Probable Approaches to Develop Particle Beam Energy Drivers and to Calculate Wall Material Ablation with X-ray Radiation from Imploded Targets[1]

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Abstract. The first subject was the development of future ion beam driver with medium-mass ion specie. This may enable us to develop a compromised driver from the point of view of the micro-divergence angle and the cost. We produced nitrogen ion beams, and measured the micro-divergence angle on the anode surface. The measured value was 5-6mrad for the above beam with 300-400keV energy, 300A peak current and 50ns duration. This value was enough small and tolerable for the future energy driver. The corresponding value for the proton beam with higher peak current was 20-30mrad, which was too large. So that, the scale-up experiment with the above kind of medium-mass ion beam must be realized urgently to clarify the beam characteristics in more details. The reactor wall ablation with the implosion X-ray was also calculated as the second subject in this paper.

1. Introduction

Although almost all programs concerning light ion beams for IFE or ICF are stopped or sleeping for the moment, we still continue the operation of our pulsed power machines which were manufactured for the former light ion beam research works more than twenty years ago. Although we use the same machines in our recent experiments, our research subjects shift a little bit to different directions, some of which are described in this paper. As the recent budget to support our experiments is not high enough for us to build new machines and to use new spaces, we must consider what we can do only with a small amount of money.

2. Assessment of Medium-weight Pulsed Ion Beam as a Future Candidate for Fusion Energy Driver

The first subject in this paper is our basic experiment for the development of future ion beam driver. After we developed a cryogenic diode to produce very pure proton beam from hydrogen ice, one of the guiding principles to continue our experiments has been the finding a new research field under the combination of the pulsed power technology and the cryogenic engineering. Although we could produce the high efficiency proton beam, the beam brightness has not been enough high (in the world-wide experiments which followed) for the future application to the target implosion. This was because the ratio (of the ion mass over the number of ion charge) is lowest in the case of proton beam, and the micro-divergence angle at the ion source was large. On the other hand, the ratio was enough high to get the enough small micro-divergence angle in the case of heavy ion beam. So that, the recent

[1] Supported by the Ministry of Education, Sports, Science and Culture in Japan, the Japan Society for the Promotion of Sciences, Tokyo Institute of Technology, Sandia National Laboratory and Institute of Laser Engineering, Osaka University, Japan.

development of particle beams in the world seems to be concentrated on the heavy ion beams. Never the less, the order of ion current of the most recent heavy ion beams is too low to make implosion-oriented experiments. This is because the cost for the heavy ion beams is very high, compared with the one for the light ion beams. This kind of consideration about the situations in the particle beam development induced us to adopt the medium-mass ion beams as a probable approach. This may enable us to develop a compromised ion beam driver with a medium-mass ion from the point of view of the micro-divergence angle and the cost.

2.1 Experimental Apparatuses

In our recent experiments, we produced nitrogen ion beams (including a small amount of oxygen ions), and measured the micro-divergence angle on the anode surface of the ion diode [1].
The schematic diagram of the experimental setup including the ion diode (on the left) and the arrayed pinhole camera for five images on CR-39 (on the right) is shown in *FIG. 1*.

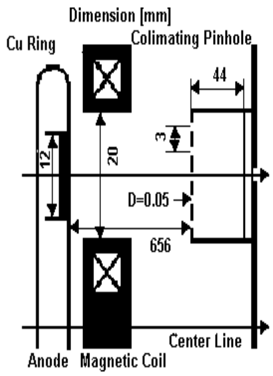


FIG. 1. Experimental Setup Including Ion Diode and Arrayed Pinhole Camera.

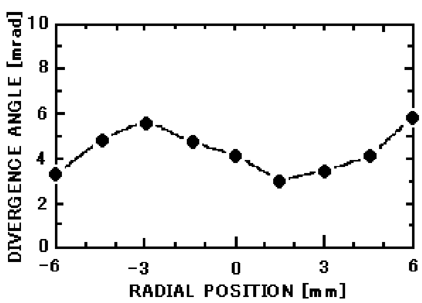


FIG. 2. Micro-Divergence Angle of Nitrogen Beam vs. Anode Radial Position.

