

# Analysis of Heat Transfer in the Material during Pulsed Laser-Metal Interaction by Using Kinetic Theory

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**Abstract**—Nowadays technological developments, the use of lasers in production is increasing and plays an important role due to low cost and high accuracy. The heat transfer, over the course of laser-metal interplay, has a great importance in metal forming. In this study, different types of materials were investigated in order to designate the temperature distributions inside material and on the material surface versus the thermodynamic properties of the material used and then the temperature distributions obtained from the analysis were compared each other. In addition, the heat transfer is occurring during the interaction of the laser power of  $1.10^{10}$  W/m<sup>2</sup> and  $5.10^{10}$  W/m<sup>2</sup> with laser power intensity in two main groups using different materials these are steel, nickel, tantalum and titanium, and numerical results are obtained using the finite-difference method. In the first step, a solution is obtained by electron kinetic theory according to the basic heat transfer. In the second step, since heat convection is formed after material has reached the melting point. Using electron kinetic theory model for convection solutions have been obtained. Moreover, the temperature distribution that occurs during the laser metal interaction was studied by variation of the time chart and the material depth. As a result of the study, material's surface at the correct temperature of liquid phase change material and increased depth in the direction perpendicular to the electro-kinetic theory approach is further demonstrated by the decrease in the first manner and then remains constant in exponential phase change temperature. In addition to this the analysis results, the substrate temperature increases, the change in phase in the material becomes smaller and smaller.

**Keywords**— Kinetic Theory, Pulsed Laser-Metal, laser.

## I. INTRODUCTION

A laser is a device electromagnetic stimulated emission of radiation that continues to happen for a while

instantly optical amplification of light emission. The term "laser" with stimulated emission of radiation "has emerged as an acronym for light amplification [1]. In today's developing technology, because of the delicate processing quality of the laser material, laser has many uses such as engineering, industrial processing [2], medicine, scientific research [3], electronic and communication field [4]. The basic principle of laser devices is the output photon energy from the light source by passing it through a medium, of electrons from atoms very and available beams are very different motion in a single direction is to obtain a new beam [5]. The process describing the laser machining necessitate a knowledge of physical properties of the material and the machining ambient, such as heat capacity, thermal diffusivity, gases and pressure in the processing environment [6]. In the laser machining —process, various phenomena that occur when the electromagnetic radiation that comes out on the surface of a material come into the form of scattering, absorption and transmission. The absorption of radiation leads to various effects in materials, such as evaporation, possible plasma formation, molten layer formation, etc., which constitute the pressures of laser material processing techniques [7].

Laser metal interacts with the free electrons in the transmission band to the surface of the photons that hit the surface of the material. As a result, electrons with increasing kinetic energy collide with excited cage molecules at higher energies. The higher vibrational energy of the molecules leads to higher temperatures. These interactions result in phonon-phonon confusion as to provide thermal equilibrium. All of these events give the definition of the heat transfer mechanism [8].

In the literature, there are many various studies that help to distribute the temperature due to laser material interaction in solids and model it using Fourier equation. Koc at al. 1995, investigated the phenomena of heat transfer occurring for the laser processing power of  $1.10^{10}$  W/m<sup>2</sup>

and  $5.10^{10} \text{ W/m}^2$ . At the same time heat conduction and convection were evaluated electron kinetic theory, in addition to this different types of materials analysed in order to determine the temperature distraction [9] Yilbas at al. 2006, analysed and developed the electron kinetic theory formulation for laser ultra-short pulse heating by estimating the comparatively low cage temperatures. Consequently, the developed formula is the analogous with found for improved formulation hyperbolic heating model [6]. Mansoor et al. 2015, The effect on the laser short-pulse temperature was investigated for an aluminium thin film and the energy transfer was calculated using the Boltzmann equation in the film. When they calculate the time-dependent change in equilibrium temperature, the laser pulse intensity in the subsystem continues. However, the equilibrium temperature is different for the electron and lattice subsystems associated with the phonon [10]. Koc et al. 2004, examining the 3-D laser heating model on four different materials (tantalum, iron, titanium, nickel) using the electron kinetic theory approach. For these materials the temperature distribution depends on the time. According to this information the surface temperature of the material is calculated and analysed. As a result of the study, He found the temperature rises up to the point of melting at the material origin and by the reason of to heat transfer by conduction. When heating for these materials, the temperature distribution is reduced in the x direction [11]. Shuja and Yilbas at al. 2013, investigated and simulated laser which is induced melting of coated carbon steel which is kept constant at 7.5 mm and is contained with alumina, boron, tungsten carbide. As a consequence of this, surface temperature raised during the first heating phase of the laser pulse, However the temperature of cooling cycle is precipitous drop [12]. They studied laser metal interactions and focuses on process of development for flexible applications. In addition to this, investigated new approaches with laser metal interaction which is flexible tool for transparent electrodes of metal or synthesis of nanomaterials [1].

## II. MATHEMATICAL MODELLING OF HEAT TRANSFER

Heat transfer analysis is required to examine the temperature distribution during the laser metal interaction. Fourier's equations of conductivity used in heat transfer processes are insufficient during high-power laser-metal interaction. For this reason, there is a need for kinetic theory to study the heat transfer phenomenon during laser-material interaction more accurately [11].

This model can be explained as follows. Electromagnetic radiation applied from the outside is absorbed by free electrons in the transmission line of metals. These electrons, rise in energy, collide with atoms and leave some

of their energy in atoms. Because of this mutual effect, the phonon energies of the atoms increase and cause the phonon energies to soar by forcing them to vibrate around the atoms around them. Some acceptances have been made to facilitate the resolution of the problem [9] [13].

