*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-2.018 (2002)*

Reflectivity and Energy Balance in Pulsed-Laser Deposition Experiments from Mono-and Bi-atomic Targets

T. Mueller[1], B. K. Sinha[2] and K. P. Rohr[1]

[1] Fachbereich Physik, Universitat Kaiserslautern,
D-67663 Kaiserslautern, Germany

[2] Laser & Plasma Technology Division,
Bhabha Atomic Research Centre, Mumbai – 400 085.

Abstract : *Reflectivity and complete energy balance from the planar targets of aluminum, copper, nickel and molybdenum have been measured using a Nd:glass laser (λ = 1060nm, τ = 5ns) in the low intensity regime of laser plasma interaction as a function of focal spot size. The magnitude of partition of total incident laser energy into different channels is observed to decrease as the focal spot size increases. It is further observed that the magnitude of partition of the incident energy into these channels, in general, decreases as the atomic number increases for any given focal spot size, although, the reflectivity component of the partitioned energy increases with focal spot size for any given element. The reflectivities of copper and tungsten and their alloy were separately measured. The reflectivity from the alloy-plasma was reduced by a factor of 6 compared to either element separately. This observation confirms the recent theory that in the multi-ion plasma the ion acoustic waves are additionally damped due to additional Joule, thermal diffusion and viscous terms in the modified ion-fluid theory of the ion acoustic waves in a multi-ion species plasma.*

Investigations of partial energy balance and reflectivity have been reported by various workers [1-13], primarily in the non-linear regime of laser plasma interaction from monoatomic targets. Earlier workers [8,9] reported the measurements of reflectivity from plasmas produced from planar monoatomic targets in the laser intensity regime of 10^{11} to 5 x 10^{13} W/cm^2. The laser intensity was varied either by keeping the focal spot diameter constant and varying the energy or by keeping the laser energy constant and varying the focal spot diameter. They observed the variation of total reflectivity in the range of 5 to 35 percent and noted that the light absorption did not depend on the laser intensity alone but was also affected by the irradiated focal spot dia- meter. In the present work we present a complete measurement of the total energy balance from laser produced aluminum, copper, nickel and molybdenum plasma hitherto unreported in any intensity regime of laser plasma interaction. We have measured the fraction of laser energy going into different channels with an accuracy varying from ± 10 to ± 15% and presented a justification for ignoring the energy going into other channels like heat conduction, collision, emission and magnetic field. Moreover, we have measured the reflectivities of tungsten and copper and their alloy W_{34} Cu_{66} within an error margin of 15%. Measurements confirm the decrease in reflectivity from the alloy based on the theory of the damping of ion acoustic waves [10,14,15].

The laser beam (λ=1060nm, τ=5ns) was incident at an angle of 45^o with respect to the target surface. The laser spot size was varied between 0.61mm^2 and 8.34mm^2 at a constant laser pulse energy of 130mJ by moving the focussing lens up and down from a fixed position. The resulting laser intensity variation, in the range of 3.1 x 10^8 to 4.3 x 10^9

W/cm^2, was suitable for LPD experiments. The particles of the freely expanding plasma were detected in an angular range relative to the target normal, between Φ_{RPA}=50° to 10° for ions and Φ_Q=80° to -15° for the total number of particles, by moving around the analyzers within the plane of incidence. The analyzers were located at a distance of 35cm from the target. The ion-spectra were fully resolved by the time of flight/retarding potential method which made it possible to obtain the absolute number of each ion-species.

In Fig.1(a-d) the relative share of the measured energy going into five different energy channels, for a laser energy of 130mJ, and its dependence on the laser spot size (B) have been displayed for the target materials Al, Ni, Mo and Ta. These energy channels have a share of the total incident energy varying from 26% (tantalum, B=8.34mm^2) to 64% (aluminum, B=0.61mm^2). All the target materials jointly show that the reflectivity increases with increasing focal spot size (B), by a factor of 3.9 for nickel and 5.7 for molybdenum. For the same variation in B, the kinetic energy of ions varies relatively strongly between by a factor of 2.9 (aluminum) and a factor of 3.1 (tantalum), whereas the residual energies vary relatively weakly between a factor of 1.3 (aluminum) and 1.6 (tantalum).

It is to be noted that for all the samples the reflectivity increases as the focal spot size increases. This is because the plasma front appears more like a smooth, plane mirror to the incident laser light for B=8.34mm^2 than for the focal spot sizes of decreasing dimensions. With the decreasing focal spot size, the curvature of the plasma front increases. As a result, the reflectivity decreases and the incident laser light is better coupled to the plasma [8,9]. A smaller laser-spot size on the target surface produces larger density gradients and the plasma expansion is less of a one-dimensional character, resulting in the availability of smaller interaction length for Brillouin scattering in the under dense plasma, and, hence, the reflectivity decreases. Spot-checks for out-of-plane emission gave negligible results. In general, Fig.1(a-d) show that the magnitude of the total incident energy transferred into these five different channels decreases as the atomic number of the target material increases, within the limits of experimental errors, estimated to be under 10%.

