# PROCESS AND EFFICIENCY OF ULTRAFINE PARTICLES PREPARED BY LASER BEAM①

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**ABSTRACT**

Both the melting and evaporating efficiencies of the preparation process for ultrafine metallic particles by laser beam have been calculated using a physical model founded on an investigation of the energy interaction between a laser beam and the surfaces of Al, Cu and Mo samples. It shows that the above efficiencies of Al rank first, and those of Mo rank last. However those of Al and Mo increase faster than those of Cu with increasing laser beam pulse intensity.

**Key words:** laser beam irradiation efficiency Al Cu Mo

## 1 INTRODUCTION

Laser beams have been widely used in welding, cutting, heat treatment and alloying for metal surfaces, since 1963. The technology for preparing metallic powders by laser beam, and the newly developed technology for preparing nm-order ultrafine particles of metallic oxides and nitrides by laser beams under oxygen and nitrogen atmospheres in particular, attracted increasing attention from many material researchers[4].

An experiment-based physical model for describing the preparation of ultrafine particles by laser beam has been developed and used to calculate the utilization efficiency of laser beam in this paper.

The experimental methods were the same as those in Ref. [3]. The depth of pit formed by laser irradiation was measured using photomicroscope with a focusing mechanism. The pit diameters were measured from the photos from a scanning Electron Microscope (SEM).

## 2 THE FOUNDATION OF THE PHYSICAL MODEL

The preparation of ultrafine particles prepared by irradiating metal (Al, Cu, Mo) surface with a laser beam can be illustrated as in Fig. 1. The laser beam irradiates on the surface and forms a plasma arc (plasmon)[5], which transfers the energy of the laser beam into heat and melts the local surface. The matter at the centre of the melted material is then evaporated by further irradiation. The gas is dilated intensely, sprayed outward companying with evaporated materials, and then condensed with ultrafine particles of various sizes. The energy of each laser pulse is consumed in heating ($V_H \varepsilon_H$), melting ($V_M \varepsilon_M$), and evaporating ($V_V \varepsilon_V$) the material, among which $V_H$, $V_M$ and $V_V$ represent the volume of material being heated, melted and evaporated respectively by one laser pulse; $\varepsilon_H$, $\varepsilon_M$ and $\varepsilon_V$ are the

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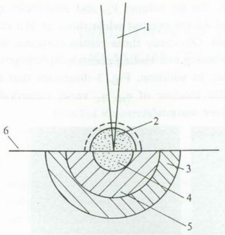



**Fig. 1 Schem of the process during the interaction between laser beam and material surface**

1—laser beam; 2—plasma arc(plasmon); 3—the heated volume; 4—the evaporated volume; 5—the melted volume; 6—the material surface

corresponding energy densities. In addition, a certain amount of energy is consumed in the formation of the plasmon (EP), and some energy is lost in diffraction and reflection of the plasmon (ER). Thus the following energy equtions can be written:

$$E_O = V_V\varepsilon_V + V_M\varepsilon_M + V_H\varepsilon_H + E_P + E_R \quad (1)$$

where $\varepsilon_M = \rho\ [(T_M - T_R)C_S + Q_S]$ ;

$\varepsilon_V = \rho\ [(T_V - T_M)C_L + Q_V]$ ;

$\rho$—material density;

$T_R$—room temperature;

$T_M$—melting point;

$T_V$—boiling point;

$C_S$—heat capacity of material in solid state;

$C_L$—heat capacity of material in liquid state;

$Q_S$—melting heat;

$Q_V$—evaporating heat;

$E_O$—energy per pulse of laser beam.

Among others, $V_V\varepsilon_V$ and $V_M\varepsilon_M$ are useful energy terems.

## 3 THE CALCULATION OF THE UTILIZATION EFFICIENCY

It is necessary to determine the volume ($V_O$) of the pit formed by the irradiation from one laser pulse (Fig. 1) and calculate the melting energy ($V_O\varepsilon_M$) and the evaporating energy ($V_O\varepsilon_V$) to determin the overall utilization efficiency. Here $V_O$ is used to replace $V_V$ and $V_M$ because they are very difficult to measure.

The calculated values of $V_O\varepsilon_M$ and $V_O\varepsilon_V$ of Al, Cu, Mo are listed in Table 1, from which the melting efficiency $\eta_M$ and evaporating efficienccy $\eta_V$ can be definited as

$$\eta_M = V_O\varepsilon_M / E_O \quad (2)$$

$$\eta_V = V_O\varepsilon_V / E_O \quad (3)$$

the overall utilization efficiency is actually between $\eta_M$ and $\eta_V$.