- It is assumed that dissipation of energy due to thermionic emission do not occur.
- Local equilibrium, is presumed at material  $t = 0$  uniform temperature.
- It is accepted that the plasma has a continuous regime, the absence of nucleation and liquid metal flushing, the neglect of the physical change of the laser beam due to the laser optical system and plasma.
- It is supposed that electrons will not be affected by temperature changes of the mean free path [14].

According to kinetic theory, it is necessary to show regard to the free electron model in the quantum field in order to study the conduction of the heat. Electrons that move freely within the surface at a certain speed are called free electrons. Within a volume confined to a particular surface, electrons can change their energy according to the law of dispersion of the fume. The electrons are placed in the molecular cage and have phonon energy according to their vibrational motion [15]. When considering the lattice vibration, the displacement of an atom at the "s" point in the lattice is given by the following expression [9].

$$A_g \cdot e^{i(gs - \omega t)}$$

Where; motion's amplitude is  $A_g$ . At the T temperature, the approximate coupling energy related to this vibration mode is given by the Planck formula [9] [14]. The energy of the lattice vibration contingent upon the phonon number (n) and frequency ( $\omega$ ). If the number of phonons (n) in the T temperature and in the thermal equilibrium is written depending on the Planck distribution;

$$\langle n \rangle = \frac{1}{e^{\hbar\omega/k_B T} - 1}$$

or;

$$\langle n \rangle + \frac{1}{2} = \frac{1}{2} \text{ctnh} \frac{\hbar\omega}{2k_B T}$$

Where;  $\langle \rangle$  : indicates the average of the thermal balance  
 $k_B$  : Boltzman constant.

$\langle n \rangle$  : The average number of photons in thermal equilibrium

$$N_{n+1} / N_n = e^{\hbar\omega/\tau}$$

$$\tau = k_B \cdot T$$

It is written in the form. In this case, the ratio of "nth" to the total number of oscillations in the quantum state;

$$\frac{N_n}{\sum_{s=0}^{\infty} N_s} = \frac{e^{-n\hbar\omega/\tau}}{\sum_{s=0}^{\infty} e^{-s\hbar\omega/\tau}}$$

If the regulation of the mean excitation quantum number of the oscillation is made and  $x = \exp(-\hbar\omega\tau)$ , the following takes the form;

$$\sum_s s \cdot e^s = x \frac{d}{dx} \sum_s x^s = \frac{x}{(1-x)^2}$$

In the classic sense, each oscillation is considered to have " $\langle n \rangle \hbar\omega \approx k_B T$ " energy. The average energy of an oscillation at frequency  $\omega$  is  $\langle h \rangle \hbar\omega$ . The average energy for one atom vibration;

$$\langle E \rangle = h \cdot \omega / [\exp(h \cdot \omega / k_B T) - 1]$$

$C_v$  is Heat capacity of the oscillations which is written in the form.

$$C_v = \left( \frac{dE}{dT} \right)_v = N \cdot k_B \cdot \left( \frac{\hbar \cdot \omega}{\tau} \right)^2 \cdot \frac{e^{\hbar\omega/\tau}}{(e^{\hbar\omega/\tau} - 1)^2}$$

follows.

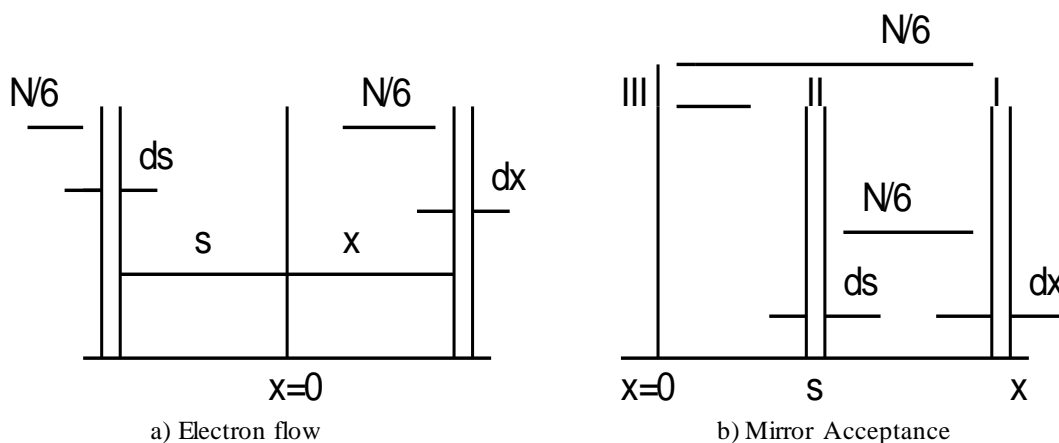


Fig.1: Direction of movement of electrons in relation to energy transport

The probability of total collisions of electrons in the surface section along the medium might be written as follows [8] [13].

$$\int_{-\infty}^{\infty} \exp\left[-\frac{|x-s|}{\lambda}\right] \cdot \frac{ds}{\lambda} \cdot \frac{dx}{\lambda}$$

Where the distance of the "x" atoms and " $\lambda$ " is the electron free path [18]. The lower limit of the integral ( $-\infty$ ) in this equation shows the electrons returning from the surface into the material.

