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Weak localization and electron-electron interactions in polycrystalline tin dioxide films

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Abstract. Electrical and magnetotransport properties of polycrystalline tin dioxide films were investigated in the temperature range 2-300 K and in high magnetic fields up to 27 T. The experimental data were analyzed using models inherent both for 2D and 3D disordered systems. A crossover from 2D to 3D behaviour was observed as the temperature was increased.

1. Introduction

Besides a number of perspective applications in optoelectronics due to the coexistence of high optical transparency in visible and infrared range of electromagnetic waves' spectra and high electrical conductivity [1], tin dioxide films provide the possibility to study different charge transport mechanisms, such as hopping, tunneling, diffusion transport. Quantum corrections to conductivity in the vicinity of metal-insulator transition as a result of weak localization (WL) and electron-electron interactions (EEI) phenomena can be also observed in tin dioxide films [2].

We recently reported the observation of negative magnetoresistance (MR) due to WL and EEI in thin polycrystalline tin dioxide films fabricated by means of combination of ion-exchange processes in polymer films with successive gas transport reaction [3].

In this work we focus our efforts on investigations of WL and EEI in polycrystalline tin dioxide (obtained from SnCl₂ solution) by means of MR measurements in high magnetic fields. Temperature dependencies of the resistance $R(T)$ and MR of polycrystalline tin dioxide films were measured within temperature range 2-300 K and in pulsed magnetic fields up to 27 T. The experimental data were analysed using models inherent both for 2D and 3D disordered systems [4]. A crossover from 2D to 3D behaviour was observed as the temperature was increased.

2. Fabrication of samples

The samples of SnO₂ polycrystalline films were fabricated following a three-stage procedure [5]: (a) formation (on either Al₂O₃ or Si/SiO₂ substrates) of a Sn-containing polymer networks, (b) gas transport of tin chloride vapour [as a result of the heating of the tin chloride hydrate (SnCl₂ · 2H₂O)] on the substrates with previously deposited Sn-containing networks. After the deposition of tin chloride on the substrate, it was decomposed to the tin (II) oxide during the thermohydrolysis, (c) during the



subsequent heat treatment in air at temperature 550°C , SnO was transformed to SnO₂. Electron diffraction results confirmed the polycrystallinity (type cassiterite) of obtained films. Typical SEM image of tin dioxide film is shown in figure 1.

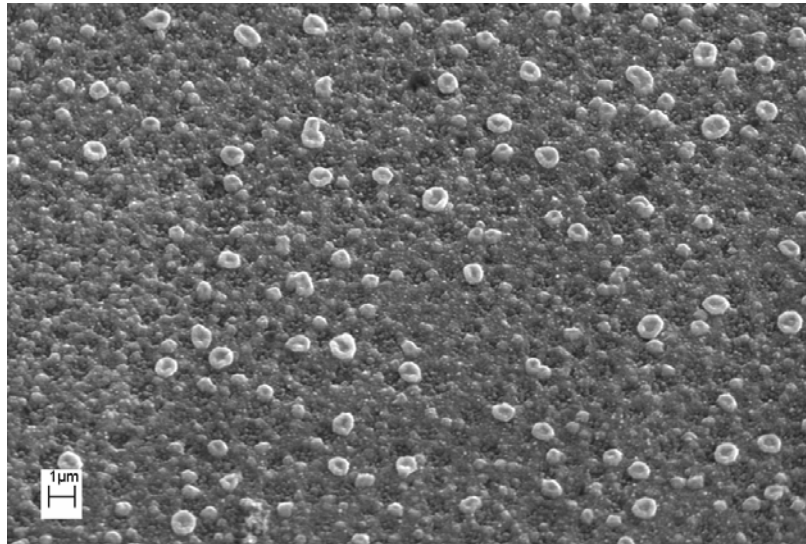


Figure 1. SEM image of tin dioxide films (after gas-transport reaction).

3. Experimental results and discussion

3.1. Temperature dependence

Typical $R(T)$ dependence for SnO₂ film is presented in figure 2.

