LASER FLASH METHOD FOR INVESTIGATING THE THERMAL DIFFUSIVITIES OF THIN FILMS

Peichun YANG, Li HOU, and Lichang QI

Research Institute of Synthetic Crystals, P.O. Box 733, Beijing 100018, China

This paper gives a mathematical model for determining the thermal diffusivities of thin films by the Laser Flash method, also the calculation and the results of computer data processing. The thermal diffusivities of Cu and Al with thickness 20 μ and 5 μ have been measured with this method, which are shown to be in good agreement with the literature.

1. Introduction

In recent years, along with the development of thin film techniques, many kinds of thin film materials can be made, which has caused thin films to be an important field in high technique—new material science. It may be or is being widely used in electronics, optics and astronautics, etc.; its prospects are immeasurable. At present, the study and measurement of properties of thin films has become very important for scientists in the material fields. It is very difficult to achieve ideal results for specific characteristics of thin films by common devices and methods. For example, thermal diffusivity is both a basic and very important property of thin film materials,[1] but until now, it could not be properly measured, especially for thin films with ultrahigh thermal diffusivities. The laser flash method has been proven to be an effective and rapid way of measuring the thermal diffusivities of body materials.[2),3)] Now we have extended its usage as a method of investigating the thermal diffusivities of thin films.

2. Calculation and computer data processing

When a focused laser beam irradiates a disc sample of thin film with radius R, the temperature versus time curve of the border of the sample is entracted under thermally insulated conditions, and thus the thermal diffusivity is achieved.

In cyclical coordinates because of the isotropic nature of the materials which is determined, the thermal conductance equation is

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} \right). \tag{1}$$

There is no heat flowing into the center of the sample after the laser flash. Also assume that the sample is in the condition of heat insulation; thus no heat will flow out of the border of the sample. Hence, the boundary condition is as follows;

$$\left.\frac{\partial T}{\partial r}\right|_{r=0} = 0 \qquad \left.\frac{\partial T}{\partial r}\right|_{r=R} = 0. \tag{2}$$

Since there is a pulse heat Q at the center of the sample, the initial condition is

$$T(r,t)|_{t=0} = T(r,0) \left| \begin{array}{ll} \dfrac{Q}{D\cdot C\cdot g^2\cdot \pi} & 0 < r < g \\ 0 & g < r < r, \end{array} \right. \tag{3}$$

where D is density, C is specific heat, Q is the pulse heat and g is small distance from the center. By using the boundary and initial conditions to solve the equation, we get:

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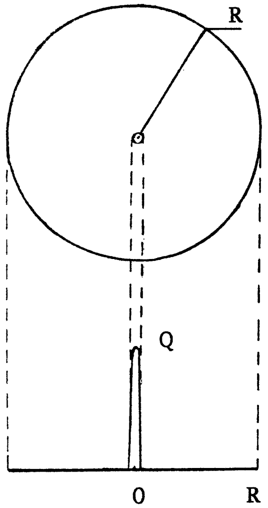

Fig. 1. Irradiation of pulse heat on the sample.

$$T(r,t)=\sum_{n=1}^{\infty}\frac{Qe^{-\lambda_n^2 \alpha t}}{\pi\cdot D\cdot C\cdot R^2 J_0^2(\lambda_n R)}J_0(\lambda_n r). \quad (4)$$

The temperature versus time of the sample at border ($r=R$):

$$T(R,t)=\sum_{n=1}^{\infty}\frac{Qe^{-\lambda_n^2 \alpha t}}{\pi\cdot D\cdot C\cdot R^2 J_0^2(\lambda_n R)}J_0(\lambda_n r). \quad (5)$$

λ_n is the intrinsic value of Bessel functions. For the purpose of short-cut calculation, two nondimensional parameters ϕ_n and $V(R,t)$ are defined.

$$\phi_n=\lambda_n R \qquad V(R,t)=\frac{T(R,t)}{T_M}. \quad (6)$$

$T_M=Q/(\pi\cdot D\cdot C\cdot R^2)$ is the maximum temperature rise at the border of the sample after the laser flash irradiation. Meantime, let

$$\omega=\frac{\alpha t}{R^2} \quad (7)$$

so we get

$$V(R,t)=\sum_{n=1}^{\infty}\frac{1}{J_0(\lambda_n R)}e^{-\phi_n^2\omega}. \quad (8)$$

