Nanoscale physics
Quantum and Semi-Classical Electron Transport in Metal Films of Nanometer Thickness

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Rapid development of modern nanoelectronics demands electrically stable metal covering with minimal sizes. Physical properties of such metal samples are essentially differ with properties concerning thick layers which are used in nowadays nanoelectronics devices. This difference first of all is caused by prevailing influence of size phenomenon on metal films structure and electrical parameters. Such phenomenon is known as "dimensional effect". The peculiarity impact of "dimensional effect" on electron transport in limited metal samples is discussed. Modern theoretical and experimental data of electron charge transport in ultrathin (2-10 nm) electrically continuous metal films (temperature coefficient of resistance $\beta > 0$) under condition $d < l$ were reviewed, here d is the film thickness and l is the charge mean free path.

The deposition of ultrathin electrically continuous metal film on the surface of dielectric substrate is a considerable difficult problem due to the action of surface tension forces. That is preventing to grow the condensed metal in layer by layer regime. As a result there is some critical thickness of layer dc at which metal film starts to conduct the current (percolation threshold is observed here). The technological features of film formation (the speed of material deposition, the substrate temperature, the modes of further heat treatment and others) defines the average of dc as well as the conduction properties of condensed material, in particular fusion temperature. One of the essential way to decrease d_c may be reached at epitaxial growth of metal film on the oriented substrate. The other is simultaneous utilization of surfactant underlayers preliminary deposition of superficially active substances of a subatom thickness on dielectric substrate and so called low temperature "quench condensed" method wich prevent coalescence in metal condensates. This technique allowed the formation of ultrathin conductive coverings. In particular, the Hall voltage and conduction of 1-3 nm thickness chrome films deposited on germanium underlayers were performed [1]. The electron transport phenomena are essentially influenced on electron scattering at film surface. The surface impact in charge carriers total relaxation time becomes comparable with bulk when the mean free path of electron is commensurable to the metal film thickness d. The thickness dependence of kinetic parameters of electrically continuous metal films usually is described within the framework of the classical and internal dimensional effect theories [2].

Further reduction of metal film thickness when the electron mean free path satisfies the condition $d < l$, the quasi-ballistic electron transport in a film (electron power spectrum in metal film remains unchanged) is observed. Thus surface scattering in metal film becomes prevailing. Macroscopic surface inhomogeneity has essential influences on surface scattering because of the mean linear grain sizes,

which are commensurable to film thickness. The quasi-ballistic electron transport in metal films can be described by size dependencies of kinetic coefficients proposed in Namba and Wissman theories [2]. The treatment of experimental data by Namba and Wissman theories gives the reliable calculated value of the average amplitude of one-dimensional surface asperity *h*. The provided quantity h well agrees with direct STM and AFM metal film surface investigation.

When the film thickness does not exceed 5 - 8 nm the quantum effects which have influence on electron transport in film are possible. Quantum size effects are most brightly displayed in semimetal films. An electron de-Brogle wave length in these materials in 10 times exceeds inter atomic distances and consequently the interference of electronic waves is influenced poorly by imperfections of film surface. In metal films the situation is essentially different as a de-Brogle electron wave length is commensurable to inter atomic distances. Therefore, to observe oscillation of the kinetic coefficients in thin metals layers it is necessary to provide low temperatures and high quality surface structure. In the electron transport quantum regime the laws of residual conductivity size dependences $\sigma_{res}=1/[\rho(d)-\rho_{\infty}]$ takes place. The theoretical expressions are most convenient for direct experimental comparison with theoretical data has been developed by Fishman and Calecki [3]. Modern theoretical approaches of quantum size effect in kinetic phenomena of metal films are based on assumption that the metal sample electronic structure is the same as in bulk materials. Quantum size effect in metal film is due to limitation of electron system along Z axis which perpendicular to the film surface. The existed theory of quantum size effect in metal films has some difficulties due to model assumptions which do not take please in real metal films. That is why we developed one dimension model of metal films conductivity in Boltzmann approach for quantum electron transport which tries to overcome such difficulties [4]. The fluctuation of film boundary has dramatic influents on electron spectra. It changes electron scattering under quantum size effect. In the frame work of developed model size dependences of metal films conductivity were calculated. The developed model was used for quantitative description of the experimental data of monocrystalline $CoSi_2$ films and fine-grained gold metal films. In the film thickness ranges of the quantum electron transport and transition to the semiclassical electron transport the comparison of calculations results of metal film size dependences conductivity were compared for our model with others theoretical approaches. The developed quantum model of charge transport in films with metallic conductivity successfully describes the transition from purely quantum to semiclassical charge transport in comparison to modern quantum theories [4]. This was possible because the proposed model considers the perturbation of energy states in the whole volume of the film due to the existence of macroscopic inhomogeneities on the metal film surface.

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