THE surface temperature, the rate of melting and evaporation of a solid induced by a high power pulsed laser are obtained through a simple mathematical treatment. The surface temperature is found to be more sensitively dependent on the laser power density \( q \) when the surface absorptance is temperature dependent. The rate of melting and evaporation is given by the ratio of the net laser irradiance acquired by the solid to the net heat energy required to melt or to evaporate a mass of unit volume. The melting and evaporation depth is proportional to the laser power density and the laser irradiance time.

1. Introduction

The advantage of the laser as a light source of a very high power density has aroused considerable interest in many processes for industrial applications. The heating effects generated within the solid, when the laser is absorbed, is important in different fields, such as spot welding, scribing and hole drilling [1—5].

The calculation of the temperature distribution after the surface has reached the melting temperature is assumed by Carslaw et al [6] to be difficult. This difficulty is a result of having to solve the problem in two regions of the solid and the liquid and of having to account for the heat of fusion that must be supplied to the moving boundary between the solid and the liquid. Rough estimation for the problem is given by Sparks et al [7].

The present treatment is oriented to study theoretically the melting and evaporation process induced in a solid due to the absorption of a pulsed laser of high power density. The attention is restricted to processes in which no plasma is formed in front of the solid surface.
2. Theory

We assume a square pulse laser with high power density of "q" W/m², incident on the surface of a solid. During the pulse duration time a heating process will at first be induced within the solid. Melting starts and continues along the solid thickness as soon as the surface temperature $T_{os}$ reaches the melting point $T_m$. During the melting process, the liquid temperature is constant at $T_m$, while the temperature rises within the solid. At the end of the melting process, a liquid temperature profile will rise above $T_m$. Evaporation starts when the surface temperature reaches the boiling point $T_b$. Thus the mathematical treatment of the problem is subdivided into the following stages:

a) Heating process $0 \leq T_{os} \leq T_m$; 

b) Solid–liquid transition;

c) Heating of the liquid phase $T_m \leq T_{ol} \leq T_b$; 

d) Liquid–vapour transition.

The diameter of the laser beam is considered to be large compared to the solid thickness. Thus the problem is solved in one dimension [8]. The cooling rate is considered negligible with respect to the incident power density. The thermal properties of the material remain constant during the heating.

3. Heating process

At any instant of time $0 \leq t \leq t_{0m}$ the temperature within the solid is assumed to decrease exponentially in the form:

$$T(x, t) = T_{os}(t) \exp \left( -x \frac{1}{V(t)} \right),$$

Such that:

$$T(x, t) \mid_{x=0} = T_{os}(t),$$

where $t_{0m}$ is the time required for the surface to attain the melting temperature; $T(x, t)$ is the temperature measured relative to the ambient temperature and $V(t)$ is the reciprocal of the temperature penetration skin depth. Equation (1) has to satisfy the following boundary condition:

i) $$-\lambda_s \frac{\partial T(x, t)}{\partial x} \bigg|_{x=0} = q \{ A + A_1 T_{os}(t) \}.$$  

This gives

$$V(t) = \frac{q}{\lambda_s} \frac{A + A_1 T_{os}(t)}{T_{os}(t)},$$

where $\lambda_s$ is the thermal conductivity of the solid phase and $A + A_1 T_{os}(t)$ is the temperature dependent surface absorptance [9, 10].

Thus the temperature profile is given by

$$T(x, t) = T_{os}(t) \exp \left[ -x \frac{q}{\lambda_s} \frac{A + A_1 T_{os}(t)}{T_{os}(t)} \right].$$