Non-equilibrium Nature of Conductivity Peaking of BaTiO$_3$ in Current-Time Characteristics

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The electrical conductivity of ideal insulators decreases monotonically towards 0 K and becomes negligible as the defects and the impurities are removed. Unlike this generally accepted behavior, we found that the quasi-equilibrium conductivity $\sigma$ of undoped BaTiO$_3$ single crystal increased steeply at all three phase transitions [1,2]. To understand the mechanisms, the present paper investigates the current-time ($I(t)$) characteristics of undoped BaTiO$_3$ single crystals.

Figure 1 shows the conductivity peaking $\sigma$ of an undoped BaTiO$_3$ TSSG crystal that is obtained through $IV$ measurement. However, the possibility exists that $\sigma$ in Fig.1 may still contain the effect of sorts of dielectric relaxation such as the long-term domain motion. Therefore, we have measured the long-period current-time ($I(t)$) characteristics (Fig 2): The applied voltage is kept constant ( $\square$ 50mV/mm) over hours at fixed temperatures to examine effect of the relaxation current. In Fig. 2 the polarization is $a$- or $a/c$- oriented, which exhibit only a low $\sigma$ peak. $\sigma$ of the ferroelectric phase that is initially higher than $\sigma$ of the paraelectric phase decreases and becomes equal to the value of the paraelectric phase. This may indicate that the initially high apparent $\sigma$ of the ferroelectric state is due to the dielectric relaxation or to the non-equilibrium.

To distinguish these two mechanisms, we have measured repeatedly the $IV$ characteristics at fixed temperature for 40 h (Fig. 3).

After 15 hours, the $IV$ characteristics of both ferroelectric and paraelectric phase start to exhibit good ohmic curves without hysteresis. $\sigma$ of the ferroelectric phase decreased and became equal to $\sigma$ of paraelectric phase as in the $I(t)$ measurements ($\sigma$ is derived from the inclination of the $IV$ characteristics). This observation demonstrates that the initially high $\sigma$ of the ferroelectric state that is origin of the $\sigma$ peaking is due to the non-equilibrium. We have still one question unresolved that is the equilibrium $\sigma$ in Fig.3 is higher than that in Fig.2, which would be a clue of the origin of $\sigma$ near $T_C$.

Fig. 1 $\sigma$-$T$ characteristics of an undoped BaTiO$_3$ TSSG crystal obtained through $IV$ measurement.

Fig. 2 $I$-$t$ of $a$- or $a/c$- domain undoped BaTiO$_3$ TSSG crystal near the $T_C$.

Fig. 3 $\sigma$-$t$ characteristics of $a$- or $a/c$-oriented undoped BaTiO$_3$ TSSG crystal near $T_C$. Insets: $IV$ characteristics at $t = 15$ h.

References