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2-D axisymmetric modeling for temperature of GaAs induced by repetitive pulse laser at 1064 nm and 532 nm

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ABSTRACT

In this paper, a two-dimensional(2-D) axisymmetric modeling for temperature of GaAs induced by repetitive pulse laser at 1064 nm and 532 nm is presented. Firstly, mathematical modeling of repetitive pulse laser heating was established based on classical heat conduction theory, and its analytical solutions was obtained by using integral transform method. Then, two types of repetitive pulse lasers are selected, and temperature distributions of GaAs were simulated considering 1064 nm and 532 nm lasers irradiation respectively. Results show that, in the thin layer of GaAs surface vicinity, temperature rises due to absorption of irradiated energy dominates over the conduction energy transport from surface to vicinity. As the depth increases, the absorption decreases, whereas the conduction enhances. The temporal temperature distributions of the 532 nm laser with depths decay more rapidly than that of the 1064 nm laser due to the difference in the absorption coefficient.

1. Introduction

Repetitive pulse laser heating material is widely used in the fields of laser processing or laser damage [1]. When the surface of material is irradiated by a repetitive pulse laser, the energy absorption of material to the incident laser is presented in an intermittent cumulation mode, so it has the energy accumulation effect and can provide sufficient energy deposited onto the material, but the single pulse or continuous wave laser does not have it. Modeling is a common method to reveal the physical mechanism of laser heating including repetitive pulse laser heating [2,3].

Considerable research studies were carried out to explore modeling of repetitive pulse laser irradiating materials. Khenner obtained an analytical solution of the classical heat conduction problem for a solid film with a surface that is simply deformed and irradiated by repetitive laser pulses using the method of separation of variables. In their studies, convective heat losses from the surface and the film-substrate interface are taken into account [4]. Kalyon derived a closed form solution of the dimensionless temperature rise including the cooling cycle for repetitive pulse laser heating using Laplace transformation method. It is found that the magnitude of the maximum surface temperature is influenced by the cooling period of two successive pulses. The rapid response of material to heating pulses is more pronounced in the region just below the surface [2]. Nath presented 1-D analytical solutions for the temperature profiles of heating and cooling cycles in repetitive pulse laser irradiation, and effects of various process parameters such as laser power, beam diameter, scan speed, pulse duration, repetitive frequency and duty cycle on the laser surface hardening were studied [5,6]. Chen introduced the thermal process

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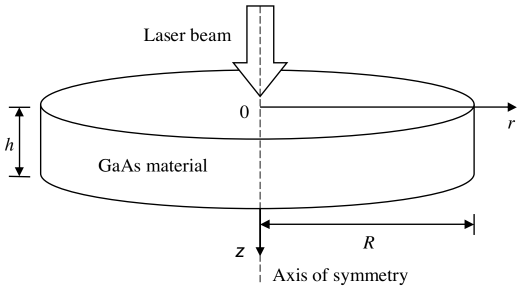

Fig. 1. Schematic diagram of laser irradiation material surface.

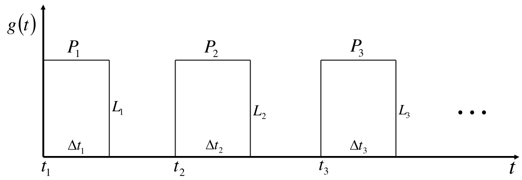

Fig. 2. Schematic diagram of the repetitive pulse.

of 1064 nm repetitive frequency pulse laser irradiated aluminum alloy using finite element method [7]. Chen obtained an analytical solution for 2-D modeling of repetitive long pulsed laser heating material using the method of separation of variables combining with Laplace transform, and temperature distributions for different radial locations, axial locations, duty cycles and repetitive frequencies are given [8].

In the current studies, most of them focused on laser irradiation at single wavelength, but few studies on laser irradiation at different wavelengths. In fact, the absorption and reflection have a great difference for different wavelengths of laser, and this difference leads to the different repetitive pulse laser heating results and characteristics [9].

In this paper, we selected GaAs as example, and its 2-D axisymmetric modeling for temperature of GaAs induced by repetitive pulse laser at 1064 and 532 nm was presented. This paper is organized as follows. In Section 2 we introduce the mathematical modeling and analytical solution of the temperature distributions induced by a repetitive pulse laser heating material. Results of temperature distribution for different repetitive pulses laser are presented in Section 3. Our main conclusions are summarized in Section 4.

2. Mathematical modeling

The classical Fourier heat transfer equation for a laser heating solid material with a 2-D axisymmetric form can be written as [10]:

$$\frac{\partial^2 T(r,z,t)}{\partial r^2} + \frac{1}{r}\frac{\partial T(r,z,t)}{\partial r} + \frac{\partial^2 T(r,z,t)}{\partial z^2} + \frac{Q(r,z,t)}{k} = \frac{1}{\alpha}\frac{\partial T(r,z,t)}{\partial t} \tag{1}$$

where, k is the thermal conductivity of the material, $\alpha = k/\rho c$ is the thermal diffusivity, ρ is the mass density and c is the heat capacity. The temperature T is defined here as a function of(r, z, t), and variable ranges of the positional arguments r, z are $0 < r \le R$,$0 < z \le H$ respectively (as shown in Fig. 1).

In Eq. (1), $Q(r,z,t)$ represents the source function of laser heating. If we assume that the laser intensity distribution is flattened profile, and the energy gain mechanism of the material to the laser is the body absorption, then $Q(r,z,t)$ can be expressed as:

$$Q(r,z,t) = I_0\left(1-r_f\right)\delta\exp\left(-\delta z\right)f(r)g(t) \tag{2}$$

where, I_0 is the laser power density,r_f is the reflection coefficient, δ is absorption coefficient of the material, $f(r)$ is the radial distribution function of laser intensity and its expression is:

$$f(r) = \begin{cases} 1, & r \le R_0 \\ 0, & r > R_0 \end{cases} \tag{3}$$

where,$R_0$is the spot radius of laser. $g(t)$ is time distribution function of repetitive laser intensity and yields:

$$g(t) = L_1P_1(t) + L_2P_2(t) + \cdots + L_{N_p}P_{N_p}(t) \tag{3}$$