Equation 3N is written for three-dimensional N atom oscillations. Because each atom has three degrees of freedom. N atomic energy in a single direction due to tremble vibrations;

$$E_x = N_x \cdot k_B \cdot T$$

3N equation can be identified as the phonon energy. For the most part, in a homogeneous material, thermal conductivity factor is described by assuming that heat conduction is continuous and the thermal conductivity factor in the single direction is given by the following relation [16] [17].

$$K = \frac{N \cdot \bar{V}_x \cdot k_B \cdot \lambda}{6}$$

In this analysis, mathematical explanations of electrons moving in the material and reflected back from the surface are strong. This situation can be removed from the surface by imaginary mirror placed on the surface. The expected arrival of an electron at x distance without collision is  $\exp(x/\lambda)$  for  $x \ll \lambda$ . The probability of collision at the end of an electron dx interval is  $dx/\lambda$ . According to the figure 1, the possibility of collision last for II, III, I ways of the electrons at dx distance is as

Electron movement is described in figure 1. Electron phonon collision result, the net energy transfer from electrons to phonons is written as follows.

$$\Delta E_{x,t} = \int_{-\infty}^{\infty} \exp\left[-\frac{|x-s|}{\lambda}\right] \cdot \frac{ds}{\lambda} \cdot \frac{dx}{\lambda} \cdot f \cdot (E_{s,t} - E_{x,t})$$

The  $E_{s,t}$  and  $E_{x,t}$  sequences in this form are the energies of electrons and atoms at one point, respectively. The parameter  $f$  is the percentage of energy that the electron gives to the atom during the atomic collision and  $f = 10^{-4}$  is taken [19] [20]. The change in the passage of heat from a homogeneous medium which is a formula of distance  $x$  is written by the following equation.

$$\frac{dI}{dx} = -\delta \cdot I(x)$$

Absorption coefficient is denoted by  $\delta$ . The negative sign here states a decrease in beam intensity thanks to absorption of the positive magnitude [21]. If we integrate this equation;

$$I = I_0 \cdot \exp(-\delta \cdot x)$$

Here;  $I_0$  is the maximum intensity of the incoming laser beam. Because of this reason, using the afore function for the high level intensity of the incoming laser beam, the energy absorbed during  $dt$  time domain  $dx$  might be given as:

$$\Delta E_{x,t} \Big|_{\text{abs}} = I_0 \cdot \delta \cdot e^{-\delta \cdot x} \cdot A \cdot dt \cdot dx$$

The overall energy augment in metal during  $dt$  time at  $dx$  [22];

$$N \cdot A \cdot (E_{x,t+dt} - E_{x,t}) \cdot dx = \Delta E_{x,t} + \Delta E_{x,t} \Big|_{\text{abs}}$$

For this reason, the total energy transfer equation is [23]:

$$N \cdot A \cdot (E_{x,t+dt} - E_{x,t}) \cdot dx = I_0 \cdot \delta \cdot \exp(-\delta \cdot x) \cdot A \cdot dt \cdot dx$$

$$\int_{-\infty}^{\infty} \frac{N \cdot \bar{V}_x}{6 \cdot \lambda^2} \cdot \exp\left(-\frac{|x-s|}{\lambda}\right) \cdot f \cdot (E_{s,t} - E_{x,t}) \cdot ds \cdot A \cdot dt \cdot dx$$

The " $V$ " in this form refers to the electron velocity. If the energy transfer in electron atomic collision is written in terms of electron and atomic temperatures, the formula is arranged as follows [24]:

$$\begin{aligned} \frac{dT(x,t)}{dt} &= \frac{I_0 \cdot \delta}{\rho \cdot C_p} \exp(-\delta \cdot x) - \frac{K \cdot f}{2 \cdot \lambda^2 \cdot \rho \cdot C_p} T(x,t) \\ &+ \frac{K \cdot f}{4 \cdot \lambda^3 \cdot \rho \cdot C_p} \left[ \int_0^{\infty} \exp\left(-\frac{|x+s|}{\lambda}\right) T(s,t) \cdot ds \right. \\ &\left. + \int_0^x \exp\left(-\frac{|x-s|}{\lambda}\right) T(s,t) \cdot ds + \int_x^{\infty} \exp\left(-\frac{|x-s|}{\lambda}\right) T(s,t) \cdot ds \right] \end{aligned}$$

### III. MATHEMATIC MODEL OF HEAT CONVECTION WITH KINETIC THEORY APPROACH

If an atom moving outward from the surface is in the vapour phase, the applied counter forces slow down the atom. If the atom's initial kinetic energy allows escape, the atom is vaporized [25]. The escape will be equal to the latent heat of evaporation. The initial minimum value required for escape  $V_x$  [26]:

$$\frac{1}{2} m \cdot V_x^2 = U_0$$

The velocity distribution of the molecules according to Maxwell law is written as follows:

$$f(V_x) \cdot dV_x = \left[ \frac{m}{2 \cdot \pi \cdot k_B \cdot T} \right]^{1/2} \cdot \exp \left[ \frac{-m \cdot V_x^2}{2 \cdot k_B \cdot T} \right] \cdot dV_x$$

Hence, the number of molecules separating the surface during time  $dt$  is:

$$N \cdot f(V_x) \cdot dV_x \cdot V_x \cdot dt$$

Here  $N$  is the number of molecules on the surface of the unit volume. All these atoms with velocities greater than  $V_{min}$  will be able to move away from the surface.  $G$  is the unit field, and the unit is the number of atoms evaporating is written as follows:

$$G = N \cdot \int_{V_{min}}^{\infty} f(x) \cdot V_x \cdot dV_x$$

$$G = N \cdot \left[ \frac{m}{2 \cdot \pi \cdot k_B \cdot T} \right]^{1/2} \cdot \frac{1}{m} \cdot \int_{\frac{1}{2} m V^2}^{\infty} \exp \left[ \frac{-m \cdot V_x^2}{2 \cdot k_B \cdot T} \right] \cdot \frac{d(m V_x^2)}{2}$$

$$G = N \cdot \left[ \frac{k_B \cdot T}{2 \cdot \pi \cdot m} \right]^{1/2} \cdot \exp \left[ -\frac{U_0}{k_B \cdot T} \right]$$

