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Study of shockwave method for diagnosing the radiation fields of laser-driven gold hohlraums

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Abstract. Besides the routinely used broad-band x-ray spectrometer (Dante or SXS), ablative shock-wave method is often used to diagnose the radiation fields of laser-driven Hohlraums. The x-ray ablation process of Aluminum and Titanium is studied numerically with a 1-D radiation hydrodynamic code RDMG [F. Tinggui et al., Chin. J. Comput. Phys. 16, 199 (1999)], based on which a new scaling relation of the equivalent radiation temperature with the ablative shock velocity in Aluminum plates is proposed, and a novel method is developed for determining simultaneously the radiation temperature and the M-band (2-4 keV) fraction in laser-driven gold Hohlraums.

1. INTRODUCTION

For laser-indirect-drive inertial confinement fusion (ICF) with the so called central-hotspot-igniting scheme, the radiation fields of high-Z cavity (or hohlraums) driven by high power laser facilities such as NIF (National Ignition Facility) and LMJ (Laser Mega-Joule), must be carefully designed and controlled to ignite and burn the DT fuels contained in a little (~1 mm diameter) plastic capsule, which is in turn placed in the centre of high-Z cavities. Firstly, to achieve an implosion velocity high enough to ignite DT capsule, the radiation temperature should be about ~300 eV. Secondly, the temporal profile of hohlraums radiation fields should be precisely shaped to launch multiple shocks for compressing the main fuel quasi-isentropically, therefore to reduce the total laser energy needed for ignition. Lastly, to reduce the hydro-instabilities at the fuel-ablator interface, and to lower the adiabat of adjacent DT fuel, high energy x rays (specifically, the Au M-band radiation emitted from laser spots) must be precluded from preheating the ablator materials near the fuel by mid- / high-Z dopants in ablator. So, accurate measurements of the peak temperature, the pulse shape and the high energy x-ray amount of the hohlraums radiation fields are of great importance. Currently, there are two independent experimental approaches [1–3] to diagnose the hohlraums radiation field: (1) direct measurement of the radiation flux with broad-band x-ray spectrometer (Dante [4] or SXS [5] and (2) observing the velocity D_s of the shock wave in an Al witness plate driven by hohlraums radiation field, where the radiation temperature is inferred via a scaling relation [2] of T_R with D_s.

What we concerned with in this proceeding is the second method. The x-ray ablation process of mid-Z materials, such as Aluminum and Titanium, is studied numerically with a 1-D radiation hydrodynamic code RDMG [6]. It is found that the ablative shock velocity in Aluminum depends not only on the peak radiation-temperature but also on the pulse shape and the spectrum (specifically, Au M-band fraction). With the postulation of equilibrium radiation sources, a scaling relation of peak radiation temperatures

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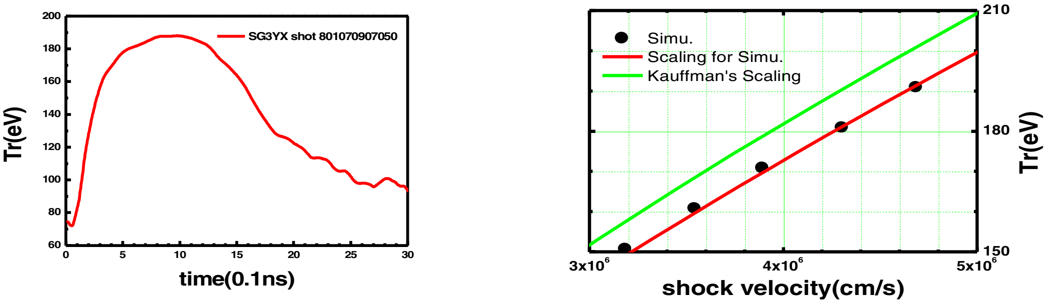

Figure 1. x-ray source of hohlraum driven by 1 ns square laser pulse on SGIII prototype (left) and the scaling relations of T_R with D_s (right).

with Al shock velocities is proposed, being applicable to 1 ns pulse laser-driven hohlraums, and the dependence on the pulse shape being negligible. Further a novel method is proposed, based on our study on the responses of ablative shock waves in Aluminum and Titanium to Au M-band flux, for determining the Au M-band (2-4 keV) fraction of x-ray sources, which provides a complementary means for diagnosing the M-band flux in laser-driven gold hohlraums.