Earlier workers [11-13] have reported a significant role for ion acoustic waves (IAW) with reference to phase conjugate reflectivity of the laser produced plasma. The works of Turner et al [14], Epperlein et al [15] and Bychenkov et al [10] are significant in this connection. Turner et al reported experiments on Nova and presented Brillouin scattering measurements obtained from cylindrical (2.5mm diameter and 2.5mm long) gas filled haulraums which contained 1 atmosphere of neoprene gas. Their data show that while large levels of SBS can be generated under some conditions, the instability is reduced to low levels for conditions in which IAW are considerably damped for multi-ion species, depending on their Z/M ratios. Bychenkov et al [10], in their theoretical formulation, observed that the SBS reflectivity depends strongly on the ion-composition. They reported that the SBS reflectivity from a C_5H_{12} target is approximately 5-10 times lower than that from a C_5D_{12} plasma with the same parameters. They related this obser-vation to the composition-dependent damping of the ion acoustic waves. The major difference between a C_5H_{12} and a C_5D_{12} plasma is the charge-to-mass ratio i.e. Z/M is ½ for C^{6+} and 1 for H^+, while Z/M is ½ for D^+. Therefore, in a C_5H_{12} plasma, the ion acoustic wave exhibits an addi-tional damping related to the friction forces. They attributed the lower scattering from a C_5H_{12} plasma to a higher damping rate of IAW than that which occurs in C_5D_{12}. Epprelein et al [15] calculated the collisional damping of ion acoustic waves for a mixture of light and heavy ions and modified the frequently used single-species average ion model. They considered the effects of a new Joule term, thermal diffusion and viscous damping terms which affect the damping of ion acoustic waves.

In Table I we can observe the reflectivities from tungsten, copper and alloy of W, Cu in the stoichemetric proportion of W_{34} Cu_{66}. For a focal spot size of B=1.74mm^2 the reflectivities from tungsten and copper were measured to be 15.7 ± 3.3% and 14.4 ± 2.9% respectively, that is, they individually showed nearly equal reflectivity. However, the alloy W_{34} Cu_{66} showed a reflectivity of only 2.5 ± 0.4%. In the case of the alloy, which is a mixture of the two elements, reflectivity showed a decrease by a factor of nearly 6. From the works of Bychenkov et al and Epprelein et al we conclude that in the case of $W_{34}C_{66}$ additional damping of ion acoustic waves takes place due to new Joule, thermal diffusion and viscous damping terms which are absent in the case of single species W and Cu plasma. As a result the reflectivity is reduced due to the relatively low magnitude of the ion acoustic waves. Our results for $W_{34}Cu_{66}$ seem to support these models.

Table I

Material	B=0.61mm^2	B=1.44mm^2	B=1.74mm^2	B=4.71mm^2	B=8.34mm^2
Aluminum	2.7 ± 0.6	3.9 ± 0.9	--	8.9 ± 1.4	12.9 ± 4.1
Nickel	6.0 ± 2.2	9.5 ± 2.9	--	20.8 ± 3.6	23.2 ± 3.8
Molybdenum	4.9 ± 1.2	7.2 ± 2.5	--	16.3 ± 3.5	27.8 ± 7.2
Tantalum	2.8 ± 0.7	8.9 ± 0.9	--	11.4 ± 2.5	14.3 ± 4
Tungsten	--	--	15.7 ± 3.3	--	--
Copper	--	--	14.4 ± 2.9	--	--
$W_{34}Cu_{66}$	--	--	2.5 ± 0.4	--	--

[1] F. Floux, J. F. Benard, D. Congnard and A. Saleres : In Laser Interactions and Related Plasma Phenomena, Vol.2, ed. by H. Schwartz and H. Hora (Plenum Press, New York) p.409 (1972).

[2] K. Eidmann and R. Sigel : In Laser Interaction and Related Plasma Phenomena, Vol.3, ed. by H. Schwartz and H. Hora (Plenum Press, New York) p.667 (1973).

[3] P. E. Dyer, D. J. James, S. A. James and M. A. Skipper, Phys. Lett. 48A, 311 (1974).

[4] C. Yamanaka, M. Yakoyama, S. Nakai, T. Sasaki, K. Yoshida, M. Matoba, C. Yamabe, T. Tschudi, T. Yamanaka, J. Mijui, N. Yamaguchi and K. Nishikawa: Plasma Physics and Controlled Nuclear Fusion Research (4th IAEA Conf. Proceedings) p. 421 (1979).

[5] N. G. Basov, A. R. Zaritskii, S. Zakharov, O. N. Krokhin, P. G. Krynkov, Yu. A. Matveets, Yu. V. Senaskii and A. I. Fedmisov, Sov. J. Quantum Electron 2, 439 (1973).