Where using this formula  $V_0 = \frac{1}{2} \cdot m \cdot V^2$ ,  $V_s$  is velocity of the evaporation of surface and can be written as:

$$\frac{G}{N} = V_s = \left[ \frac{k_B \cdot T}{2 \cdot \pi \cdot m} \right]^{1/2} \cdot \exp \left[ -\frac{U_0}{k_B \cdot T} \right]$$

There is no restriction to prevent molecules from escaping inside the cage. However, there will be a gap in the cage area behind the unreleased molecules. This space is filled by the free energy and other free molecules. The molecules released in the cage immediately form a new equilibrium position. In this way, the molecule is absorbed by a void of metal and can be moved at the lattice level. The average velocity of moving free molecules in the cage is much lower than the thermal velocities  $V_{th}$  [8] [11]. The  $V_f$  rate of the free molecules is approximately;

$$V_f = V_{th} \cdot \exp \left[ -\frac{U}{k_B \cdot T} \right]$$

Here  $U$  is the energy essential to obtain the free molecule. This is important to take into account the energy delivered by free molecules and holes. The number of free molecules in any unit volume ( $N_f$ ) in the  $T$  temperature;

$$N_f = N_0 \cdot \exp \left[ -\frac{U_1}{k_B \cdot T} \right]$$

The amount of the voids contained in a unit volume [11];

$$N_h = N_0 \cdot \exp\left[-\frac{U_2}{k_B \cdot T}\right]$$

Here  $U_2$  is the activation energy. In this case,  $N_0$  is the number of cage places in the unit cell. As a consequence,

$$N_f = N_h$$

But this acceptance is not exactly true.

$$N_{bm} + N_h = N_0..$$

The number of conjugated molecule shown in  $N_{bm}$ . If  $\mu$  is the average free path for a molecule that collides with alternative molecules, there is a possibility of a collision at  $dx$  is [6]:

$$1 - \exp\left[-\frac{dx}{\mu}\right] = \frac{dx}{\mu}$$

The possibility of collision in a space  $P_h$  ;

$$P_h = \frac{N_h}{N_{bm} + N_{fm} + N_h} = \frac{N_h}{N_0 + N_{fm}} = \frac{\exp\left[-\frac{U_2}{k_B \cdot T}\right]}{1 + \exp\left[-\frac{U_1}{k_B \cdot T}\right]}$$

The probability of collision with a free molecule is  $P_m$  ;

$$P_m = \frac{N_{fm}}{N_{bm} + N_{fm} + N_h} = \frac{N_{fm}}{N_0 + N_{fm}} = \frac{\exp\left[-\frac{U_1}{k_B \cdot T}\right]}{1 + \exp\left[-\frac{U_1}{k_B \cdot T}\right]}$$

The probability of collision with a compound molecule is  $P_{bm}$  ;

$$P_{bm} = \frac{1 - \exp\left[-\frac{U_2}{k_B \cdot T}\right]}{1 + \exp\left[-\frac{U_1}{k_B \cdot T}\right]}$$

There are two types of energy carriers that transport molecules. These are free molecules and holes. If the number of free molecules that collide with a space is equal to the number of moving molecules that are separated from the cage by any period at the time  $dt$ . This expression describes the results of the transmission energy from any  $dx$  cross section due to the escaping mobile molecules of the appropriate number for the free molecule hole collision operation [27] In the elastic collision process, the re-captured molecule will transfer some energy. Transfer energy [24] [28] ;

$$U(s) + 3 \cdot k_B \cdot \phi(s, t)$$

Here;  $\phi(s, t)$  is the lattice temperature in the  $s$  position at time  $t$ . The amount of energy that escaped molecules will take with it

$$U(x) + 3 \cdot k_B \cdot \phi(x, t)$$

The energy balance in  $dx$  results amount of energy.

$$U(s) - U(x) + 3 \cdot k_B \cdot [\phi(s, t) - \phi(x, t)]$$

Where  $U(s)$  is the activation energy in the free position of the molecule  $s$  and is usually a function of the temperature. But

since the surface is surrounded by molecules with a small amount, there is a decrease in the surface  $V_0$ . The number of free molecules separated from  $ds$  to  $dx$  in the time  $dt$  after a collision, where the molecules held in the eye are transferred from the energy  $ds$  section to the  $dx$  section;

$$N_{sx} \cdot A \cdot \bar{U}_{sx} \cdot dt \cdot \frac{ds}{\mu}$$

Here;  $U_{sx}$  is the relative velocity of the free molecules from  $s$  to  $x$ . The probability of collision of these molecules first in the  $dx$  section;

$$N_{sx} \cdot A \cdot \bar{U}_{sx} \cdot dt \cdot \frac{ds}{\mu} \cdot \frac{dx}{\mu} \cdot \exp\left(-\frac{|x-s|}{\mu}\right)$$

The number of collisions with the free molecules is:

$$N_{sx} \cdot A \cdot \bar{U}_{sx} \cdot dt \cdot \frac{ds}{\mu} \cdot \frac{dx}{\mu} \cdot \exp\left(-\frac{|x-s|}{\mu}\right) \cdot P_{fm}$$

The number of the collisions with escaping molecules is [11]:

$$N_{sx} \cdot A \cdot \bar{U}_{sx} \cdot dt \cdot \frac{ds}{\mu} \cdot \frac{dx}{\mu} \cdot \exp\left(-\frac{|x-s|}{\mu}\right) \cdot P_{bm}$$

The number of collision with the holes is:

$$N_{sx} \cdot A \cdot \bar{U}_{sx} \cdot dt \cdot \frac{ds}{\mu} \cdot \frac{dx}{\mu} \cdot \exp\left(-\frac{|x-s|}{\mu}\right) \cdot P_h$$