2.1 Experimental Results

We measured the divergence angle along the anode surface, which result is shown in *FIG. 2*. The measured value was 5-6mrad for the above mixture beam with 300-400keV energy, 300A peak current and 50ns duration. This value is enough small and tolerable in the future development of the energy driver for the target implosion, if the absolute value does not become larger under the (voltage and current) scale-up of our machine.

2.2 Comparison with Light Ion Beam Case

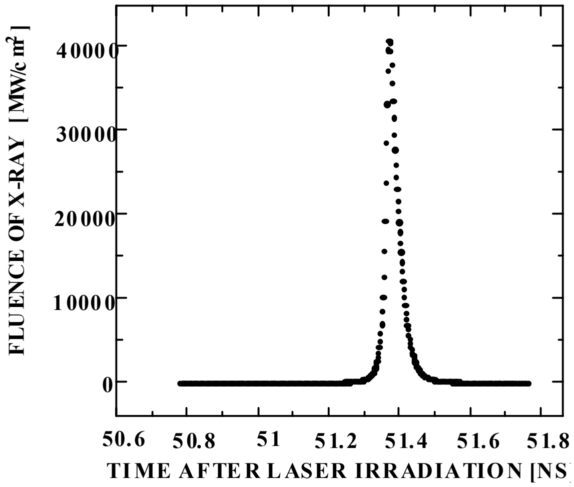
The corresponding value for the proton beam with higher peak current was 20-30mrad, which was too large for our future purpose. So that, the scale-up experiment with the above kind of medium-mass ion beam driver must be done urgently to clarify the beam characteristics in more details.

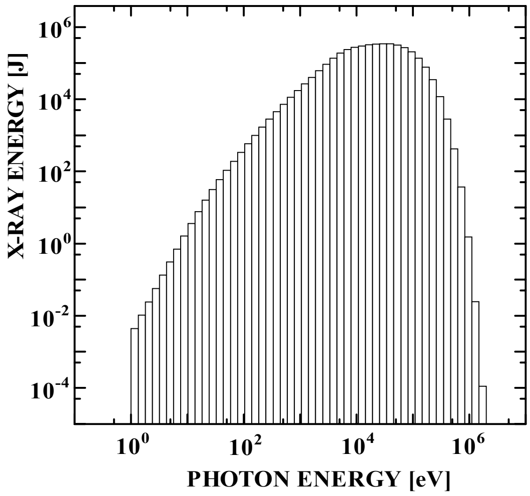
3. Simple Calculation of Wall Material Ablation Induced by X-ray Associated with Target Implosion

The second subject in this paper is our numerical estimation of the wall ablation with the target implosion X-ray. Recently we started the preliminary calculation of the thickness of the wall material which is ablated during the implosion. We gathered the necessary data for X-ray absorption as a function of radiation wavelength. Taking into account of the spectral distribution of the implosion X-ray and the absorption data, we obtained the absorbed X-ray energy to estimate the evaporated wall thickness, for example.

3.1. Example of X-ray Produced by Laser-Target Implosion

One example of target implosion calculations is shown in reference [2]. When a laser energy of 3MJ hits a target with the energy gain of 148, we get a nuclear fusion energy of 445MJ, a X-ray energy of 4MJ, a neutron energy of 303MJ and a charged particle energy of 138MJ. The time history and the spectrum of the X-ray are shown in *FIG. 3(a) and (b)*. The inner radius of the solid reactor wall is assumed to be 4m. Although the energy of X-ray is lower than the other ones, it hits the reactor wall at first and the peak power is highest among others. As this kind of X-ray may degrade the first wall of the inertial confinement fusion reactor, we estimated the ablated thickness of the solid state wall.





