Impedance spectroscopy: A non-power law approach and its exploration for the electrical characterization of materials

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Abstract: The electrical response in ion conducting solids is often graphically represented by means of a plot in the complex impedance or admittance plane. In many cases these impedance plots are depressed semicircles and its physical basis is a challenging problem in impedance spectroscopy. An equivalent circuit consisting of a constant phase element with resistors and power law are often used to describe such semicircles. Recently, a simple non-power law approach is proposed and it describes the depressed semicircle in terms polarization of charges and their rate processes. At a given thermo-dynamical condition, the model shows the existence of two stages of polarization processes. In first stage, charge carriers \( n_c qZ \) is involved in the polarization and hopping conduction. It is a short time fast process. In second stage, the charge carriers \( n_c qZ \) involved in the initial stage divide into (i) \( gn_c qZ \) and (ii) \( (1-g)n_c qZ \) in the lattice sites of material and involved in the polarization and hopping conduction, where \( n_c \) charge carrier density, \( qZ \) is the ionic charge, \( g \) is a phase memory delay polarization exponent \( 0<g<1 \). In time scale, the second stage is a slow or delayed process and the delay is with respect to the first process. The charge \( qZ \) follows exponential decay polarization, whereas, the charges \( gqZ \) and \( (1-g)qZ \) follow delayed exponential decay polarization. The polarization rates, energy barrier, and equilibrium current-current fluctuation of polarizing charges \( gqZ \) and \( (1-g)qZ \) are correlated and coupled with \( qZ \). The impedance spectroscopy is shown to be related to the delayed exponential decay polarization. The present approach demonstrates, that, impedance spectroscopy contains the microscopic process in terms macroscopic measurable impedance, and it is a powerful tool for the electrical characterization of wide variety of materials.

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