The amount of energy that the molecule transfers during the collision with a vacancy is;

$$U(s) - U(x) + 3 \cdot k_B \cdot [\phi(s, t) - \phi(x, t)]$$

The amount of the energy transferred by the molecule during the collision with a bound molecule is:

$$\frac{1}{2} \cdot g \cdot k_B \cdot [\phi(s, t) - \phi(x, t)]$$

Herewith, the energy which is transferred to the cross section  $dx$  from all the fields in  $ds$  is:

$$\frac{\Delta E}{A \cdot dx \cdot dt} = \int_{-\infty}^{\infty} \frac{N_{sx}}{2 \cdot \mu^2} \cdot \bar{U}_{sx} \cdot h \cdot k_B \cdot P_{fm} \cdot \exp\left(-\frac{|x-s|}{\mu}\right) [\phi(s, t) - \phi(x, t)] ds$$

$$\int_{-\infty}^{\infty} \frac{N_{sx}}{2 \cdot \mu^2} \cdot \bar{U}_{sx} \cdot g \cdot k_B \cdot P_{bm} \cdot \exp\left(-\frac{|x-s|}{\mu}\right) [\phi(s, t) - \phi(x, t)] ds$$

$$\int_{-\infty}^{\infty} \frac{N_{sx}}{\mu^2} \cdot \bar{U}_{sx} \cdot P_h \cdot \exp\left(-\frac{|x-s|}{\mu}\right) [U(s) - U(x) + 3 \cdot k_B \cdot [\phi(s, t) - \phi(x, t)]] ds$$

Thus, taking into account the transmission equation involving convection effects, the transmission and convection equation for the kinetic theory that gives the temperature distribution is written as follows [8] [29]

$$\frac{dT(x, t)}{dt} = \frac{l_0 \cdot \delta}{\rho \cdot Cp \exp(-\delta \cdot x)} - \frac{K \cdot f}{2 \cdot \lambda^2 \cdot \rho \cdot Cp} T(x, t)$$

$$+ \frac{K \cdot f}{4 \cdot \lambda^3 \cdot \rho \cdot Cp} \left[ \int_0^{\infty} \exp\left(-\frac{|x+s|}{\lambda}\right) T(s, t) \cdot ds \right]$$

$$\begin{aligned}
 & \left[ \int_0^x \exp\left(-\frac{|x-s|}{\lambda}\right) T(s, t) \, ds + \int_x^\infty \exp\left(-\frac{|x-s|}{\lambda}\right) T(s, t) \, ds \right] \\
 & - \frac{P_{fm} \cdot h \cdot K^m}{2 \cdot \mu^2 \cdot \rho \cdot C_p} \cdot T(x, t) + \frac{P_{fm} \cdot h \cdot K^m}{4 \cdot \mu^3 \cdot \rho \cdot C_p} \cdot \left[ \int_0^\infty \exp\left(-\frac{|x+s|}{\mu}\right) T(s, t) \, ds \right. \\
 & \left. + \int_0^x \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds + \int_x^\infty \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds \right] \\
 & - \frac{P_{bm} \cdot g \cdot K^m}{2 \cdot \mu^2 \cdot \rho \cdot C_p} \cdot T(x, t) + \frac{P_{bm} \cdot g \cdot K^m}{4 \cdot \mu^3 \cdot \rho \cdot C_p} \cdot \left[ \int_0^\infty \exp\left(-\frac{|x+s|}{\mu}\right) T(s, t) \, ds \right. \\
 & \left. + \int_0^x \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds + \int_x^\infty \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds \right] \\
 & - \frac{P_h \cdot K^m}{2 \cdot \mu^2 \cdot \rho \cdot C_p} \cdot T(x, t) + \frac{P_h \cdot K^m}{4 \cdot \mu^3 \cdot \rho \cdot C_p} \cdot \left[ \int_0^\infty \exp\left(-\frac{|x+s|}{\mu}\right) T(s, t) \, ds \right. \\
 & \left. + \int_0^x \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds + \int_x^\infty \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds \right] \\
 & - \frac{3}{2} \cdot \frac{P_h \cdot K^m}{\mu^2 \cdot \rho \cdot C_p} \cdot T(x, t) + \frac{3}{4} \cdot \frac{P_h \cdot K^m}{\mu^3 \cdot \rho \cdot C_p} \cdot \left[ \int_0^\infty \exp\left(-\frac{|x+s|}{\mu}\right) T(s, t) \, ds \right. \\
 & \left. + \int_0^x \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds + \int_x^\infty \exp\left(-\frac{|x-s|}{\mu}\right) T(s, t) \, ds \right]
 \end{aligned}$$

### Mathematical Modelling of Pulse Heating

The output of the beam from the solid lasers peaks in a few millimetres. The series of these peaks rise and eventually result in a fall. In the pulsed heating process,  $\beta$  and  $\zeta$  are chosen appropriately. These two exponential functional analytical equations are used and parameters give rise time.  $I_1$  is the maximum amplitude determined.

$$I_0 = I_1 \cdot [\exp(-\beta t) - \exp(-\zeta t)]$$

In order to see the effect of the impulse in the temperature distributions, the impulse  $N$  is modified to remain equal to the total power density and is shown in Figure 2.



