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Time constant of laser-induced thermoelectric voltage device made by $LaCaMnO_3$, $YBa_2Cu_3O_{7-\sigma}$ and $LaSrCoO_3$ thin films

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Abstract: The influence of the three parameters δ (laser penetration depth), D (thermal diffusion constant), d (film thickness) of $LaCaMnO_3$ (LCMO), $YBa_2Cu_3O_{7-\sigma}$ (YBCO) and $LaSrCoO_3$ (LSCO) thin films on the time response of laser induced thermoelectric voltages in the thin films is analyzed. The time constant can be shortened by decreasing δ or d or increasing D of the thin films.

Key words: Time response, Laser-induced thermoelectric voltage, YBaCuO, LaCaMnO, LaSrCoO

Laser-induced thermoelectric voltage effect (LITV) had been observed in YBaCuO (YBCO) and $LaCaMnO_3$ (LCMO) thin films grown on tilted substrates,[1-6] and it was found that this effect is originated from the anisotropic Seebeck effect in the crystals.[7-16] Recently, we found the same effect in $La_{0.5}Sr_{0.5}CoO_3$ (LaSrCoO or LSCO) thin films grown on titled $LaAlO_3$ substrates[17] and it was observed that this thin film shows faster response than that of LCMO. It is well known that the time response is a key factor of the detectors; therefore, it is very important to study which parameters of a thin film show strong influence on the time constant of a LITV device.

Using a micro-cell network model, based on the atomic layer thermopile model, we deduced a formula which describes the time-dependence of LITV: [18]

$$U(t)=\frac{\alpha_0 El\sin(2\alpha)}{4d\rho\, c_0\sqrt{\pi Dt}}(S_{ab}-S_c)\left(e^{-\frac{\delta^2}{4Dt}}-e^{-\frac{d^2}{4Dt}}\right), \quad (1)$$

where E is the laser energy density per pulse, α_0 is the laser absorption coefficient, ρ is the mass density, c_0 is the specific heat, δ is the laser penetration depth, and D is the thermal diffusion constant of the thin film. It can be seen from Eq. (1) that only δ, D and d are related to the time response of LITV signal, and the other parameters such as E and α_0 et al only influence the amplitude of LITV signal. Therefore, these parameters can be treated as constant during the discussion of the time response.

Eq. (1) can be written as:

$$U(t)=\frac{A_1}{\sqrt{t}}\left(e^{-\frac{A_2}{t}}-e^{-\frac{A_3}{t}}\right), \quad (2)$$

where

$$A_1=\frac{\alpha_0 E I \sin(2\alpha)(S_{ab}-S_c)}{4\sqrt{\pi}\, d\rho c_0\sqrt{D}},\ A_2=\frac{\delta^2}{4D},\ A_3=\frac{d^2}{4D}. \quad (3)$$

In the experiment with a $La_{0.9}Ca_{0.1}MnO_3$ thin film ($d=250nm$) grown on a tilted $LaAlO_3$ substrate with $\alpha=10°$ and irradiated by a pulsed Nd:YAG laser with the wavelength $\lambda=1064nm$, we obtained $A_1=3.60\times10^{-5}V\cdot s^{0.5}$, $A_2=3.00\times10^{-7}s$, $A_3=2.00\times10^{-6}s$, by fitting the measured time dependent LITV signal.[18] From Eq. (3) we deduced $\delta=96.8nm$ and $D_{LCMO}=7.81\times10^{-9}m^2/s$.[18] The induced LITV curve (with the above values of A_1, A_2, and A_3) based on Eq. (2) is shown in Fig. 1. With the same fitting method we obtained the correspounding parameters from YBCO and LSCO thin films.

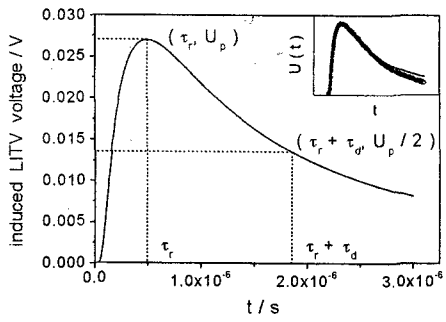

FIG. 1 An induced LITV curve in a LCMO thin film. τ_r and τ_d are the rising time constant and the dropping time constant respectively. Inset shows the measured (circles) LITV in the LCMO thin film and the fitted curve (solid curve) using Eq. (2).[18]

We define that τ_r is the rising time constant (for the LITV signal to rise from 0 to the peak), and τ_d, the dropping time constant (for the LITV signal to drop from the peak to the half of the peak value). This definition can be seen in Fig. 1.

Now we discuss the influence of δ, D and d on τ_r and τ_d according to Eq. (2). For convenience, when discussing one parameter of these three parameters we suppose that the other two parameters are fixed. The fixed values are $\delta_0=96.8nm$ (the value of LCMO at $\lambda=1064nm$), $D=D_{LCMO}$ ($7.81\times10^{-9}m^2/s$), D_{LSCO} ($1.11\times10^{-7}m^2/s$ [17]), D_{YBCO} ($7\times10^{-7}m^2/s$ [13]) respectively, and $d_0=250nm$.

Fig. 2 shows the influence of δ, D and d on the rising time constant τ_r.