[6] J. N. Olson, E. D. Jones and C. W. Gobeli, J. Appl. Phys. 43, 3991 (1972).

[7] A. Carion, J. Lancelot, J. DeMetz and A. Saleres, Phys. Lett. 45A, 439 (1973).

[8] R. P. Godwin, C. G. M. Van Kessel, J. N. Olson, P. Sachsenmaier, R. Sigel and K. Eidmann, Z. Naturforsch, 32A, 1100 (1977).

[9] H. C. Pant, S. Sharma, T. P. S. Nathan and T. Desai, Appl. Phys. 23, 183 (1980).

[10] V. Yu. Bychenkov, W. Rozmus and V. T. Tikhonchuk, Phys. Rev. E 51, 1400 (1995).

[11] J. Lahiri and B. K. Sinha, Opt. Comm. 113, 407 (1995).

[12] J. Lahiri and B. K. Sinha, Phys. Plasmas 2, 1696 (1995).

[13] G. P. Gupta and B. K. Sinha, Phys. Plasma 3, 3614 (1996).

[14] R. E. Turner, C. A. Back, R. L. Berger, R. L. Kaufmann, D. H. Kalantar, D. E. Klem, B. F. Lasinski, B. J. MacGowan, D. S. Montgomery, L. V. Powers, T. D. Shepard and G. F. Stone, Bull. Am. Phys. Soc. 39, 1662 (1994).

[15] E. M. Epperlein. R. W. Short and A. Simon, Phys. Rev. (E) 49, 2480 (1994).

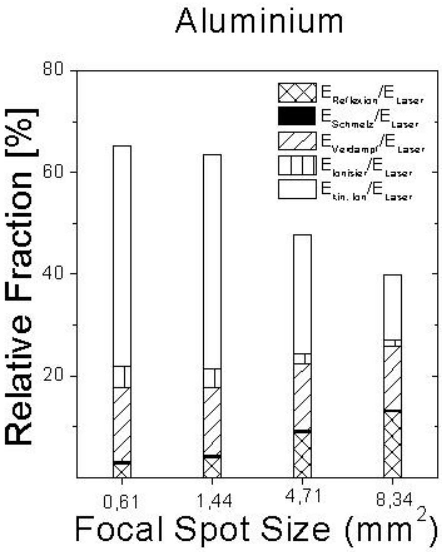

Fig.1(a)

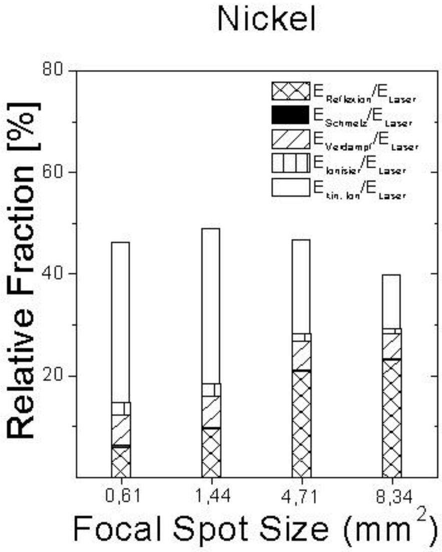

Fig.1(b)

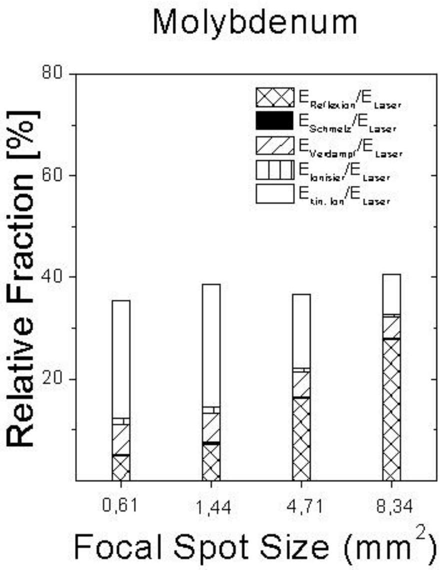

Fig.1(c)

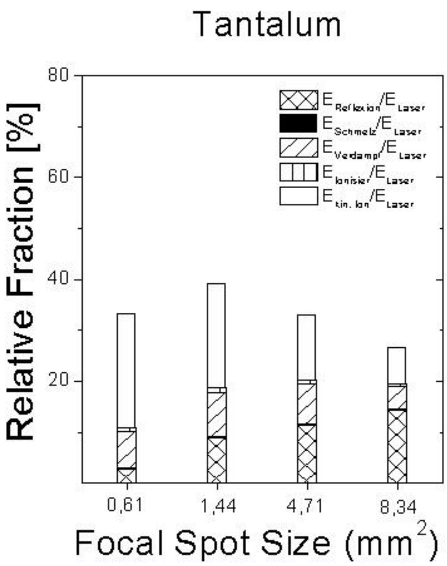

Fig.1(d)