**Table 1 Pit volume $V_O$, melting energy $V_O\varepsilon_M$, evaporating energy $V_O\varepsilon_V$ and corresponding efficiencies $\eta_M$ for melting and $\eta_V$ of evaporating at different pulse intensities $D_P$**

| material | $D_P$ / $10^3\times$ kW · mm$^{-2}$ | $V_O$ / $10^{-6}$mm$^3$ | $V_O\varepsilon_M$ / mJ | $\eta_M$ / % | $V_O\varepsilon_V$ / mJ | $\eta_V$ / % |
|---|---|---|---|---|---|---|
| Al | 0.86 | 5.00 | 0.014 | 2.3 | 0.180 | 30 |
| | 1.43 | 17.0 | 0.046 | 4.6 | 0.630 | 63 |
| | 1.98 | 26.0 | 0.068 | 4.9 | 0.950 | 68 |
| | 2.50 | 40.0 | 0.109 | 6.2 | 1.480 | 84 |
| Cu | 0.86 | 1.42 | 0.009 | 1.5 | 0.078 | 13 |
| | 1.43 | 3.80 | 0.021 | 2.1 | 0.021 | 21 |
| | 1.98 | 7.10 | 0.039 | 2.8 | 0.380 | 27 |
| | 2.50 | 10.9 | 0.060 | 3.4 | 0.600 | 34 |
| Mo | 0.86 | 0.30 | 0.003 | 0.5 | 0.030 | 5.0 |
| | 1.43 | 1.20 | 0.012 | 1.2 | 0.090 | 9.0 |
| | 1.98 | 3.00 | 0.029 | 2.1 | 0.230 | 17 |
| | 2.50 | 6.90 | 0.069 | 3.9 | 0.510 | 29 |

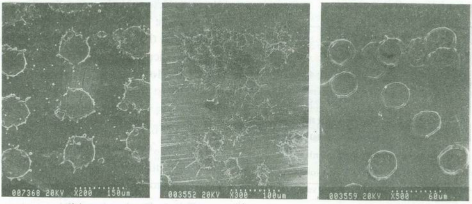
Table 1 indicates that, the values of $\eta_M$ and $\eta_V$ for Al, Cu, Mo are 2.1%~4.9% and 17%~68% respectively when the energy contained in one laser pulse is $E$= 1.4 mJ ($\overline{D}_P$= 1.98 kW / mm$^2$). Pit volume ($V_O$) can be calculated as

$$V_O = [\pi h(3d^2 / 4 + h^2)] / 6 \quad (4)$$

where $h$—pit depth;

$d$—maximum pit diameter

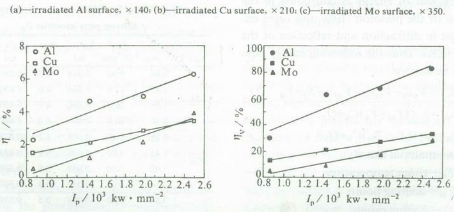
Irradiation intensity $\overline{D}_P$ increases with increasing pulse energy $E_O$. Experimental results for Al, Cu, Mo under different values of $\overline{D}_P$ reveal that both $\eta_M$ and $\eta_V$ increase also with increasing $\overline{D}_P$(see Table 1). When $D_P$=constant, the pit volume $V_O$ and efficiencies $\eta_M$, $\eta_V$ of Al are greatest while thoes of Mo rank lowest. Obviously those results correlate with the melting and boiling points of the materials tested. In addition, Fig. 3 illustrates that the rate of increase of $\eta_M$, $\eta_V$ varies remarkably between materials.




(a) (b) (c)

**Fig. 2 SEM-photos of surfaces irradiated by laser beams at $\overline{D}_P$ = 1.98 × 10³kW / mm²**

(a)—irradiated Al surface, × 140; (b)—irradiated Cu surface, × 210; (c)—irradiated Mo surface, × 350.




(a) (b)

**Fig. 3 Pulse intensity $I_P$ as function of efficiency $\eta_M$ and $\eta_V$ of Al, Cu, Mo**

(a)—$\eta_M$ for melting; (b)—$\eta_V$ for evaporating

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