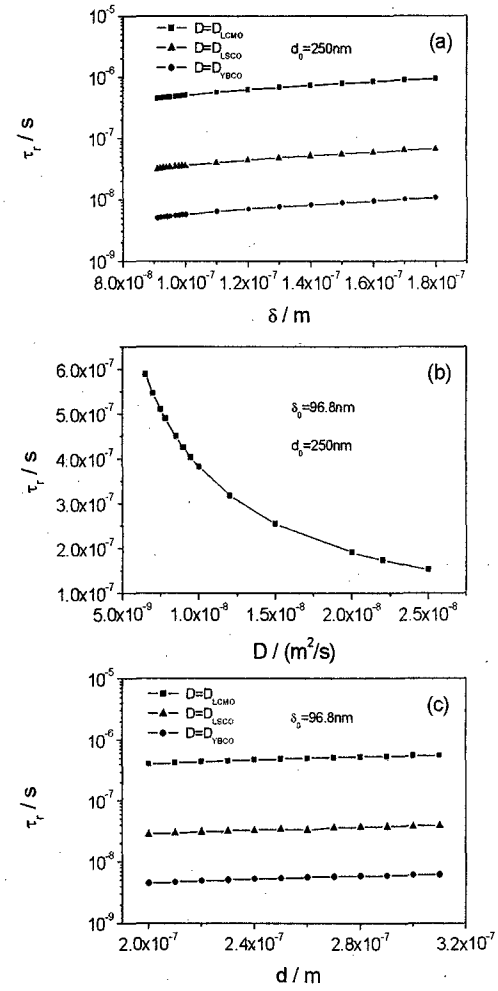

FIG. 2 (a), (b) and (c) shows the influence of δ, D and d on τ_r respectively.

Firstly we discuss the influence of δ on τ_r ($D_0=D_{LCMO}$, D_{LSCO} and D_{YBCO}; $d=d_0$). Fig. 2 (a) describes the relationship between δ and τ_r. With the

increasing of δ, the rising time constant τ_r increases gently. It is clear that to obtain fast response one may take measures to decrease the value of δ.

Secondly we discuss the influence of D on τ_r ($\delta = \delta_0$; $d = d_0$). From Fig. 2 (b) we can see that τ_r decreases exponentially with the increasing of D. That is to say the thin films with the high value of D have the fast response. It is easy to understand this; for D reflects the diffusing speed of the heat, then the bigger D is, the faster the temperature difference disappears, hence the faster the time response is. Therefore we can improve the response by synthesizing and/or using the materials with high D value.

Thirdly we discuss the influence of d on τ_r ($\delta = \delta_0$; $D = D_{LCMO}$, D_{LSCO} and D_{YBCO}). From Fig. 2 (c) we can see that τ_r increases slightly with the increasing of d. Therefore to obtain fast response one can use the films with thinner thickness. However it is not to say that the thinner the better, for there exists an optimum thickness for the thin films to obtain the highest detectability.[19] Therefore, there exists a compromise value of d to obtain fast response as well as high detectability.

From Fig. 2 (a), (b) and (c) we can see that, due to $D_{YBCO} > D_{LSCO} > D_{LCMO}$, YBCO thin films have the fastest response, secondary are LSCO thin films, and tertiary are LCMO thin films.

Fig. 3 shows the influence of δ, D and d on the dropping time constant τ_d. From Fig. 3 we can draw the same conclusion as that from Fig. 2. That is τ_d increases with the increasing of δ, the decreasing of D and the increasing of d. And YBCO thin films have the fastest response, then are LSCO thin films and LCMO thin films due to $D_{YBCO} > D_{LSCO} > D_{LCMO}$. In this time scale and the nano-second laser pulse duration heating, we do not observe dramatic difference in τ_r and τ_d. However it may be different in pico- or femto-second regime.

In conclusion, it was observed that the LITV signals show different time constant in YBCO, LCMO and LSCO thin films. Since δ is a parameter related both to the radiation wavelength and the material properties, the selection of the thin film materials is critical for the detection of radiation. From the analysis of the influence of δ, D and d on the rising time constant τ_r and the

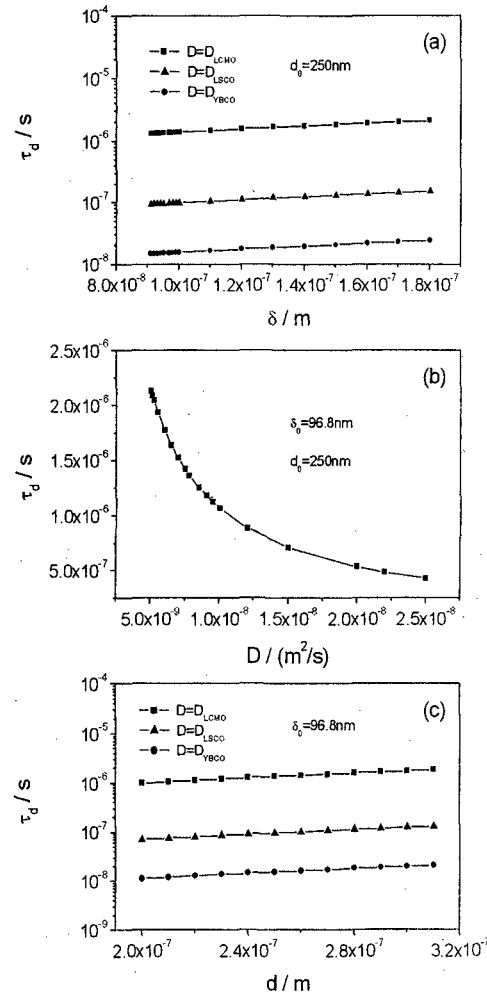

FIG. 3 (a), (b) and (c) shows the influence of δ, D and d on τ_d respectively.

dropping time constant τ_d, one can come to the conclusion that τ_r and τ_d increases dramatically with the decreasing of D and gently with the increasing of δ and d. Furthermore, for $D_{YBCO} > D_{LSCO} > D_{LCMO}$, YBCO thin films have the fastest response among these thin films.

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