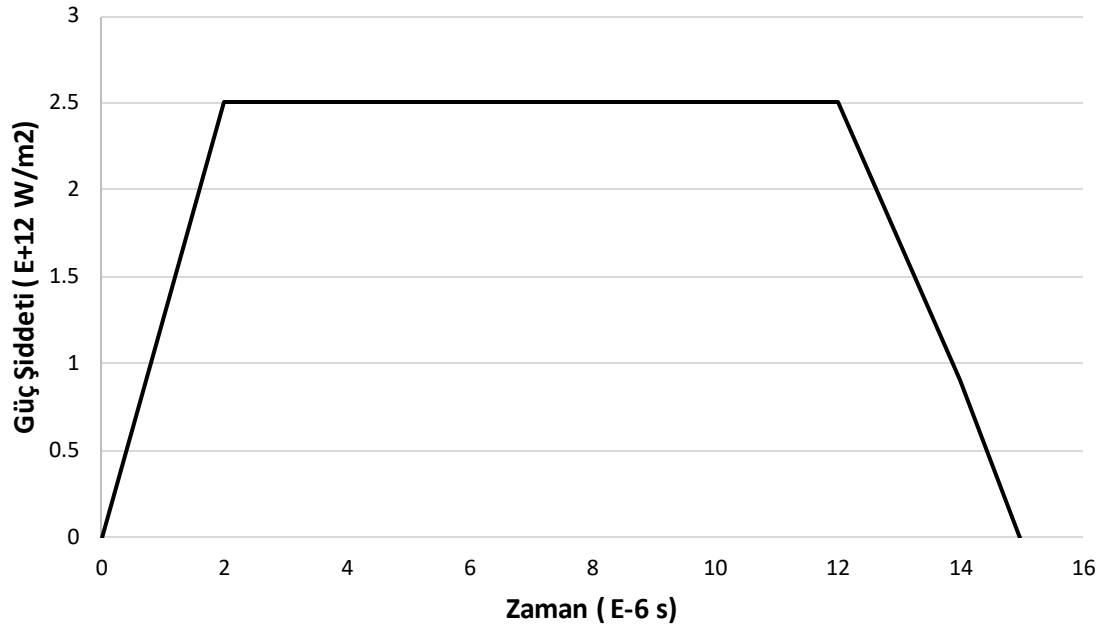


Fig.2: The change in power density of the pulsed laser over time.

**Pulse Heating Analysed and Numerical Solution**

During the laser-material interaction, the distribution of temperature in the material was analysed in one dimension depending on the time. In this study, the analysis of the temperature distributions during the interaction of the laser power of  $1.10^{10}$  W/m<sup>2</sup> and  $5.10^{10}$  W/m<sup>2</sup> with the laser power intensity of Steel, Nickel, Tantalum and Titanium materials was made according to kinetic theory.

The temperature variations at the material surface during the interaction of steel, nickel tantalum and titanium materials, respectively, with laser intensities of power densities of  $1.10^{10}$  W/m<sup>2</sup> and  $5.10^{10}$  W/m<sup>2</sup>, found according to the electro kinetic theory approach which is given in Figures 3 and 4.

**Times of melting temperature of materials;**

	<u>1.10<sup>10</sup> W/m<sup>2</sup> Power Intensity</u>	<u>5.10<sup>10</sup> W/m<sup>2</sup> Power Intensity</u>
Steel	0.014 µsn,	0.0028 µsn,
Nickel	0.0174 µsn,	0.0035 µsn,
Tantalum	0.0224 µsn	0.00448 µsn
Titanium	0.0149 µsn	0.00298 µsn

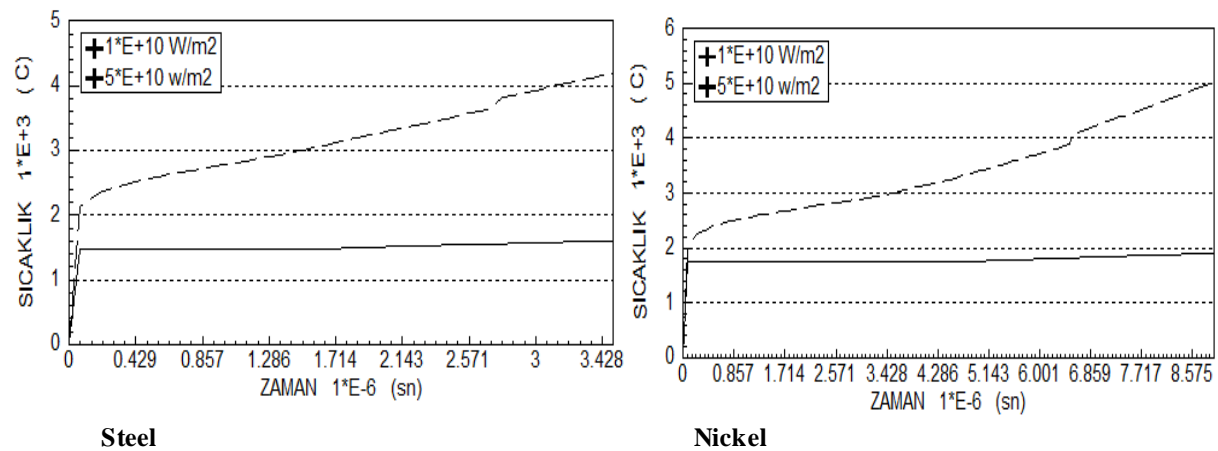


Fig.3: Time-dependent variation of the temperature distribution of the steel and nickel material surface during the interaction with the laser beam at the power densities of  $1.10^{10}$  W/m<sup>2</sup> and  $5.10^{10}$  W/m<sup>2</sup>, respectively, by electrokinetic theory approach.

