high temperatures. When an energetic ion beam is incident on a cold sample, the incident ions first transfer their kinetic energy to target electrons via Coulomb collisions. Subsequently, these electrons collide with ions within the sample, and electron-ion relaxation process begins. Since laser-driven ions travel very fast often exceeding several percent of the speed of light, they can deliver a significant portion of their kinetic energy to the sample very rapidly. The whole heat transfer process takes less than a nanosecond, and the heated sample does not have time to expand hydrodynamically during heating and maintains its initial density. Sometimes the heated sample near solid density reaches temperatures far beyond those attainable through conventional heating sources, and scientists have used it in research areas such as warm dense matter and ion fast ignition.

At GIST, we have shown that a thick (> 1 cm) solid-density aluminum sample can be heated rapidly, uniformly, and efficiently all at the same time using an energetic proton beam with a finite energy spread.[4,5] We find that a 100 MeV proton beam with a Gaussian energy spread of $\Delta E/E$ ~ 70% can transfer heat into a 32 mm thick solid-density aluminum sample uniformly (temperature nonuniformity < 2–6%) and efficiently (> 62% heat transfer efficiency) on a sub-nanosecond time scale.

This work was supported by NRF grant funded by the Korea government (MSIT) (No. 2023R1A2C1002912).

References

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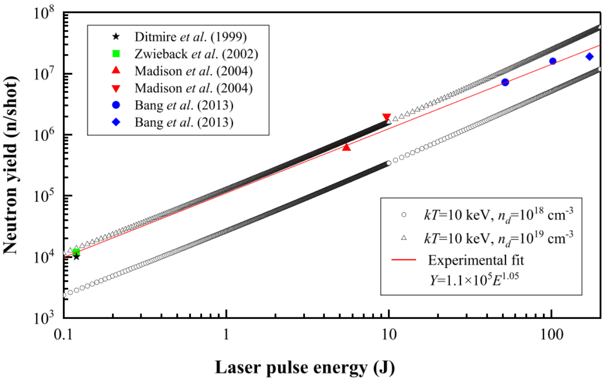

Figure 1. Fusion neutron yield is shown as a function of the incident laser pulse energy varying from 0.1 J to 200 J. The scaling law for the neutron yields reported from previous experiments is shown as a solid red line.