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Energy-transfer and expansion-dynamics of a collisional laser-plasma from planar, atomic and binary targets

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Abstract

Charge resolved average integrated kinetic energy of ions from plasmas produced from, monoatomic targets of copper and tungsten as well as binary targets of copper and tungsten, with two different stoichiometric compositions, have been obtained using 130 mJ – 5 ns Nd:YAG laser pulse, at a focal intensity of about 8 x 10^9 W/cm^2. It is concluded that ion-acceleration due to built-in electrostatic potential is not significant and the kinetic energy spectra are determined by the recombination during the plasma expansion. On the basis of the numerical results obtained from Monte-Carlo simulation, a significant energy-transfer from the lighter to the heavier ions seems reasonable in the case of binary targets.

Introduction

Knowledge of average kinetic energy distribution among different ionization state plays an important role in the theoretical understanding and practical application of laser ablation process. Above all results from compound targets are closely related to many practical applications in the field of material synthesis techniques. Detailed data which include efficiency of energy coupling to the plasma and partition of the laser energy into different channels would allow for a straightforward optimization of e.g. applications like PLD. In this contribution we present for the first time detailed comparative measurements of average kinetic energy of different ionization states from a binary target and its single components.

Experimental set-up

The plasma is created by a Nd-YAG Q-switch pulse (E_L = 130mJ, τ = 5ns and λ = 1.06μm) incident at a fixed angle of - 45° onto flat targets inside a vacuum chamber. The ablation area is about 0.3 mm². The energy spectra of the ions are fully resolved by the time-of-flight/retarding potential method which makes it possible to obtain the absolute number of each ion species. Ions are analyzed in an angular range relative to the target normal between ϕ_{RPA} = 50° to -10° by moving around the detector within the plane of incidence at a distance of 35 cm from the target. The neutral component is deduced from the difference of the total particle signal obtained from the frequency change of a quartz crystal after the plasma has been deposited and the number of ions measured with the retarding potential analyzer. The experiment includes a series of precautions to increase the reliability of the results. Details of the experimental arrangement and the measurement and control procedures are described in foregoing publications [e.g. 1].

Results and discussion

Figure 1 shows time-of-flight spectra of ions from the compound system WCu8020. One observes that for both atoms W and Cu the velocities increase with the charge state.

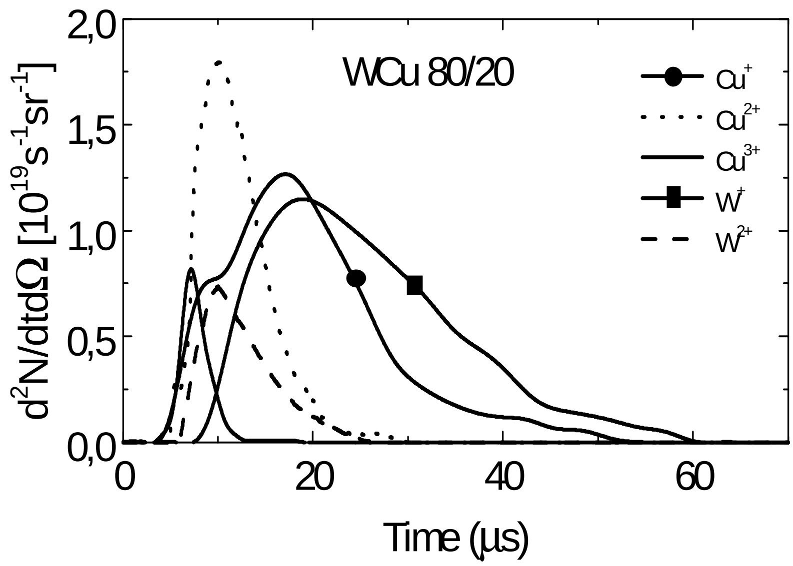

Fig. 1: Time-of-flight spectra of W and Cu ions from the compound system WCu8020.

