Dynamic Conductivity of Ultrathin Copper and Gold Films

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Optical properties of thin metal films provide important information about electron transport phenomenon in metal films. Optical properties of thin silver and gold films have been studied already but fundamental analysis of thickness dependencies of effective optical parameters is lacking. We have developed methodology for assessing transport kinetic parameters on the basis of the thickness dependent optical constants of the films. Ultrathin silver films in the vicinity of percolation threshold have been studied. The critical thickness of the films, mean linear grain size and grain boundary scattering parameters of charge curriers have been determined from the size dependencies of the effective optical constants. The experimental data are in good agreement with those obtained by structural and electron transport investigations of the samples.

Ultrathin metal films have been fabricated by the thermal evaporation on the glass substrate under high vacuum condition (P ~ 10^{-7}torr) at the room temperature. Mass thicknesses of the films have been assessed by the shift of the resonance frequency of the piezoquartz vibrator. Measuring the resistance of the films was carried out electronically by the Ohmmeter Щ301-1. Transmittance and reflectance spectra were measured by broadband spectrophotometer Shimadzu UV-3600.

Dynamic conductivity size dependencies of silver films with thicknesses from 8 to 25 nm in the wavelength range 200-2500 nm were investigated. Optical coefficients n and k have been calculated from the spectral data using Murmann's equations [1]. Optical conductivity, effective charge carrier mass, effective relaxation time, skin depth values were calculated. The critical thickness at which metallic phase is formed was found to be 15 nm. It was determined within the framework of the percolation theory [2] (in the vicinity of the percolation threshold transmittance and reflection spectra do not depend on the frequency). This is confirmed by the dynamic conductivity data which are frequency independent for this thickness value of the film. Another proof is the dramatic change of the sign of the first derivative of the dielectric permittivity on frequency ($d\varepsilon_1/d\nu$) around the thicknesses of silver layer 15-16 nm. The effective mass of the charge carrier was around 1,2 ± 0,2 m_0, which allowed us to use the free electron model [3] in finding of dielectric constants. Mean grain sizes were estimated. They proved to be commensurable with film thicknesses. For example, for film thickness d = 15 nm linear grain size is D =22 nm and for thickness d = 20 nm, D = 25 nm. The skin depth thickness was evaluated [4]. It was shown, that its thickness dependence has descending character up to the percolation region. For thin films with thicknesses above 15 nm this parameter remains constant and approximately 25 nm. Structural investigations of the films showed that grain sizes of the samples similar to those obtained by the optical studies. The intergrain tunneling coefficient for thin silver films with metallic type conduction were calculated. It is value about t ~ 0,6-0,7. The data is in good agreement with those investigations by the direct electro transmission microscopy of the films in the framework of grain boundary scattering theories.

On the basis of the curried out optical and structural studies was found kinetic charge transport parameters for the silver films with the thicknesses 8-25 nm. It is shown, that the average linear grain sizes obtained in different ways are the same and are commensurable with the thickness of the films. Grain-boundary scattering parameters obtained from spectral characteristics are in full agreement with those previously obtained values from electrical resistivity studies of the films. Effective critical thickness of silver film with metal phase conductivity was estimated and, it was found to be 15 nm.

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