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Classical percolation threshold and resistance versus temperature behaviour of RuO_2-glass films

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Abstract

Two transition concentrations of the conducting component in RuO_2-glass films are defined. The first is identified with the classical percolation threshold v_c and its value has been found as lying usually in the range 0.02–0.04. At the second, denoted v_q, the temperature coefficient of resistance, measured at room temperature, changes its sign and it is found that v_q is most often between 0.12 and 0.16. The relatively small value of v_c is interpreted within the framework of a percolation model including segregation. A segregation coefficient is defined as particle size ratio $\chi = D/d$ of the glass and RuO_2 particle mean diameters D and d, respectively, with χ ranging from 10 to 150. Our computer simulation results $v_c(\chi = 1) \cong 0.16$ and $v_c(\chi = \infty) \cong 0.02$ agree with the literature data for uncorrelated site-percolation and random-void models, respectively. The transition observed at v_q is interpreted as quantum percolation threshold, separating a system with localized states for $v < v_q$ from a system with extended states for $v > v_q$. This is illustrated by results of numerical studies of the dimensionless conductance g in a quantum percolation model; the calculations are made using Landauer–Büttiker formula and a Green's function method. Studies of conductance versus temperature characteristics from 4.2 to 300 K show $G = a + bT^y$ low-temperature behaviour with $y \cong 0.33$ for compositions below and above v_q but close to it. An interpretation of this behaviour is given within a localization/delocalization picture assuming that inelastic scattering processes play a dominant role in the transport properties. Other approaches like those based on electron–electron interaction effects and hopping conduction are also discussed.

Keywords: RuO_2-glass films; Metal–insulator nano composites; Percolation model; Segregation coefficient; One-electron localization; Metal–insulator transition; Landauer–Büttiker formula

1. Introduction

The disordered systems considered in this paper are random, macroscopically homogenous structures consisting of two components: an insulating one and a metallic one. They are produced by firing RuO_2-based pastes deposited by screen printing on alumina substrates [1, 2]. The thickness of the fired films usually ranges from 12 to 18 μm. The final film structure has been observed as consisting of chains of 100 Å size RuO_2 particles surrounding larger, 1 μm size regions of insulating lead borosilicate glass. The room temperature D.C. conductivity, σ, and temperature coefficient of resistance (TCR) of RuO_2 single crystals are $\sigma \cong 2.9 \times 10^4\ \Omega^{-1}\,cm^{-1}$ and 5800 ppm/K; the TCR has been observed as always positive down to 4.2 K [3]. Thus, the RuO_2-glass films represent specific metal–insulator nanocomposites. They have been widely used as resistive components of thick-film microelectronic circuits.

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