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Hugoniot measurements in copper up to 1.7 TPa using directly laser-driven shocks

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Hugoniot measurements with impedance match method were performed on copper in the pressure range of 0.5-1.7 TPa using directly laser-driven shocks. The data of these measurements exhibited good accuracy and were in good agreement with previous reported Hugoniot measurements from other methods. Using the beam smoothing technology of lens-array, the region of shock planarity was about 650~750 μm. Optical streak camera monitored emission while shock breakout from the base and steps surface and shock velocities were calculated from the transit times across the known-height steps.

Experimental investigations of the EOS of materials at high pressures (above 1 TPa) are very important in astrophysics, inertial confinement fusion (ICF) research, material sciences, and other related fields. As we all know, the materials' EOS data at pressures low than 0.5 TPa can be accurately measured in such gas-guns, chemical explosives, etc., conventional shock-compressed experiments.[1] At the extremely high pressures (tens of TPa), the EOS data of materials can be calculated through T-F models[2] with highly accuracy. But at the mid-range pressures, materials can be a strongly coupled, partially ionized fluid that is extremely difficult to model, needing experimental data to support at this range pressures. In the past, EOS measurements in the several TPa domain could be performed only by nuclear explosions, which have been exhibited now, and only a few EOS data were available. [3] Fortunately, high pressure (above 1 TPa) now can be generated in laboratory by pulsed lasers (direct [4] or indirect laser drive [5]), some materials' Hugoniot data have been measured in the laser-driven shock experiments,[6] only a few data had good accuracy.[7] But highly accuracy of shock velocity is necessary to compare with data from chemical-explosive and nuclear underground test experiments and the theoretical EOS's based on, or supported by, these data.

So, it is our aim that shock velocity measured accuracy in laser experiments reach to the level of chemical explosive or gas-gun conventional experiments.

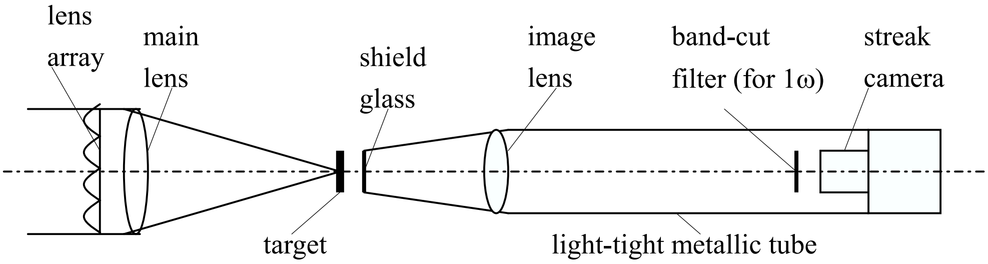

FIG.1. Schematic configuration of the experimental setup for EOS measurements.

In this paper, we present our EOS experiments performed at SG-Ⅱ laser facility. A schematic view of the experimental configuration is shown in Fig.1. One beam of the SG-Ⅱ laser (λ=0.53 μm, 2ω) was focused onto the target, the beam had a 1 ns temporally near-trapezoid profile with a rise and fall time of 300 ps. Optical streak camera was used to monitor self-emission while shock breakout from the target rear surface. And a light-tight metallic tube was used to protect the diagnostics light path. Target thicknesses were measured by α-step 500 Surface Profiler.

Flatness of the shock fronts, constant velocity and low preheating of the materials ahead of the shock are essential to obtain accurate measurements of EOS. In order to obtain spatial planar and uniform shock front, lens array optical smoothing technique was applied.[8] The flatness of the shock front was verified in the experiments with planar Al targets with 20 to 30 μm thickness. A typical streak camera recorded image of the Al planar target self-emission while shock breakout from the rear surface is shown in Fig.2. The central flat region of the shock wave was estimated as over 700 μm diameter, which was wide enough for EOS experiments, and which was convenient for target fabrication.

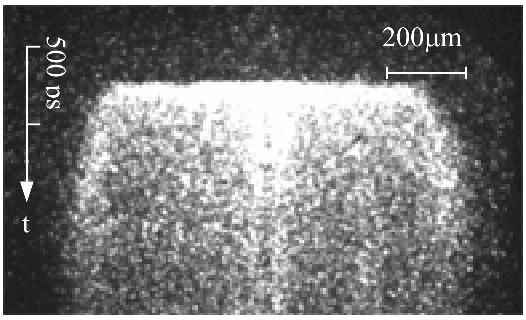

FIG.2. A typical streak camera recorded image of the Al planar target self-emission.

The shock stability can be confirmed with a wedged target.[6] The experimental configure is shown in Figure 3(a), and Figure 3(b) is a streak camera recorded image of the rear self-emission from a wedged target, which shows shock breakout times proportional to wedge thickness. From this image we can see that the shock undergo three-sequence regions in the target, first is an increasing region, then is a relatively stable region, and end is an attenuating region. The experimental results agreed with the numerical simulation results very well, see in FIG. 3(c). In our EOS experiments, the typical targets' thickness region was 20-30 μm, which was within the fairly stable region and to ensure precise EOS measurement.

