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SHORT COMMUNICATION
Thermoelectric Power in Thick Film Resistors

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Advances in thick film technology have progressed up to the present time along empirical lines motivated largely by economic factors, so at present we have a poor and inadequate understanding of the transport mechanism(s) in thick film resistors and conductors.[1] Contributions to a better knowledge of these materials could be derived from the measurement of quantities other than those usually considered, which include temperature-dependence of resistivity and noise.

This note presents the main results of thermoelectric power measurements in thick film resistors and discusses the observations on the basis of the current models for electrical conduction in these particle-aggregate components.

Thick film resistors of the systems PdO/Ag–Pd and $Ru_2Bi_2O_7$ with sheet resistivity ranging from 10^2 to 10^5 ohm/square have been investigated. Patterns were prepared 8 mm to 10 mm long and 1 mm to 3 mm wide on alumina substrates, terminated with conductive islands of Pd–Ag and Au–Pt compositions. Two small gauge iron-constantan thermocouples were fixed near the extremes of the resistors in order to measure the mean temperature and the temperature gradient along the resistors. Thermoelectric voltages were measured with a Keithley electrometer Mod. 601 ($>10^{11}$ ohm input impedance). The temperature dependence of the resistivity was also measured in order to identify the temperature ranges where the temperature coefficient of the resistance (TCR) has positive or negative sign (Figure 1.).

Typical results of thermoelectric power α are shown in Figure 2 for PdO/Ag–Pd based resistors, for which α is positive. Results in $Ru_2Bi_2O_7$ based resistors have quite similar behaviour except for the sign of α.

Interesting features of the thermoelectric power data are: (i) α has very low values, (ii) α is a monotonic function of temperature with no apparent changes of behaviour (no change in sign nor change in slope) near the temperature T_m at which the sign of TCR changes from negative to positive values,

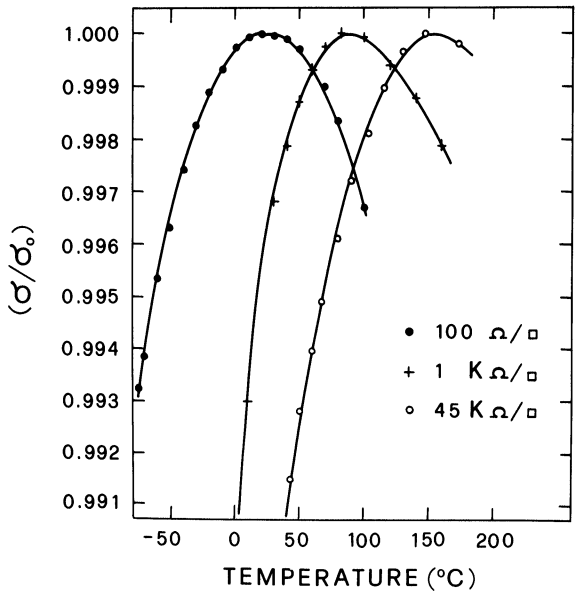

FIGURE 1 Normalized temperature dependence of conductivity in thick film resistors of the PdO/Ag–Pd system.

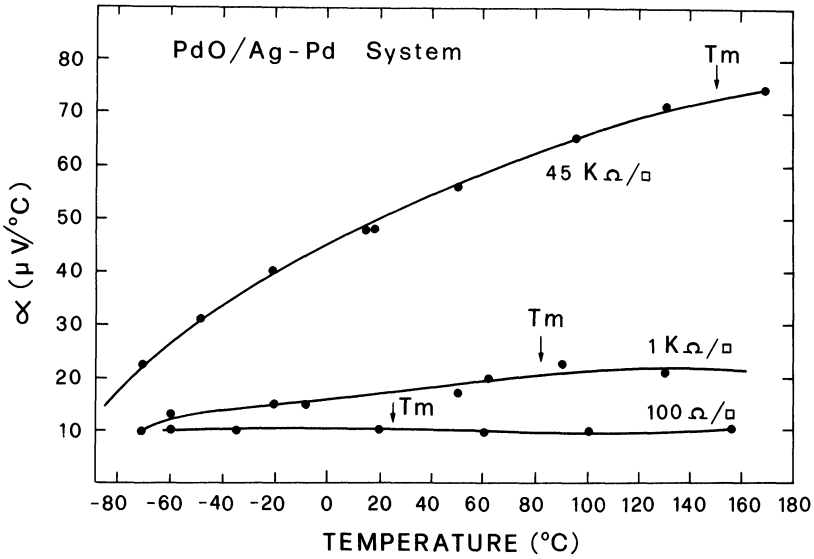

FIGURE 2 Typical results of the thermoelectric voltages as a function of temperature in thick film resistors. The arrow marks the temperature at which the TCR changes from negative to positive sign.

(iii) α is an increasing function of temperature.

The findings at points (i) and (iii) are contrary to those expected in the case of transport properties based on the conductivity of semiconducting oxide grains, according to the model proposed by Melan and Mones[2] and elaborated by Kahan.[3] In particular, if transport in thick film resistors is dominated by semiconducting properties of the constituents, thermoelectric power should decrease on increase of the temperature.

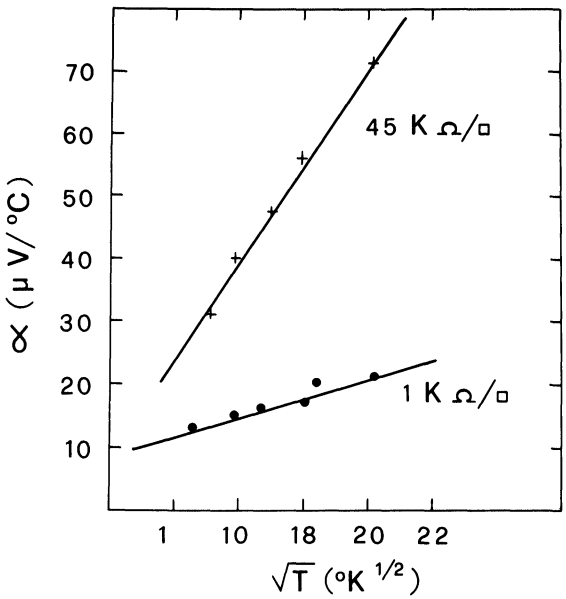

FIGURE 3 The thermoelectric voltage values of Figure 2 replotted as α vs $\sqrt{T}$.

Point (ii) suggests that the transport mechanism at low and at high temperatures is essentially the same, in spite of the change in TCR sign, contrary to that which has been argued by Vest.[4] All the observations mentioned are in qualitative agreement with a model of electrical conduction by percolative tunnelling from grain to grain,[5] recently proposed. Unfortunately the theory of thermoelectric power in systems where the transport is dominated by percolative tunnelling is not well established.[6–9] Various authors agree with the very low values of thermoelectric voltages to be expected, of the order of magnitude we have measured, and with increasing values with increasing temperature, in agreement with our finding. However the analytical relation between thermoelectric power and temperature is controversial.[9] Our results are in agreement with the recent analysis by Kosarev[9] which predicts $\alpha \propto \sqrt{T}$ (Figure 3).

Finally we note that the thermoelectric power voltages of the thick film resistors considered are a little higher than that of carbon resistors and metal film resistors.[10] Thermoelectric voltages originated by possible temperature gradients through the thick film resistors, not contrasted by the low thermal conductivity of alumina substrates, should be

considered in the case of networks operated at very low voltage levels.

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