Hopping Charge Transport in Honeycomb Carbon Network Structures

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Honeycomb-type nitrocellulose network patterns based on a hexagonal elementary cell with a diameter of about 2 μm have been fabricated by means of a self-organized preparation process. Our method takes advantage of the spreading of a drop of the initial polymer solution on the surface of distilled water cooled down to a temperature of 3 to 5°C and the subsequent influence of the water vapor (i.e., air with relative humidity in the range from 19 to 100 %) on the resulting polymer thin film. In the following, an advanced structuring model is proposed capable to explain the morphology and growth of the individual cells inside the network obtained in the experiment. The values of their electrical conductivity extending steadily from insulator to metal behavior distinctly change via heat treatment under vacuum conditions and at process temperatures ranging from 600 to 1000 °C. Upon variation of the ambient temperature T from 4.2 to 295 K, four different transport mechanisms can be unveiled. For the case of carbon nets, the conductivity of which is far beyond the metal-insulator transition, the specific resistivity ρ depends on T as $\rho(T) \propto T^{-b} \exp\left(\left[T_0/T\right]^{1/p}\right)$. In the low-temperature regime, a Coulomb gap in the density of states located near the Fermi energy level occurs, that means, the characteristic value of the exponent is p = 2. At high temperatures, the pre-exponential part $\rho(T) \propto T^{-b}$ dominates. In the intermediate temperature range, we disclose Mott's hopping law with p = 3. The electrical field dependence of the variable range hopping process of porous carbon networks is examined in the region of validity of the law ln $\rho(T) \propto T^{-1/2}$. We show that the electrical conductivity σ caused by thermally nonactivated charge carriers at high fields complies with ln $\sigma(E) \propto E^{-1/3}$. The current density j changes as ln $j(E) \propto E^{-1/6}$. The temperature dependence of the threshold electrical field E_{th}, which characterizes the transition from the low-field to the high-field regime, follows $E_{\rm th} \propto T^{1.5}$.

Key words: Self-organized Network Structures; Variable Range Hopping Charge Transport; Metal-insulator Transition, Coulomb Gap.