ϕ_n is the tabulated values of Bessel functions. When $V(R,t_{1/2})=0.5$ the thermal diffusivity α equals

$$\alpha=\omega_{1/2}\frac{R^2}{t_{1/2}}. \quad (9)$$

$\omega_{1/2}$ is the value of ω when the temperature rise is half of maximum. To get $\omega_{1/2}$, we use the computer to handle the data. Putting the first five intrinsics of Bessel function into Eq. (8), and running it on the computer, we achieve

$$V(R,t)=1+\left[-\frac{e^{-3.80^2\omega}}{0.402}+\frac{e^{-7.1^2\omega}}{0.299}-\frac{e^{-10^2\omega}}{0.250}+\frac{e^{-13.4^2\omega}}{0.217}\right]. \quad (10)$$

ω from 0–0.5, the interval of the value is 0.001. The result is $\omega_{1/2}=0.112$, when $V(R,t)=0.5$ which is shown in Fig. 2. Putting this coefficient into Eq. (9), we finally gain thermal diffusivity

$$\alpha=0.112\frac{R^2}{t_{1/2}} \quad (11)$$

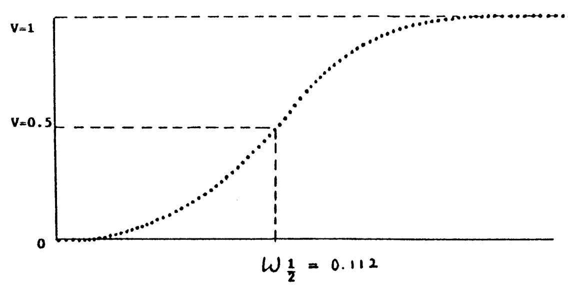

Fig. 2. Dimensionless plot of the result of computer data processing.

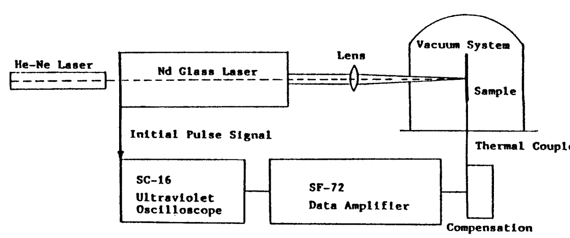

Fig. 3. Schematic of test setup.

$t_{1/2}$ is the time when the temperature reaches its half maximum.

3. Experimental Procedure

Through the collimation of an He–Ne laser, the heat is irradiated onto the center of the disc sample of thin film by a Neodymium glass laser. The temperature rise versus time is measured by a thermalcouple connected to the border of the sample, and is amplified by data amplifier. Furthermore, it is recorded on the ultraviolet ray oscilloscope as shown in Fig. 4.

In order to satisfy the initial conditions and boundary conditions of the theoretical analysis and calculation, the sample is put in a vacuum system. The thin film sample measured should have high thermal diffusivities, or the substrate materials, should have very low thermal diffusivities; therefore we can assume that the sample is in a heat insulated condition.

With this method, the thermal diffusivities of Cu film with a thickness of 20 μ and Al film with a thickness of 5 μ is measured, which is shown in the Table 1 compared with literature values.

From the experimental results we can see that the thermal diffusivities measured with this method fit well with the thesis value; also, the correctness of the theoretical analysis is proved.

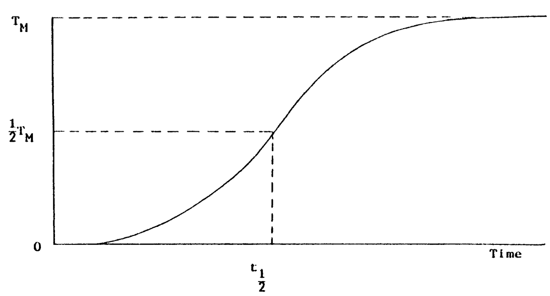

Fig. 4. The curve recorded on the oscilloscope.

4. Conclusion

1. The model and theoretical analysis of this method fits well with the experiment. This yields an effective, correct and rapid way of investigating ultrahigh thermal diffusivities both for metals and nonmetals, function and structure thin film materials.
2. Because the sample is heated at its center, and the temperature is measured at its border, it makes the surveying of thermal diffusivities of visible and infrared ray transparent thin film materials available.
3. Since this is quick measuring process, it can remove many disturbances. Also the heating and signal examining procedure is not affected by circumstances, so it proves a prospect of determining the diffusivities of thin film materials at high and low temperatures.
4. This method will be effective for measuring the thermal diffusivities of diamond thin films which are made in different ways after suitable treatment.

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Table 1. Thermal diffusivity

Sample	Thickness (μ)	Radius (cm)	$t_{1/2}$ (s)	Measured α (cm^2/s)	Literature α[3),4)]
Cu	20	1.30	0.164	1.15	1.17
Al	5	1.30	0.200	0.95	0.97