Polaronic behavior of $\text{La}_{0.8}\text{Te}_{0.2}\text{MnO}_3$

Cene Filipič* and Adrijan Levstik

Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia

*cene.filipic@ijs.si

Received 19 July 2013; Accepted 9 September 2013; Published 2 December 2013

We have analyzed recently published data of the ac electrical conductivity and dielectric constant in $\text{La}_{0.8}\text{Te}_{0.2}\text{MnO}_3$ (LTMO), and at temperatures below 500 K both quantities follow the universal dielectric response (UDR) typical of hopping or tunneling of localized charge carriers. A detailed analysis of the temperature dependence of the UDR parameter s in terms of the theoretical model for tunneling of small polarons revealed that below 500 K, this mechanism governs the charge transport in LTMO system.

Keywords: Manganites; tunneling; low-field transport; dielectric loss and relaxation.

1. Introduction

Recently¹ dielectric properties of $\text{La}_{0.8}\text{Te}_{0.2}\text{MnO}_3$ (LTMO) were studied. The authors described the frequency dependent electrical conductivity with expression,^{2–4} $\sigma' = \sigma_{\text{dc}} + \sigma_0 \nu^s + \sigma_1 \nu^n$, where s is universal dielectric response (UDR) exponent.⁵ The frequency dependent dielectric constant was described with expression^{2–4} $\epsilon' = \epsilon_{\infty} + \epsilon_0 \nu^{s-1} + \epsilon_1 \nu^{n-1}$ which was obtained by the Kramers–Krönig transformation of $\sigma'(\nu)$. These equations have been extensively used in manganites to explain the frequency depended conductivity and dielectric constant.^{2–4} Authors determined temperature dependence of the UDR exponent s and exponent n by fitting σ'_{ac} and ϵ' separately. The value n had unusually high values ($n \sim 1.8$). Temperature dependence of parameter s exhibited typical behavior of polarons, which was the motivation for us to analyze their data, particularly because existence of small polarons, which are dominant charge carriers at low temperatures, have been already confirmed in $\text{Pr}_{1-x}\text{Ca}_x\text{MnO}_3$ (PCMO, $x = 0.3$ and 0.5) system.^{3,4}

2. Results and Discussion

The ac electrical conductivity of LTMO was measured as a function of temperature at several frequencies which is shown in Fig. 1 (see Ref. 1). The observed behavior is typical of the existence of polarons in the system. At higher temperatures σ' are strongly temperature dependent, but at low temperature the ac conductivity becomes temperature independent; $\sigma'(T)$ plateaus are strongly frequency-dependent, which suggests that the hopping or tunneling of localized charge carriers governs the electrical transport in the whole temperature range.⁶ Like in many other amorphous materials^{7–10} similar temperature dependence of the ac electrical conductivity has been observed in many semiconductor systems, i.e., lithium phthalocyanine and its iodinated version¹¹ and in

many semiconductor glassy systems: bismuth-vanadate,¹² iron bismuthate,¹³ vanadium germinate,¹⁴ silver vanadate¹⁵ and other semiconductor glassy systems.

Figure 2(a) shows the frequency dependence of the logarithm of the real part of the ac electric conductivity, $\log \sigma'$, at various temperatures and the logarithm of the real part of the dielectric constant, $\log \epsilon'$, versus frequency at the same temperatures (Fig. 2(b)). The solid lines in Figs. 2(a) and 2(b) were obtained by simultaneous fits of the experimental $\sigma'(\nu)$ and $\epsilon'(\nu)$ data to the above expressions. Simultaneous fitting of $\sigma'(\nu)$ and $\epsilon'(\nu)$ data had two consequences. The value of n is close to 1 (the straight line in Fig. 2(a)) and the values of s are smaller than the values determined previously.¹

Figure 3 shows the temperature dependence of UDR parameter s . Such a behavior was predicted by the tunneling polaron model (originally this model was developed for the tunneling of overlapping large polarons^{9,10} but it was argued later¹⁶ that it is in fact applicable to small polarons), which yields the temperature dependence of s as^{9,10}

$$s = 1 - \frac{4 + 6W_{\infty}r'_0/(kTR'^2)}{R'[1 + W_{\infty}r'_0/(kTR'^2)]^2}, \quad (1)$$

where, W_{∞} denotes the energy barrier and r'_0 the reduced polaron radius. The reduced tunneling distance R' is also a function of W_{∞} and r'_0 and, additionally, of the inverse attempt frequency τ_0 as^{9,10}

$$2R' = \ln \frac{1}{\omega\tau_0} - \frac{W_{\infty}}{kT} + \left[\left(\ln \frac{1}{\omega\tau_0} - \frac{W_{\infty}}{kT} \right)^2 + \frac{4r'_0W_{\infty}}{kT} \right]^{1/2}, \quad (2)$$

where $\omega = 2\pi\nu$. The fits of the experimental data to Eqs. (1) and (2) (the solid lines in Fig. 2) yield values of W_{∞} , r'_0 , and τ_0 for s determined in this paper. The values of parameters are given in Fig. 3.

Fig. 1. The real part of the complex ac electrical conductivity, σ' , measured at several frequencies, as a function of the inverse temperatures.

Fig. 2. (a) Frequency dependence of the electrical conductivity, $\sigma'(\nu)$, at different temperatures. (b) Frequency dependence of the real part of the complex dielectric constant, $\varepsilon'(\nu)$, at the same temperatures as above. The solid lines are fits, performed simultaneously for $\sigma'(\nu)$ and $\varepsilon'(\nu)$, with an expression combining a dc contribution, a UDR hopping contribution, a ν^n power law, and a limiting high frequency dielectric constant ε_∞ . The straight line in Fig. 2(a) indicates the slope with $n = 1$.

Fig. 3. The temperature dependence of the UDR parameter s obtained from the simultaneous fits of $\sigma'(\nu)$ and $\varepsilon'(\nu)$ [as presented in Figs. 2(a) and 2(b)].

3. Conclusions

The data for $\sigma'(\nu, T)$ and $\varepsilon'(\nu, T)$, from Ref. 1, below 500 K follow the UDR being typical of hopping or tunneling of localized charge carriers. A detailed analysis of the temperature dependence of the UDR parameter $s(T)$ in terms of the theoretical model for tunneling of small polarons revealed that below 500 K, this mechanism governs the charge transport in LTMO system. The values of the energy barrier for polarons, reduced polaron radius, and inverse attempt frequency were thus determined.

Acknowledgments

Research was supported by the Slovenian Research Agency (P1-0125).

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