2. EFFECTS OF PULSE SHAPE OF X-RAY SOURCE

For strong shock waves, the velocity D_s scales as $\sim P^{1/2}$, and according to a steady ablation model [7] for low-Z materials, the radiative ablation pressure P scales as $\sim T_R^{3.5}$. So it can be derived that $T_R \sim D_s^{4/7}$. Considering the influence of the equation of state (EOS) and reradiation of Aluminum, the radiative ablation process is no longer stationary, but a similar relation may be expressed as $T_R = \alpha \times D_s^{\beta}$, where the parameters α and β can be determined via numerical simulation and fitting. Kauffman et al. [2] proposed the following scaling relation

$$T_R = 0.0126 \times D_s^{0.63}, \tag{1}$$

and it was believed that α was determined by the EOS and β by the reradiation of Aluminum. Yet that is not the whole story. We simulated the ablation process of Aluminum plates using the x-ray source of the Hohlraums driven by 1 ns square laser pulse on SG III Prototype, as shown in Fig. 1 (left). The simulated shock velocity at a given peak radiation temperature is faster than that derived from formula (1), as shown in the right figure of Fig. 1. Fitting our simulation results can produce a new scaling relation

$$T_R = 0.0092 \times D_s^{0.647}, \tag{2}$$

which is about 10 eV lower than formula (1) at a given shock velocity of $(4–8)\times10^6$ cm/s, as shown with red line in the right figure of Fig. 1. Detailed analysis [8] show that, compared to the x-ray source shown in the left figure of Fig. 1, the prepulse of the PS22 x-ray source on NOVA (Fig. 4 in Ref. [2]) used to derive formula (1) ablates more Aluminum plasmas before the arrival of the main pulse, which absorbs and reemits backward more x-ray flux, therefore little x-ray flux arrives at the ablation front and produces a smaller ablation pressure and a slower shock wave. That means the scaling relation of the peak radiation temperature T_R with the ablation shock velocity D_s in Aluminum plates can be affected, to some extent, by the temporal profile of x-ray sources, *i.e.* there are no universal scaling relations. Note that the scaling relation (2) is only applicable to the hohlraums powered by 1 ns square laser pulse.

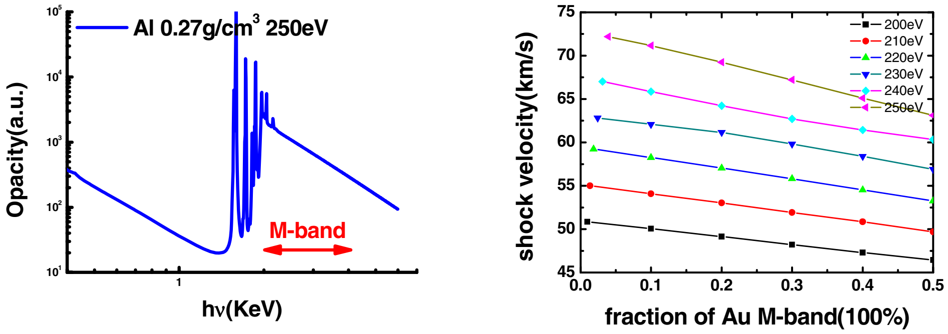

Figure 2. Opacity of Aluminum plasmas (left) and shock velocties vs. M-band fraction (right).

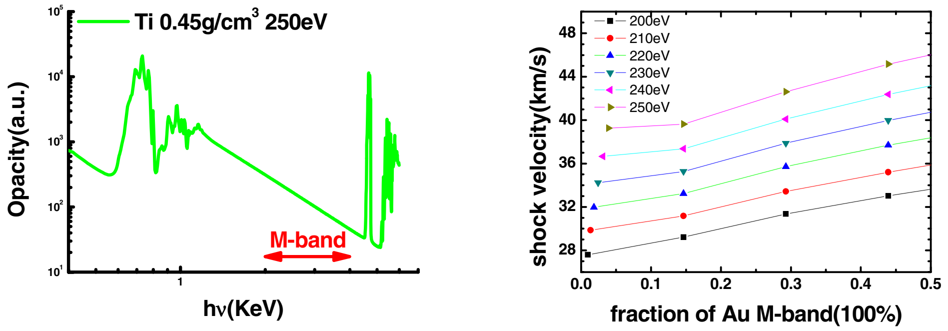

Figure 3. Opacity of Titanium plasmas (left) and shock velocties vs. M-band fraction (right).

