of the period of the hologram-grating in the second exposure is due essentially to the fact that the plates are slightly wedge-shaped and the ends of the crystals are slightly rounded), as a result of which the diffracting properties of the gratings are slightly altered and the spectrum is accordingly distorted.

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OBSERVATION OF QUANTUM OSCILLATIONS OF CONDUCTIVITY IN THIN ANTIMONY FILMS

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The quantum size effect in thin films, consisting in the appearance of an oscillatory dependence of the kinetic characteristics of films on their thickness, is considered in a number of theoretical papers [1,2]. The first to report experimental observation of this effect in Bi film were Ogrin et al. [3]. The presence of quantized states in Bi films was confirmed in [4] with the aid of the tunnel effect. It must be noted that observation of a clear-cut dependence of the electric characteristics of thin films is hindered by the fact that the properties of thin films are not exactly reproducible, and that the characteristics exhibit a large scatter. This is due to the inflence of many often-uncontrollable parameters describing the condensation conditions and determining the scatter of the structural characteristics of the films, thus affecting in turn the scatter of their electric properties. Attempts to solve this problem by using many samples are quite hopeless in the case of antimony, since the expected period of the oscillations is in this case 30 Å (as against about 400 Å for Bi).

We investigated antimony films using samples of variable thickness. They were in the form of long strips (1 x 70 mm) with potential leads ("whiskers") every 2 mm. The thickness variation of the sample (by an approximate factor of 2) was effected by naturally varying the density of the molecular beam in space while the metal was being evaporated from a cylindrical crucible. The density distribution of the molecular beam was investigated by us in preliminary experiments. The film thickness (up to 300 Å) was determined with the aid of a plot we obtained for the optical density S of the Sb films vs. the thickness d by a method described in [5].

When the antimony is condensed on a substrate of room temperature, an amorphous phase is produced at first. When a thickness exceeding 100 Å is reached, crystallization in the film begins [6] and spreads from the thicker to the thinner region. According to our observations, the boundary of the crystallized region in a film of variable thickness corresponds to a critical thickness $d_c \approx 80 - 90$ Å, at which a transition occurs from a continuous layer of amorphous antimony to an island structure having no conductivity. The crystallization of the amorphous antimony is due to the production and growth of spherolites - polycrystalline formations with a radial ray-like structure, having a clearly pronounced texture, viz., the (111) plane of the crystallites is parallel to the film surface. The crystalline antimony layer thus has local regions of high perfection, owing to the existence of the texture, to the relatively small disorientation angles of the contacting crystals, and to the relatively large dimensions of the latter (> 10^{-5} cm).

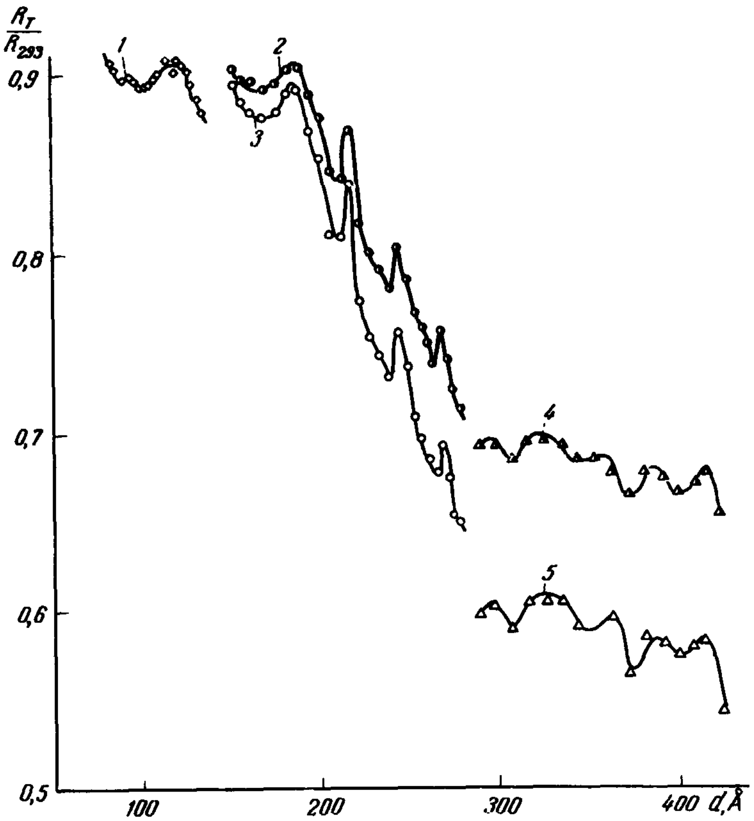

Fig. 1. R_T/R_{293} vs. thickness d of antimony film. Temperature T = 4.2°K for curves 1, 2, and 5 and T = 78°K for curves 2 and 4.