(a) Time history (b) Energy spectrum

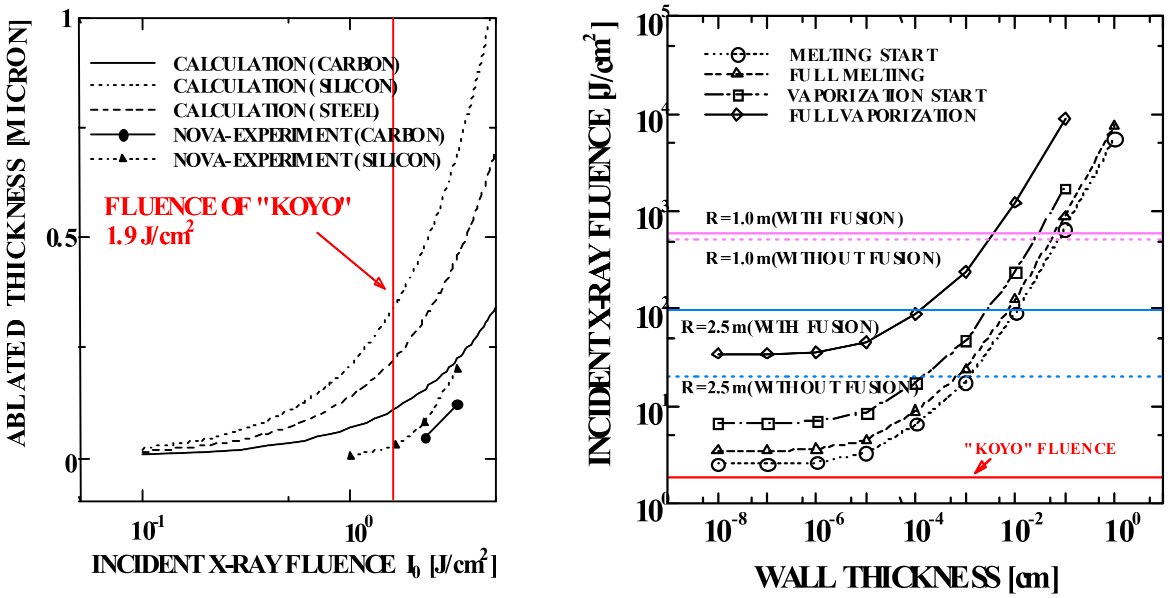
FIG. 3 Typical Characteristics of X-tray Associated with Target Implosion in Laser Fusion.

3.2. Numerical Results of Ablated Wall Thickness in Various Cases

Three kinds of species (carbon, silicon and steel) were considered as the wall material for the case of laser target implosion X-ray. The classical absorption coefficients as a function of X-ray energy were gathered. Then, we calculated the ablated thickness as a function of X-ray fluence, which result is shown in *FIG. 4(a)*. The NOVA experimental results for carbon and silicon [3] and the fluence of "KOYO" reactor design are also shown in the same figure.

The same calculations were performed for the case of Z-pinch implosion X-ray. Some of Sandia National Laboratories and their collaborators are estimating how strong the X-ray is if a steel first wall is placed in the neighborhood of a wire-arrayed high speed pinch implosion to protect the reactor [4]. The X-ray fluences are shown with horizontal lines in *FIG. 4(b)*, for the cases of steel wall radii of 1.0 and 2.5m and with and without the nuclear fusion reaction. The "KOYO" X-ray fluence is also shown in the same figure. Four kinds of curves correspond to the necessary fluences (1) to start the melting, (2) to complete the melting, (3) to start the vaporization and (4) to complete the vaporization of the relative amount of ablated thickness.

The absolute value of the ablated wall thickness was not so large so far in the above results. The more



(a) Ablation by Laser Implosion X-ray *(b) Ablation by Z-pinch Implosion X-ray*

FIG. 4. Comparison of Solid Wall Thickness Ablated by Two kinds of Target Implosion X-rays.

severity is anticipated if the optical machine parts of the laser fusion must be placed under the reactor conditions. So that, we next considered the ablation of dielectric mirror surfaces. The results are shown in *FIG. 5* for the various species of surface coating materials (Al_2O_3, NaF, MgF_2, SiO_2, TiO_2, ZrO_2 and PbF_2). The X-ray fluence of "KOYO" reactor design is 1.9J/cm^2 at the reactor wall radius of 4m. This value is reduced with the increase of distance from the chamber center as is shown with the horizontal lines in *FIG. 5* (15, 25, 35 and 45m). Many curves in the same figure correspond to the X-ray fluences at the radius of 4m which are necessary to start the melting of the various coating materials. The curves can be divided into three groups. The strongest one is Al_2O_3, the weakest one is PbF_2 and the others in a same group which come between the first two ones.

