11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

IDENTIFICATION OF THE THICKNESS OF THIN METAL FILM SUBJECTED TO THE ULTRASHORT LASER PULSE

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Key Words: *microscale heat transfer, two-temperature model, inverse problem, gradient method*

In the paper the micro-scale heat transfer is considered. The process is described using the two-temperature hyperbolic model determining the temporal and spatial evolution of the lattice and electrons temperatures (T_l and T_e) in the irradiated metal by two coupled nonlinear differential equations [1] (taking into account the geometrical properties of metal film domain the 1D problem is analyzed)

$$C_e(T_e)\frac{\partial T_e(x,\, t)}{\partial t} = -\frac{\partial q_e(x,\, t)}{\partial x} - G(T_e)\left[T_e(x,\, t) - T_l(x,\, t)\right] + Q(x,\, t) \tag{1}$$

and

$$C_l(T_l)\frac{\partial T_l(x,\, t)}{\partial t} = -\frac{\partial q_l(x,\, t)}{\partial x} + G(T_e)\left[T_e(x,\, t) - T_l(x,\, t)\right] \tag{2}$$

where $T_e\,(x,\ t)$, $T_l\,(x,\ t)$ are the temperatures of electrons and lattice, respectively, $C_e\,(T_e\,)$, $C_l\,(T_l\,)$ are the volumetric specific heats, $G(T_e\,)$ is the electron-phonon coupling factor which characterizes the energy exchange between electrons and phonons, $Q(x,\ t)$ is the source function associated with the irradiation.
In a place of classical Fourier law the following formulas are introduced

$$q_e(x,\, t+\tau_e) = -\lambda_e(T_e, T_l)\frac{\partial T_e(x,\, t)}{\partial x} \tag{3}$$

and

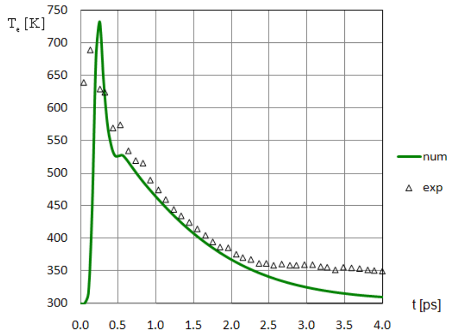
$$q_l(x,\, t+\tau_l) = -\lambda_l(T_l)\frac{\partial T_l(x,\, t)}{\partial x} \tag{4}$$

where $\lambda_e\,(T_e,\ T_l)$, $\lambda_l\,(T_l)$ are the thermal conductivities of electrons and lattice, respectively, τ_e is the relaxation time of free electrons in metals, τ_l is the relaxation time in phonon collisions.

The laser irradiation is considered as a source term [2]

$$Q(x,\, t) = \sqrt{\frac{\beta}{\pi}}\,\frac{1-R}{t_p\,\delta}\,I_0\,\exp\left[-\frac{x}{\delta} - \beta\frac{(t-2t_p)^2}{t_p^2}\right] \tag{5}$$

where I_0 is the laser intensity, t_p is the characteristic time of laser pulse, δ is the optical penetration depth, R is the reflectivity of the irradiated surface and $\beta = 4\ln 2$.
Taking into account the short period of laser heating, heat losses from front and back surfaces of thin film can be neglected, this means both equation (1) and (2) are supplemented by the adiabatic boundary conditions. The initial conditions are known and are assumed to be the constant ones.
The problem above described can be solved applying the numerical methods. The solution presented in Figure 1 [3] (thickness of the gold film L=100 nm and L=20nm, respectively) was obtained using a certain variant of FDM [3, 4]. The results are close to the experimental ones presented in [2].



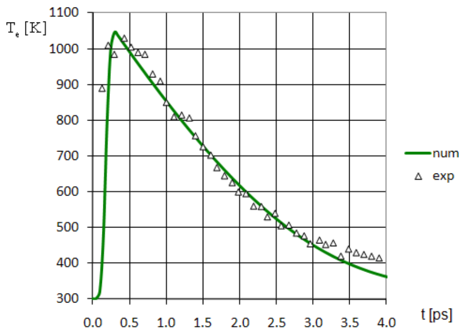


Fig. 1. Calculated electron temperature on irradiated surface and experimental data

The inverse problem considered in this paper concerns the identification of metal film thickness on the basis of the knowledge of temperature history at the point (sensor) situated on the irradiated surface (as in Figure 1). The solution results from the minimization of the functional corresponding to the least squares criterion

$$S(L) = \frac{1}{F}\sum_{f=1}^{F}\left[T_e(0,t^f) - T_{ed}(0,t^f)\right]^2 \tag{6}$$

where F is a number of time steps, $T_e(0,t^f), T_{ed}(0,t^f)$ are the calculated and measured temperatures at the point corresponding to sensor position.
This was achieved using the gradient method. The sensitivity coefficients necessary to solve the problem are found on the basis of the methods of shape sensitivity analysis.

The work was done as a part of Project 2012/05/B/ST8/01477.

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