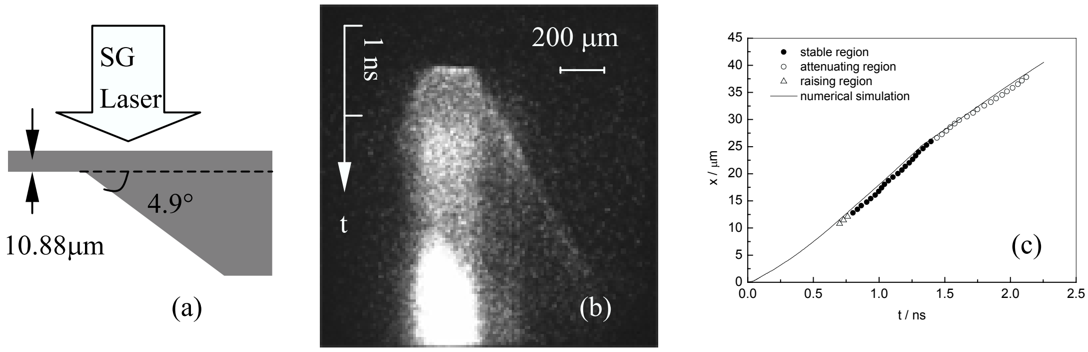

FIG.3. (a) The structure of the wedged target. (b) Typical image of the self-emission from the wedged Al target rear surface recorded by streak camera. (c) Experimental result compared with numerical simulation result (black solid line).

Copper (Cu) Hugoniot points were be measured by using the impedance matching method (IMM).[9] We used aluminum (Al) as the standard material and copper as a tested material because of ease of target fabrication and the adequate existing Hugoniot data to compare our results with. The streak image shows a very good flatness in breakout times. Once the shock velocities of Al and Cu had been measured, a Cu Hugoniot point could be determined using the IMM principle. In our IMM experiments, the shock pressure were up to 1.0 TPa in Al and 1.7 TPa in Cu, respectively. The present experiment shows errors of 1.0~3.0% in shock velocity, with the largest contribution coming from the errors in streak camera resolution. The impedance match analysis then yields errors of 2~6% in pressures and particle velocities. We compare the pressure–particle velocity principal Hugoniot with other

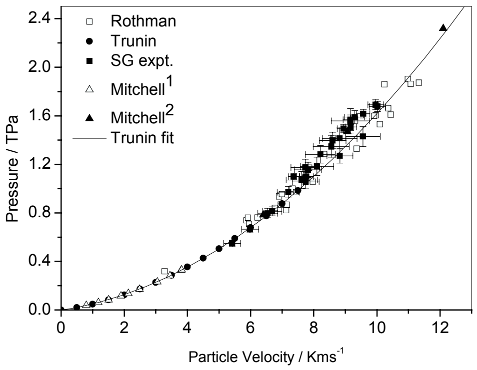

FIG.4. Pressure vs particle velocity for Cu principal Hugoniot. SG experiments (solid square, laser). Rothman (open square, laser) (Ref. 7). Trunin (solid circles,) (Ref. 10), and fit of Trunin's data (solid line). Mitchell^1 (open triangle, gas gun) (Ref. 1). Mitchell^2 (solid triangle, nuclear explosive) (Ref. 3).

experimental data, which shown in FIG. 4. It can be seen that our results are fully consistent with these previous works using different techniques.

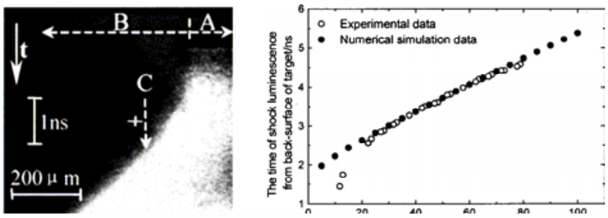

FIG. 5. (a) Photo of shock luminescence from rear surface of flyer-inclined target, (b) The comparation between the experimental results and the numerical simulation's.

Using a special flyer-inclined target, the dynamic characters of a flyer were investigated experimentally for the first time.[11] The results shows that the flyer has a steady flying velocity of ~30.3 km/s after flying a distance longer than ~30 μm at irradiance of ~0.83×10^{14} W/cm^2. And the experimental results agrees with the numerical simulation very well, shown in FIG.5.

In conclusion, we have presented EOS researches on SG facility. The shock fronts are quite flat and the shocks have long stable range under our experimental conditions. Reliable Hugoniot data of Cu are obtained in a pressure range of (0.5-1.7) TPa, and are fully consistent with these previous works using different techniques.

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