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The generalized Jonscher's relationship for conductivity and its confirmation for porous structures

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ABSTRACT

The theoretical generalization of the Jonscher's relationship for the complex conductivity of carriers moving in self-similar medium is derived. It is shown that the correction derived enters to more general expression, which, in turn, we define as the generalized Jonscher's relationship. The basic idea which was used for the derivation of the relationship is based on the supposition that disordered medium has self-similar property. The derived relationship is confirmed on dielectric spectroscopy data related to sodium nitrite embedded to porous glasses. Based on new relationship there is a possibility to extract additional information about relaxation processes of a system of dipoles from the processes related to conductivity. It is important in the cases when the contribution to relaxation peaks is small and unnoticeable on the background of essential domination of processes related to conductivity.

1. Introduction

As it has been noticed in the review [1] namely the 70th of the last century became the reference point of the "universality" period in the physics of disordered media. In this period one can observe the first evidences in favor of the universal frequency behavior of the conductivity complex for different media [2–4] on the mesoscale region. Approximately in the same time A. Jonscher in his papers [4–6] and later in his first monograph [6] based on numerous experimental observations introduced a simple correction in frequency behavior of the complex conductivity, which (in his interpretation) accepted the following final form [6]:

$$\sigma(\omega) = \sigma_0 + A(i\omega)^{\nu}, \tag{1}$$

where the power-law exponent ν is located in the limit $0<\nu<1$. This correction was unusual because from the theoretical point of view it is difficult to develop a model explaining the dependence of such kind. There are attempts to associate this correction with near-electrode polarization phenomena. In paper [7] the electrode surface is presented in the form of the Cantor's comb and the corresponding self-similar circuit was constructed. The expression for impedance obtained allows to explain the correction (1). But the results of this model are correct only in low-frequency region and this conclusion forced to think that this asymptotic result can follow from more general expression. Similar and asymptotic results taking into account the log-periodic corrections have been obtained in [8]. As far as we know, at the given moment the general expressions for conductivity covering a wide frequency range are absent [9]. In addition in some papers appeared in the last time this correction is considered as doubtful. Some authors started to suggest new dependences for description of the frequency behavior for the complex conductivity. These expressions one can find in table that is given in the comprehensively written review [1].

In this paper we are going to give new evidences to support relationship (1) alongside with paper [8], where the oscillating properties for the a.c. complex conductivity have been derived. We are going to show also that the Jonscher's correction in (1) follows from more general relationship, which, in turn, is confirmed experimentally.

2. Theoretical derivation of the generalized Jonscher's relationship

As it is known under the application of external electric field an electric current is appeared. The density of the total current contains the current of free carriers $\mathbf{j}_0 = \sigma_0\mathbf{E}$ and the polarization current $\mathbf{j}_p = \partial\mathbf{P}/\partial t$. In the case of the harmonically oscillating field we receive the following expression for the total current density

$$\mathbf{j}_{tot} = \sigma_{tot}(\omega)\mathbf{E} = \mathbf{j}_0 + \mathbf{j}_p = \left(\sigma_0 + \frac{i\omega}{4\pi}(\varepsilon(\omega) - 1)\varepsilon_v\right)\mathbf{E}, \tag{2}$$

here $\varepsilon_v = 8.887\times10^{-13}$ F/m - is the dielectric permittivity of a vacuum. The total expression for the current contains also the current of

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