Temperature Measurements of Laser Heated Cavities

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Abstract: The heating of small cavities with pulsed laser or particle beams makes it possible to study phenomena of high-temperature radiation hydrodynamics and the state of matter at very high pressure, i.e. the physics of stars, for the first time in the laboratory [1].

In this note we report preliminary results of temperature measurements made with gold cavities irradiated by 60-100 J/300 ps pulses from the iodine laser Asterix III at wavelengths of \( \lambda = 1.3 \mu m \) (1 eV) and \( \lambda = 0.44 \mu m \) (3 eV). Cavities with 250-300 \( \mu m \) diam. and 1000 \( \mu m \) diam. were used. A 280 \( \mu m \) diam. cavity (with entrance hole for the laser beam and two diagnostic holes) as well as the geometry of irradiation and observation are shown in the insets of Figure 1. The fraction of laser radiation rejected by the cavity target was monitored with an integrating box fitted into the experimental chamber. Absolute measurements of the x-ray radiation emanating through the diagnostic holes were made with a transmission grating spectrometer (TGS) and with two x-ray sensitive photo diodes (XRD). The TGS employed a 1000 lines/mm free-standing gold transmission grating [2] integrated into a 25 \( \mu m \) diam. pinhole, thus providing spectral and spatial resolution. The spectra were registered on Kodak 101-01 film, digitized on a 2 D densitometer and computer un-folded using the film calibration data obtained recently in our laboratory [3]. The two XRDs (copper cathode, rise-time \( \sim 340 \) ps) received either unfiltered (XRD 1, open) or filtered radiation (XRD 2, 2 \( \mu m \) Makrofol filter). A brightness temperature was derived from both measurements. The radiation time was measured independently with an x-ray streak camera to be 550 ps. The measured temperatures are shown in Fig. 1 versus the absorbed flux \( S_L = a/4 \tau_L \), i.e. the absorbed laser power \( E_{abs}/\tau_L \) averaged over the inner surface \( A \) of the cavity (\( \tau_L \) the laser

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Fig. 1. Laser heating of gold cavities of 1 mm diameter (\(S_L\) below \(10^{13}\) W cm\(^{-2}\)) and 250–300 \(\mu\)m diameter (\(S_L\) above \(10^{13}\) W cm\(^{-2}\)). Full and open experimental points correspond to measurements at \(\lambda = 0.44\ \mu\)m and \(\lambda = 1.3\ \mu\)m, respectively.

the first mechanism has not yet been investigated quantitatively, the existence of a rapidly expanding plasma is inferred from the reduced total absorption of \(\sim 0.3\) measured with the small cavities (> 0.8 for the large cavities), which is attributed to rapid plasma filling of the cavity.

The perfect coupling (\(\approx 1\)) observed with large cavities (the large cavities are represented by the experimental points below \(10^{13}\) W cm\(^{-2}\)) may be somewhat deceptive; we tend to attribute it to non-uniform energy deposition in the cavity. In our experiments the number of thermal reemissions of the absorbed energy (see [1])

\[
N_B = \frac{\sigma T_B^4}{S_L},
\]

i.e. the measured circulating flux of thermal radiation divided by the absorbed laser flux is only 0.1–0.5. Thus the "primary" flux rather than the thermal circulating flux will determine the heating of a given wall element. It seems likely that in the large cavities irradiated at \(\omega\) the observed wall element was preferentially heated by laser light reflected geometrically from the laser spot on the rear wall of the cavity, and that the intensity in this region was higher than the average intensity \(S_L\).

In conclusion, the heating experiments with small diameter gold cavities have shown that brightness temperatures of about \(10^6\) K can be reached with laser energies below 100 J. These results are consistent with predictions of a model that considers diffusion of radiation into the wall as the main energy loss mechanism. Effects of plasma filling and entrance hole closure should be avoidable with cavities which are larger than the smallest ones used here. Heating larger cavities to even higher temperatures with the benefit of generating uniform conditions in the cavity would require a more powerful laser.

Finally we would like to mention that cavity heating experiments similar in scope were recently done at ILE Osaka [6].

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