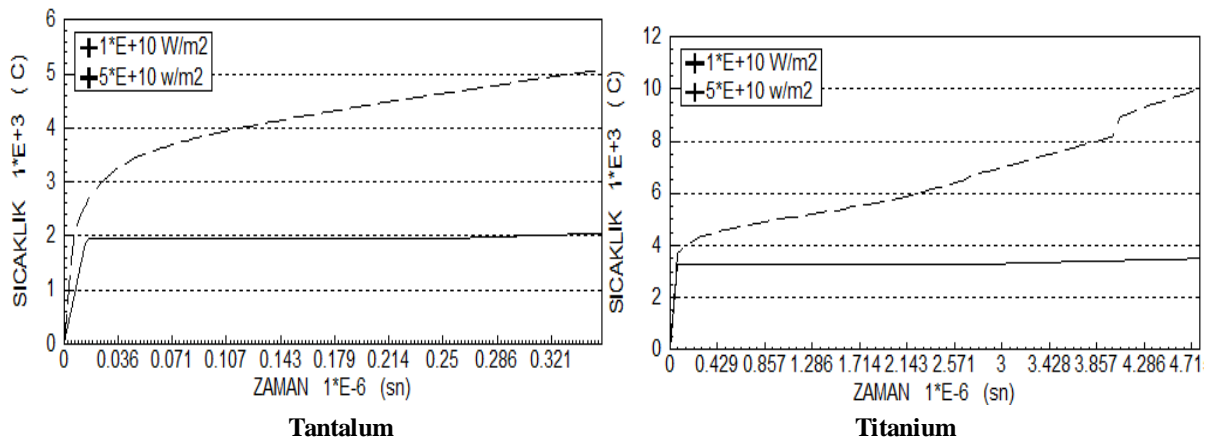


Fig.4: Time-dependent variation of the temperature distribution of the tantalum and titanium material surface during the interaction with the laser beam at the power densities of  $1.10^{10}$  W/m<sup>2</sup> and  $5.10^{10}$  W/m<sup>2</sup>, respectively, by electro kinetic theory approach.

As can be seen from these figures, at a power density of  $1.10^{10}$  W/m<sup>2</sup>, the temperature of the material surface step-up rapidly until the melting temperature, then the temperature proceeds constant until the phase change is completed at the melting temperature. At a power density of  $5.10^{10}$  W/m<sup>2</sup>, the temperature increases slowly until it reaches the melting temperature, then increases slowly after reaching the melting temperature. The reason for this is that in high power density phase change occurs in a shorter period.

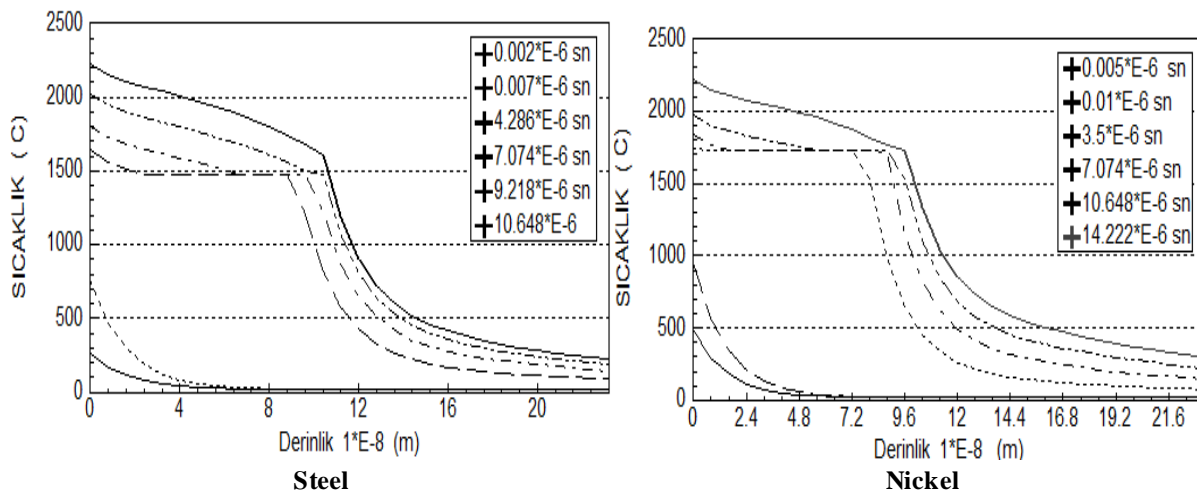


Fig.5: Variation of the temperature distributions in the material according to material depth found by the electro kinetic theory approach during interaction with the laser beam at the power density of  $1.10^{10}$  W/m<sup>2</sup> the steel and nickel.

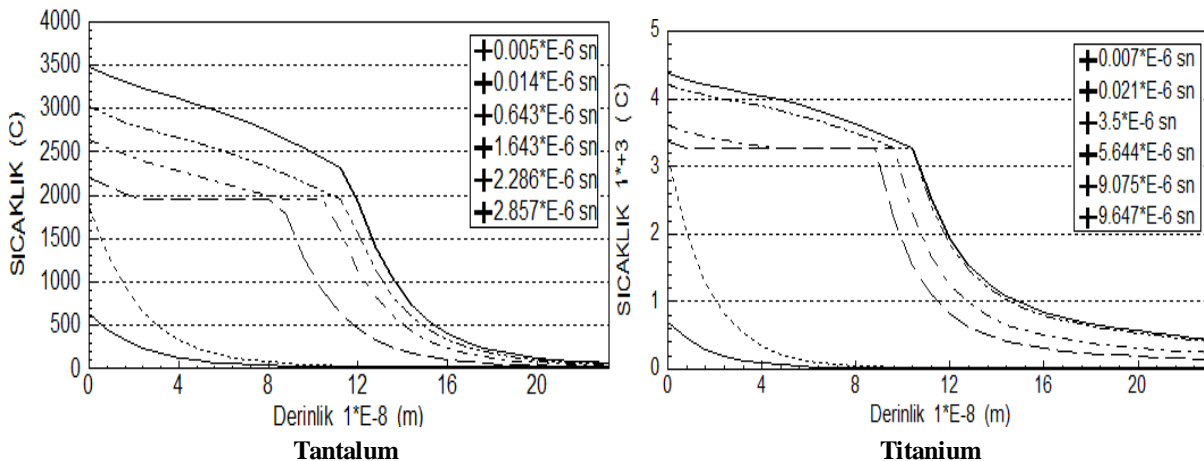


Fig.6: Variation of the temperature distributions in the material according to material depth found by the electro kinetic theory approach during interaction with the laser beam at the power density of  $1.10^{10}$  W/m<sup>2</sup> the tantalum and titanium.