4. Discussions

For HIF, the current mainline target requires a particle current of about 5kA per beam, and each beam must hit a spot on the target that is elliptical with a minor axis of 0.18cm. Typically, the beam radius at the final focus magnet is less than 10cm, and the beam is ballistically focused over a distance of 5m or more to the target. To hit a 2mm radius spot at 5m requires a beam divergence at final focus of 0.4mrad (or considerably less if the ion beam is not adequately charge-neutralized). The present paper reports about a cryogenic ion source coupled with a high voltage diode. For a diode voltage of 400kV, an ion current of 240A is reported with a divergence of about 6mrad. If the ions are all nitrogen ions with charge state q=1, then the beta=0.008; and if these ions could be post accelerated with no emittance growth to the beta > 0.1, then the divergence would be reduced to < 0.6mrad. In HIF accelerators, allowance for an emittance growth in the accelerator of a factor of 100 or more is typically included, so the typical HIF ion source should have an emittance of a factor of about 100 better than the emittance at the final focus. While the present paper has interesting results, it does not appear to be an adequate ion source for a HIF linear induction accelerator. If post acceleration with no emittance growth can be achieved, then the ion source of this paper may be of interest for a medium-mass ion IFE driver.

It is still necessary to consider deeply the effects, which are brought with the surface ablation of the solid wall materials in the future. For the moment, we can not say clearly if the above amount of

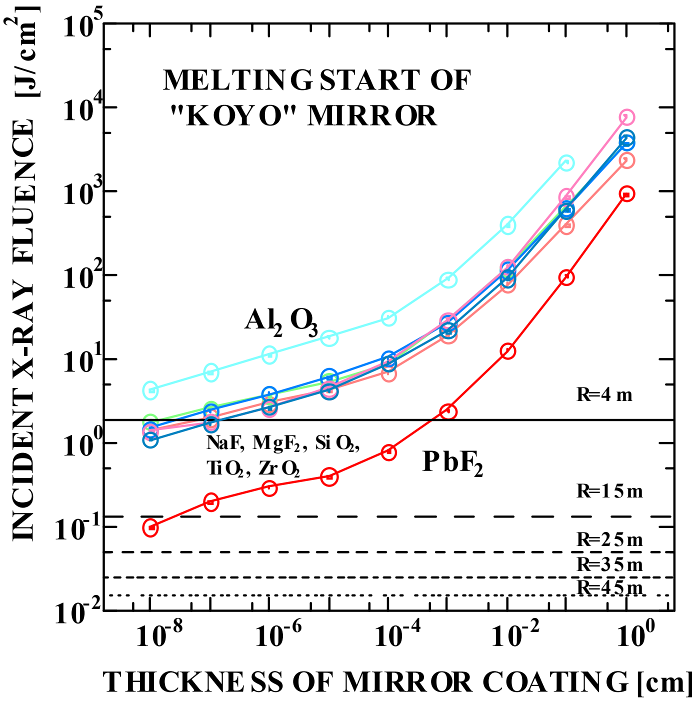


FIG. 5. Ablation of Mirror Coating Materials by Laser Implosion X-ray

ablated thickness is small or large enough to keep the surface conditions of the wall materials to continue the successful rep-rate operation of the inertial fusion reactors or not.

5. Summary

The recent results of our preliminary experiments and calculations concerning beam divergence diagnostics and wall surface ablation calculations were shown briefly. We obtained a rather small beam micro-divergence angle for the nitrogen beam (medium-mass ion beam), compared with the result for hydrogen beam (light ion beam). It is expected for us to extend our experiments to the higher power region in the near future to demonstrate the potentiality of such beams so as to show that the medium-mass ion beam is one of the future candidates of energy drivers for the inertial fusion. The ablated wall thickness by the implosion X-ray under laser-target and Z-pinch-target interaction showed us the different response of various materials including carbon, silicon, steel and a variety of coating materials for the optical components for the laser and Z-pinch facilities.

6. References

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