3. INFLUENCE OF AU M-BAND FLUX ON SHOCK VELOCITY

Not only the temporal profile, but also the spectrum of x-ray sources can affect the ablation shock velocities in Aluminum plates. As shown in Fig. 2 (left), the opacity of Aluminum plasmas varies with frequency, and is much higher within the Au M-band (2∼4 keV) than within 400 eV∼1 keV. Ascribed to this property, the shock velocity in Aluminum driven by an x-ray source with a higher fraction of Au M-band flux will be slower than that driven by an x-ray source of the same intensity but with a lower fraction of Au M-band flux. We have performed lots of simulations of the x-ray ablation process of Aluminum plates using RDMG, with the peak radiation temperatures varying from 200 eV to 250 eV. By increasing the Au M-band fraction f_M in the x-ray source, the shock velocity decreases monotonically, as shown in Fig. 2 (right).

On the contrary, the Titanium opacity and the response of its ablation shock velocity to the Au M-band fraction of x-ray sources are quite different from those of Aluminum. Fig. 3 (left) shows the opacity of Titanium, the opacity within Au M-band is quite smaller than within 400 eV∼ 1 keV, and the shock velocity increases with the increasing of M-band fraction in x-ray sources. Since the Au M-band fraction can apparently influence the shock velocities in Aluminum and Titanium, they can not be solely used to determine the peak radiation temperatures of high-power-laser driven gold hohlraums, where the Au M-band flux contributes a high enough fraction of x-ray flux. But due to their contrary opacity properties, they can be used jointly to determine the peak radiation temperature and M-band fraction simultaneously, which will be detailed in next section.

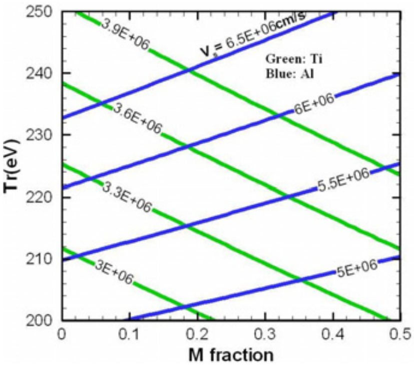

Figure 4. Shock velocity contours in T_R-f_M plane for Aluminum (blue line) and Titanium (green line).

4. AL/TI SHOCKWAVES TO DETERMINE F$_M$ AND T $_R$ SIMULTANEOUSLY

As has been detailed above, for x-ray sources with a higher fraction of Au M-band fraction, both the temporal profile and the Au M-band fraction can apparently affect the shock velocities of Aluminum and Titanium. The scaling relations of T_R with D_s and f_M can be expressed with the following formula $T_R = \alpha \times D_s^{\beta}$, where $\alpha = a \times b^{f_M}$ and $\beta = c + d \times f_M$. By fitting our simulation results shown in Fig. 2 and Fig. 3, we can obtain that $\alpha = 0.01379 \times 0.0508^{f_M}$, $\beta = 0.6205 + 0.2012 f_M$ for Al and $\alpha = 0.01267 \times 0.2671^{f_M}$, $\beta = 0.6520 + 0.07156 f_M$ for Ti. If the shock velocities of Al and of Ti can be obtained in one shot, we can draw out the velocity contours of the two materials in a T_R-f_M plane. The cross point tells us, simultaneously, the peak radiation temperature and Au M-band fraction of the laser-driven gold hohlraums. More details can be found in Ref. [9].

5. SUMMARY

The scaling relation of T_R with Al shock velocity depends on the temporal profile of x-ray source. Or, there are no universal scaling relations. For the cases where the M-band fraction in x-ray sources is higher enough, the velocities of Al and Ti ablation shocks depend on both the total incident flux and the M-band fraction of it. A new method is proposed to diagnose the peak radiation temperature and M-band fraction simultaneously.

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