Figures 5 and 6 show the temperature distributions of the material depth at various times according to the electro kinetic theory approach of the interaction of steel, nickel, tantalum and titanium materials with the power density of  $1.10^{10}$  W/m<sup>2</sup> power density,  $5.10^{10}$  W/m<sup>2</sup> power density, respectively, in figures 7 and 8.

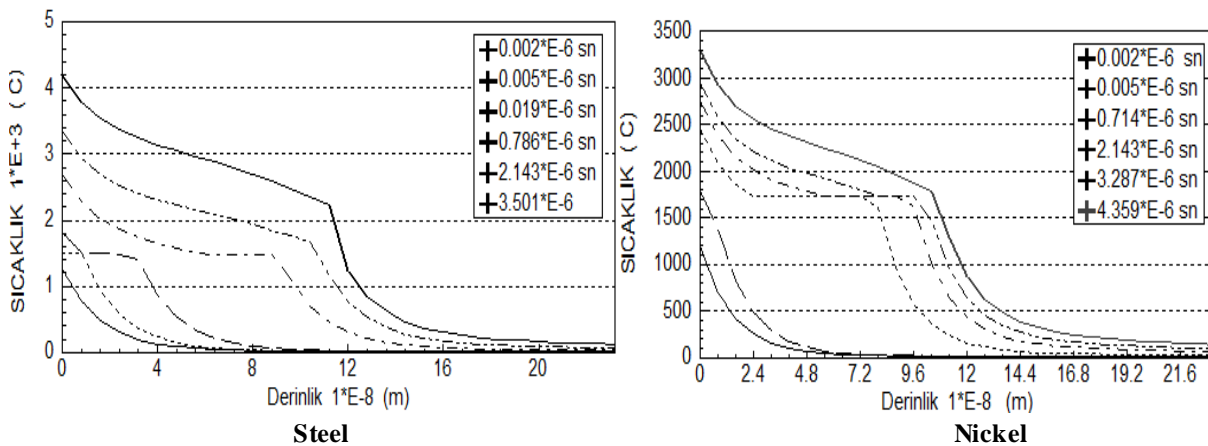


Fig.7: Variation of the temperature distributions in the material according to material depth found by the electro kinetic theory approach during interaction with the laser beam at the power density of  $5.10^{10}$  W/m<sup>2</sup> the steel and nickel.

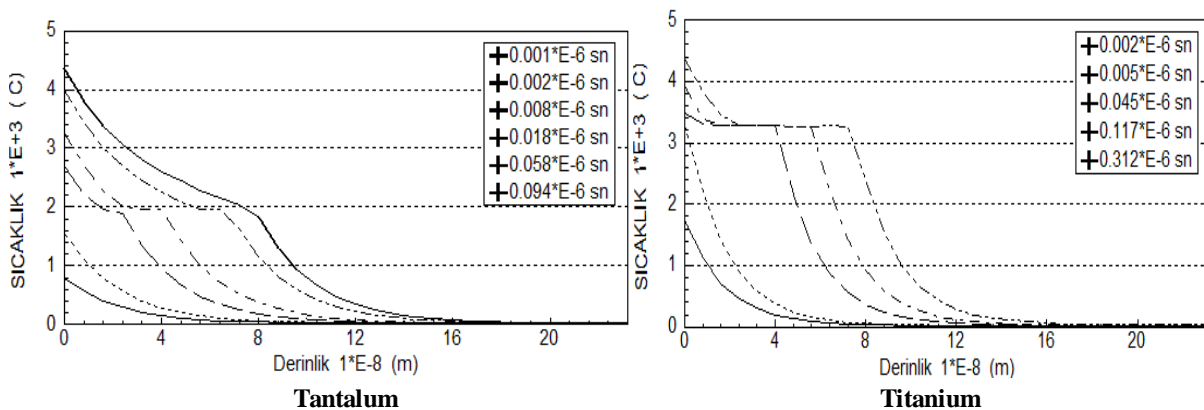


Fig.8: Variation of the temperature distributions in the material according to material depth found by the electro kinetic theory approach during interaction with the laser beam at the power density of  $5.10^{10}$  W/m<sup>2</sup> the tantalum and titanium.

As shown, material is coming reduction occurs at the correct temperature to the depth from the surface temperature distribution in the liquid phase at least one exponential by showing decreased and remained stable at the phase change temperature, then showed a rapid decline in exponential solid phase then continues as asymptotically. Phase change material in the surface temperature increases, the temperature remains constant, decreases gradually in the liquid layer.

#### IV. CONCLUSION

When the surface of the material upon temperature increase take into account, the results of analysis made by electro kinetic theory approach can be considered in three regions. The solid phase found in the first zone. Although it appears linear graph very slight increase in temperature continues until the melting point of the parabolic. The energy density at low temperatures of the liquid phase of the second, first remains constant and then increases gradually. In this case the energy of the electrons and the kinetic energy increases

pausing of atoms that is defined and explained by the increase in potential energy is converted into latent heat needed to phase changes. However, when high concentrations of the phase change material in contact with the laser beam is formed within a shorter time.

When analysed as a time-dependent increase in surface temperature; heat transfer coefficient and absorption coefficient of the small increase in surface temperature of the material was determined to be faster than large ones. In contrast, materials with large heat transfer coefficient, the surface temperature increase becomes slow and material temperature increases towards depth is more rapid.

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