Anomalous scattering of photoinjected electrons in an amorphous film

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(Submitted 28 January 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 7, 400–402 (5 April 1978)

An anomalously strong scattering of photoinjected electrons was observed experimentally in an amorphous film. At a distance $L \approx 5$ Å, the electron loses an excess energy of ~ 1 eV. This result points the need for developing a quantum-mechanical approach to photoemission in a disordered medium.

PACS numbers: 79.60.–i, 73.60.–n

The absence of long-range order in amorphous films leads to a strong scattering of electrons, as a result of which the kinetic-effect signals, which make it possible to determine the mean free path, are too small to be measured. The mean free path of electrons in amorphous films can be determined in experiments on the scattering of photoinjected electrons on the path to the maximum potential of the image force. The quantum yield of the photoemission depends exponentially on the distance X_m between the maximum of the image-force potential and the interface between the emitter and the dielectric[1]

$$J = A(h\omega)(h\omega - \Phi_0 + \beta_m \sqrt{E})^K \exp\left(-\frac{X_m}{L}\right) = J_0 \exp\left(-\frac{X_m}{L}\right); \quad X_m = \frac{\beta_m}{2\sqrt{E}} . \tag{1}$$

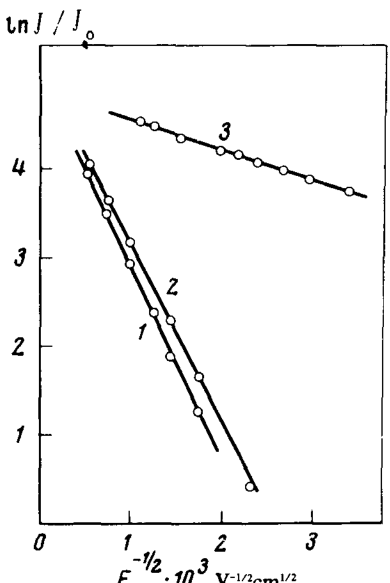

FIG. 1. Field dependence of the photoemission current (photoemission of electrons from silicon) for $Si_xN_yO_z$: 1—$h\omega$=4.5 eV, 2—$h\omega$= 5.0 eV, 3—for SiO_2, $h\omega$=5 eV.

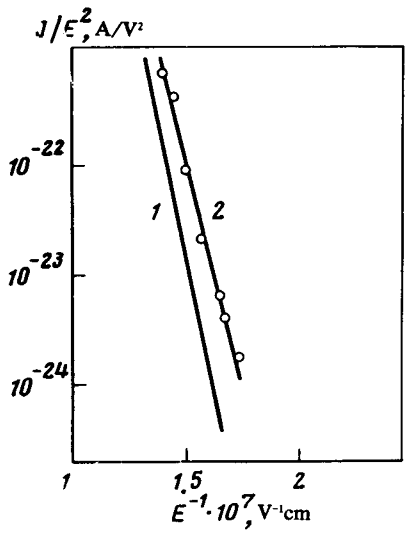

FIG. 2. Current-voltage characteristic of the dark current of SiO_2 (1) taken from[6], and of $Si_xN_yO_z$, in coordinates corresponding to the Fowler-Nordheim law.

Here $\beta_m = \sqrt{q^3/4\pi\epsilon\epsilon_0}$ is the Schottky constant, ϵ is the optical dielectric constant, E is the intensity of the electric field in the dielectric, and K is a parameter whose value depends on the mechanism of the scattering in the emitter.[2]

We have performed experiments aimed at determining the mean free path of electrons in amorphous films of silicon oxynitride ($Si_xN_yO_z$), which is close in composition to SiO_2. The nitrogen content, according to an x-ray spectral analysis, was ~ 5 at.%, corresponding to a nitrogen volume concentration $\sim 10^{21}$ cm^{-3}. Figure 1 shows the dependence of the quantum yield of the photoemission on a quantity proportional to the value of X_m for the investigated $Si_xN_yO_z$ films and for SiO_2. From the data on Fig. 1 we obtain the values $L = 535$ Å for $Si_xN_yO_z$ and SiO_2, respectively. The last value agrees well with the known published data.[1] L is taken in[1] to mean the path averaged over the momentum, but it was shown later[3] that the momentum relaxation cannot explain the experimentally observed strong dependence of the quantum yield on X_m. It is indicated in these papers that the exponential dependence of J on X_m is due to energy relaxation.

It is known that the concept of the mean free path can be introduced in the case when $\lambda_D < L$. The de Broglie wavelength of the electron can be estimated knowing the excess of its energy above the barrier. For $\hbar\omega = 5$ eV and $\Phi_0 = 4$ eV (the height of the barrier was determined experimentally from the spectral dependence of the photocurrent) we obtain $\lambda_D = h/mV = h/\sqrt{2m/(h\omega - \Phi_0)} = 12.3$Å, which is double the mean free path obtained in the experiment. This result indicates that the notion that the electron moves like a classical particle is insufficient, and that a quantum-mechanical theory of photoemission in strongly scattering scattering media must be developed. An attempt of this type was made in,[4] where scattering of photoelectrons by a surface lattice of adsorbed atoms was considered. The cause of the anomalously strong scattering of the electrons in the investigated films, in our opinion, is the strong disorder of the oxynitride of silicon produced when nitrogen atoms are introduced into the SiO_2

matrix. The latter follows from an investigation of the radial distribution function of the atomic density.

The strong disorder of $Si_xN_yO_z$ (compared, for example, with SiO_2) is in our opinion the cause of the strong fluctuation of the potential, but, in contrast to the large-scale-fluctuation model proposed by Shklovskiĭ,[5] the characteristic scale of the fluctuations in $Si_xN_yO_z$ is of the order of the dimensions in which the short-range order is conserved. It is interesting to note that despite the strong scattering of the electrons in the mobility zone, the below-the-barrier tunneling of the electron from the silicon to $Si_xN_yO_z$ is well described, just as for SiO_2, by the well know Fowler-Nordheim law

$$J = \frac{qE^2}{8\pi h\Phi_0} \exp[-4(2m^*)^{1/2}\Phi_0^{3/2}/3hqE]. \quad (2)$$

The effective mass determined from experiment (Fig. 2) is $m^*/m_0 \approx 0.4$, which is close to the corresponding value for SiO_2. Thus, in the investigated films we observed no effects due to resonant tunneling, which might be expected in strongly disordered materials because of the presence of localized states in the forbidden band.

The authors thank A.S. Ginovker and V.M. Popov for synthesizing the $Si_xN_yO_z$ films, and to A.V. Chaplik for useful discussions.

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