This finding corresponds to the well known situation in monoatomic plasmas which in the older literature has sometimes been discussed by two main controversial models: the charge selective acceleration model and the recombination model. In the recombination model the initial ion energy determines the charge state at large distances from the target and not conversely as in acceleration model. The slower, higher charged ions have recombined to lower charges due to strong ($\sim T^{-9/2}$) dependence of the three body recombination on temperature and for higher charged ions due to the Z^3 dependence upon the ion charges. In more recent theoretical investigations [2] it could be shown, indeed, that in the case of collision dominated plasmas solely the recombination model is able to explain all findings observed in differential ions measurements away from the focal range [3]. The situation in the present case of a binary plasma the collision frequency is similar to that in corresponding monoatomic plasmas (10^{12}-10^{14}/s). Therefore we assume that the observed velocity distribution have to be interpreted in terms of recombination and ionization processes as well.

In figure 2 we have depicted average kinetic energies of copper and tungsten ions for monoatomic as well as for binary targets, respectively. For monoatomics W and Cu data are for charge states 1 to 4, in the case of the two different compounds of stoichiometric compositions WCu60/40 and WCu80/20, we could resolve three charge states for Cu and two for W, respectively. Angular integration is over the complete half-space.

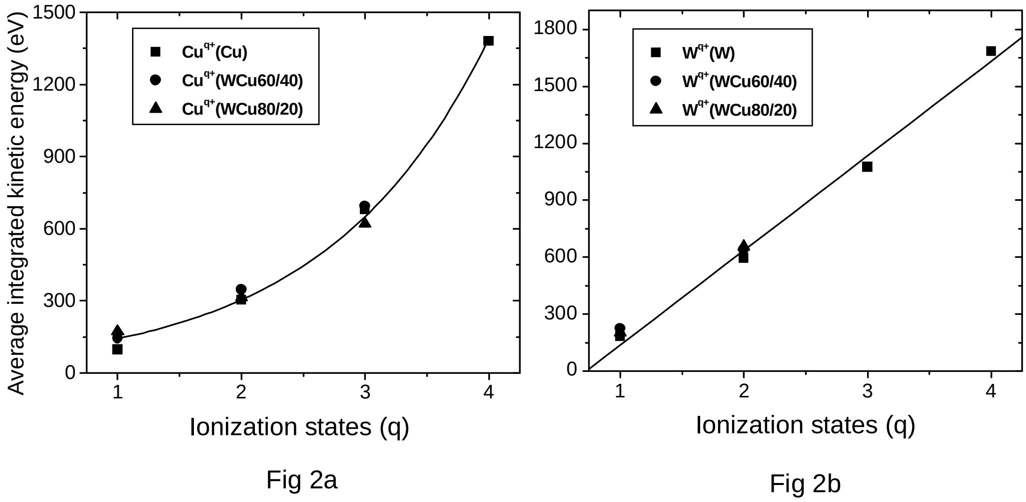

Fig. 2 : Average integrated kinetic energy of copper and tungsten ions from the targets Cu, W, WCu 60/40 and WCu 80/20 as a function of the ionization state.

One observes that with increasing charge states the energies of copper ions increases exponentially. This also holds true for copper ions from the binary targets. If we compare the corresponding ionization states of copper ions from two different binaries, we observe that their energies are essentially the same, independent of their mass composition. Similar results can be seen for tungsten ions in figure 2b. Here the increment is rather linear. One further observes that the W ions with higher masses ($m(W)/m(Cu) \approx 3$) have higher energy than the Cu ions of corresponding ionization states. This holds as well for the binary target. Tungsten ions have always higher energies than the copper ions of the same ionization states.

In the case of binary targets, apart from general mass effect it is useful to draw the attention to the works of Urbassek and Sibold [4]. They have considered the pulsed laser desorption of neutral particles from binary targets using Monte-Carlo simulation. They observed that the energy is transferred from the lighter to the heavier particles and that the lighter species is desorbed with a higher velocity than that of the heavier ones, but accelerates the latter and focuses it towards the target-normal. However, the mean-energy of the heavier species is always higher than that of the lighter ones. Though they have performed the simulation for neutral particles, the interaction and energy transfer between two species in a binary target seems appropriate for our situation also, as the plasma contains more than 90% of neutrals.

Conclusion

In compound systems, higher kinetic energies of higher charged ions can be well described by recombination mechanism as in monoatomics.

The results indicate that the energy-transfer among light and heavy particles in a binary target seems appropriate in agreement with Monte-Carlo simulation.

References

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