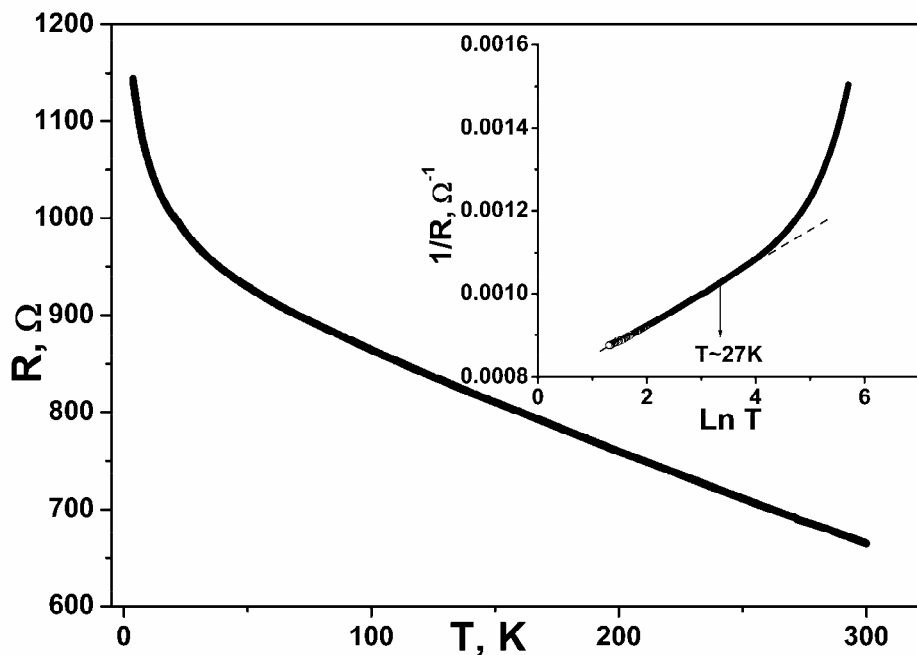


Figure 2. Temperature dependence of resistance of SnO₂ film. In the inset figure temperature dependence of conductance in the scale $1/R-\ln T$ is shown. Dashed line corresponds to linear approximation of experimental data at low T.

Such types of $R(T)$ dependencies (with negative temperature coefficient of the resistance ($dR/dT < 0$) and ratio $R(2\text{ K})/R(300\text{ K}) \sim 1-2$) are inherent for different disordered systems in the vicinity of metal-insulator transition. WL and EEI effects define the temperature dependence of conductivity of these systems [4].

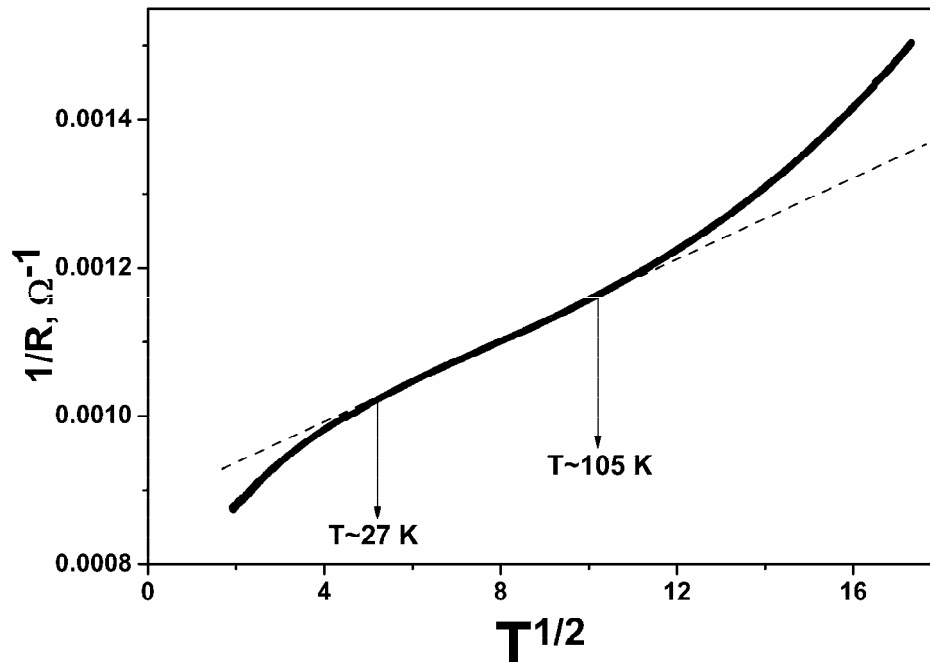


Figure 3. Temperature dependence of resistance of SnO₂ film in the scale $1/R - T^{1/2}$ is shown. Dashed line corresponds to linear approximation of experimental data in the intermediate temperature range.

At low temperatures temperature dependence of conductivity for 2D disordered systems can be expressed as [6]:

$$\sigma_{2D} = \sigma_0 + aG_0 \ln \frac{T}{T_0} + K_{ee} G_0 \ln \frac{kT\tau}{\hbar}, \quad (1)$$

where first term is a constant related to the residual conductivity of the system at $T=0$ K, the second and the third term are the temperature dependence of conductivity due to effects WL and EEI, respectively. Thus, according Eq. (1) both the WL and EEI produce $\sim \ln T$ dependence of conductivity of 2D disordered systems.

