Quantum and Classical Size Effect in "Quench Condensed" Ultrathin Metal Films

Stasyuk Z.V., Bihun R.I.

Ivan Franco Lviv national university, Lviv, Ukraine.

Thin layers of substance are basic elements of many devices of modern electronic techniques. The further development of electronics is impossible without microminiaturisation of electronic systems by nanotechnology, in particular, by techniques of electrically stable ultrathin-thickness covering formation. Properties of ultrathin slabs can essentially differ from properties concerning thick layers which are used in nowadays engineering. This difference first of all is caused by prevailing influence of the surface phenomena on ultrathin layer structure and electric parameters.

The current theoretical and experimental researches on electron charge transport in ultrathin (layer thickness are 2-10 nm) electrically continuous metal films (temperature coefficient of resistance $\beta > 0$) under the condition of inequality realization $d < l$ were analysed and reviewed. Here d is the film thickness, l is the charge mean free path. The peculiarities of film structure are meant as crystal lattice parametres and the crystalline average linear sizes.

The fabrication of ultrathin electrically continuous metal film on dielectric substrate surface is a problem of considerable difficulty due to the action of surface tension forces. These phenomena lead to coalescence of metal particles. As a result there is some critical thickness layer d_c at which current starts to flows (*percolation threshold* is observed here). The technological features of film formation (the speed of material condensation, the substrate temperature at layer deposition, the modes of further heat treatment) defines the average of d_c as well as the properties of condensate material, in particular fusion temperature. Essential decrease d_c may be reached at epitaxial growth of metal film on the oriented substrate. The other effective way of d_c decreasing is preliminary deposition of surfactant underlayers of superficially active substances of a subatom thickness on dielectric substrate or so called "quench condensed" method wich prevent coalescence in metal condensates. This technique allowed the formation of ultrathin conductive coverings. In particular, the Hall voltage investigation on 1-3 nm thicknees chrome films deposited on surfactant germanium underlayer was performed in [1]. The electron transport phenomena are essentially influenced by electron scattering on film surface when the mean free path of electron becomes commensurable to the thickness of a metal film d. Thus the contribution of surface scattering in the total electron relaxation time is close to the contribution of bulk scattering. The thickness dependence of kinetic parameters of electrically continuous metal films is described within the framework of the classical and internal size effect theories [2].

With further reduction of metal layer thickness when the electron mean free path satisfies the condition $d < l$, the quasiballistic electron transport in a film (without changes of the power spectrum of electron in metal film) is presented. Thus charge carriers surface scattering in metal film becomes dominating. The contribution of surface scattering has essentially influenced the macroscopic surface inhomogeneity because the mean linear grain sizes are commensurable to film thickness. The quasiballistic 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 the mentioned theories allows the reliable calculation of the average amplitude of one-dimentional surface asperity *h*. The calculated values *h* well coordinate with experimental data of direct STM and AFM 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 interatomic 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 interatomic distances. Therefore, to observe oscillation of the kinetic coefficients in thin metals layers it is necessary to provide high perfection surface structure. In the quantum electron transport range of films thickness the laws of residual conductivity size dependensis $\sigma_{res}=1/[\rho(d)-\rho_{\infty}]$ takes place. The theoretical expressions are most convenient for direct experimental comparison with theoretical data has been received 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 a consequence of electron system size limitation along Z axis in thin film thickness direction. That is why we developed one dimension model of metal films conductivity in Boltzmann approach for quantum electron transport. 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 can more successfully describe 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 energy states in the whole volume of the film due to the existence of macroscopic inhomogeneities on the metal film surface. Perturbation calculated in the linear approximation with assumption that Δh is d independent.

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