Temperature dependence of conductivity for 3D disordered systems follows the law[7]:

$$\sigma_{3D} = \sigma_0 + \alpha T^{1/2} + \beta T^{p/2}, \quad (2)$$

taking into account both WL and EEI effects. The first term is a constant related to the residual conductivity of the system at $T=0$ K, the second and the third terms takes into account the effects of EEI and WL, respectively. If the characteristic length parameters, describing WL and EEI (inelastic scattering length $L_\phi = (D\tau_\phi)^{1/2}$ and thermal length $L_T = (D\hbar/k_B T)^{1/2}$, respectively, where D being the diffusion constant, τ_ϕ is the inelastic scattering time), exceeds the thickness of the system, the temperature dependence of the resistance follows a behaviour inherent for 2D disordered systems. As far as L_ϕ and L_T are temperature dependent parameters, which decrease when the temperature rises, a crossover from the $\sigma(T)$ behaviour typical for 2D systems to the behaviour inherent for 3D disordered materials is expected as the temperature increases. As one can see from inset to Fig.2, $\sim \ln T$

dependence of conductivity is observed in the low temperature range (up to ~ 27 K). In the temperature range $T \sim 27$ -105 K dependence of conductivity on temperature can be linearized in scale $\sigma - T^{1/2}$ as shown in Fig.3. Thus, we can assume existence of crossover from 2D to 3D behaviour for SnO_2 films at $T \sim 27$ K with prevailing of quantum corrections to conductivity due to EEI.

3.2. Magnetic field dependences

MR data measured in pulsed magnetic fields up to 27 T and in the temperature range 2.5-80 K are shown in Fig.4. The negative MR in the whole range of available magnetic fields was observed. In the low-temperature range upturn from negative to positive MR with tendency to saturation in the high magnetic field range was observed. The minimum position of negative MR shifts to higher fields as the temperature rises. At temperatures $T > 15$ K only negative MR was observed.

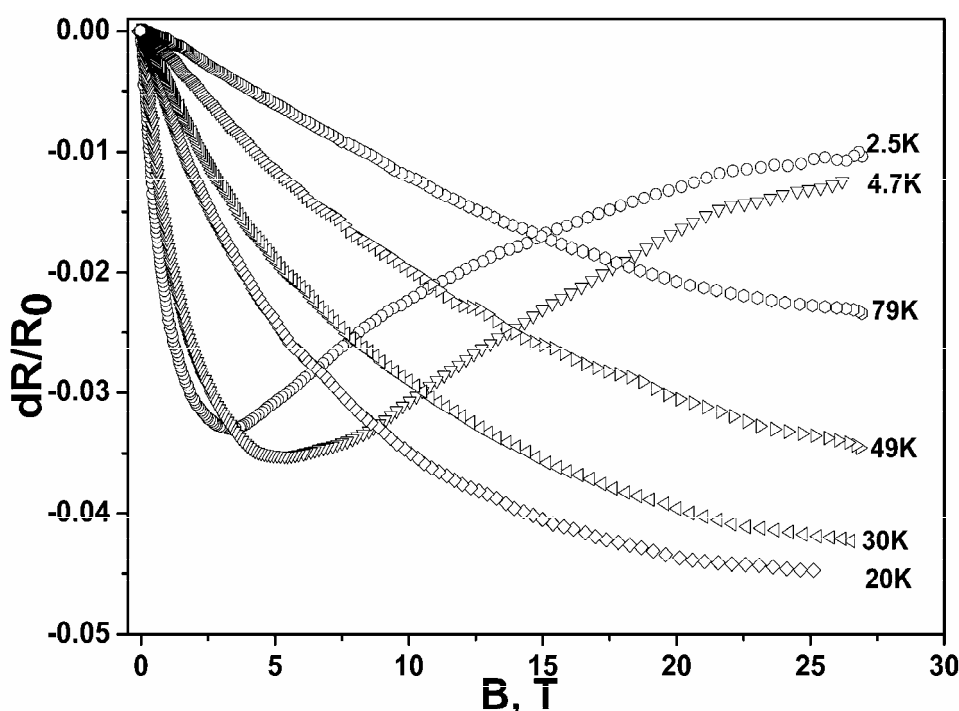


Figure 4. Magnetic field dependences of normalized magnetoresistance of SnO_2 films obtained from SnCl_2 solution, measured in the temperature range 2.5-80 K.

Negative MR due to WL effect usually dominates at higher temperatures and lower fields, while at lower temperatures and higher fields, such that the energy difference between the Zeeman split levels is much more than the thermal energy ($g\mu_B H \gg k_B T$) electron-electron interactions should be taken into account, providing possibility to observe positive MR.

Existence of both negative and positive MR indicate on the possibility of interplay of EEI in addition to WL effects in polycrystalline tin dioxide films. Detailed analysis of MR data in order to distinguish influence of WL and EEI by means of method proposed in [8] will be reported elsewhere.

4. Conclusion

Quantum corrections to conductivity of thin polycrystalline tin dioxide films, fabricated by means of combination of ion-exchange processes in polymer films with successive gas transport reaction, were observed. Both weak localization (WL) and electron-electron interactions (EEI) effects can influence on the conductivity of films. A crossover from 2D to 3D behaviour was observed at temperature $T \sim 27$ K.

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