The procedure described above has enabled us to observe that when the thickness of thin antimony films is varied there are produced conductivity oscillations attributable to the quantum size effect [1,2]. Figure 1 shows several typical plots of $R_T/R_{293}(d)$, where R_T is the resistance at 78 or 4.2°K. All the R_T/R_{293} plots obtained by us reveal a practically constant period, $\Delta d \approx 28$ Å. The relation [2]

$$\Delta d = \pi\hbar(2M\Delta)^{-1/2} = 6{,}15\cdot 10^{-8}\left(\frac{M}{m_0}\Delta\right)^{-1/2}, \qquad (1)$$

where $1/M = 1/m_e + 1/m_h;\ \Delta = (\epsilon_F)_e + (\epsilon_F)_h$ (in eV)

(m and ϵ_F are respectively the effective mass and the Fermi energy for the electrons and holes) allows us to determine the value of $(M/m_0)\Delta$, which we found to be 0.048 eV. If we take for Δ a value 0.2 eV [7, 8], we get $M \approx 0.25m_0$. Different authors [7-12] give greatly differing values for m_e and m_h of Sb. If we assume for the component m_{33} of the electron effective-mass tensor the most frequently encountered value $m_e \approx 0.5m_0$ (see [9-12]), we get for the holes $m_h \approx 0.5m_0$, which lies between the values given in [11] and in [7, 8, 12].

For comparison with the theory [2], we attempted to obtain the true conductivities of the films (Fig. 2). To take into account the geometric dimensions of the individual sections of the sample, we used an object that exhibits no conductivity oscillations with variation of the thickness to determine the correction coefficients that allow for the inaccuracy of the mask geometry. We can point to the following peculiarities of the curves of Fig. 2, which agree qualitatively with the predictions of the theory [2] constructed for a perfect film, for a specular reflection of the electrons, and for low temperatures (curve on the left): a) the conductivity increases with thickness, but at a faster rate than follows from [2]; b) the variation of the conductivity takes on a jumplike character at certain values of the thickness above 200 Å. The latter is proof that scattering has a relatively small effect on the change of the state density at these thicknesses. Thinner films exhibit smeared oscillations of small amplitude and with a weak temperature dependence. These facts in conjunction with the very rapid decrease of the conductivity with decreasing d and the weak temperature dependence of the conductivity (increase of R_T/R_{293} to ∿ 0.9 in Fig. 1) offer evidence that the film defects become more plentiful when the thickness decreases. The amplitude of the oscillations on Fig. 2 decreases markedly with rising temperature [13] (this is also evidenced by the oscillations of R_T/R_{293} on Fig. 1); however, the oscillations do not disappear entirely even at room temperature, owing to the relatively large (compared with kT) distance between the energy levels near the Fermi energy (thus, for example, $(\Delta\varepsilon)_F \approx 60 \times 10^{-3}$ eV when d = 200 Å).

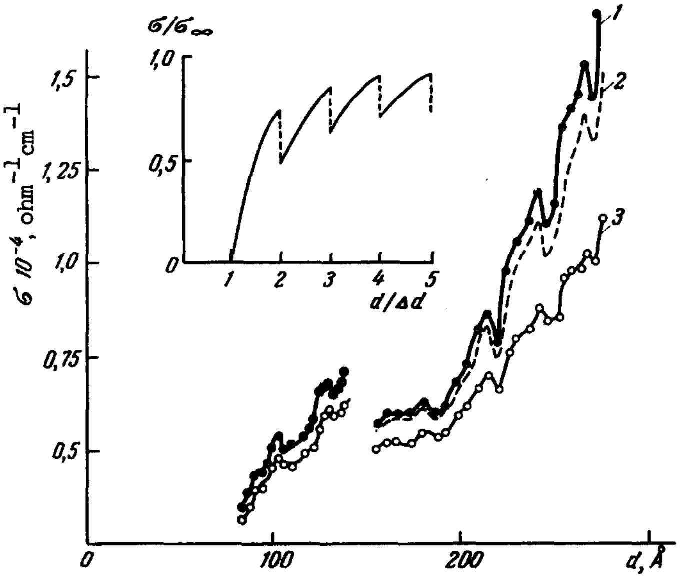

Fig. 2. Conductivity vs. Sb film thickness d at 4.2°K (1), 78°K (2), and 293°K (3).

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ACCELERATION OF IONS IN ELECTRON BEAMS

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The process of acceleration of ions in electron beams was observed in 1960 in experiments on the formation of ion [1] and electron beams from vacuum-spark plasma.

A schematic diagram of the experiments is shown in Fig. 1. Plasma from a spark source [2] (1) proceeds through the emission aperture (2) into the accelerating gap ℓ. An alternating or constant (electron-accelerating) voltage V is applied to the gap. At the instant when the voltage is turned on there may be no plasma in the gap; the plasma may also fill the gap fully or in part. The ion acceleration develops when the electron current is unstable. The gist of the phenomenon is that at the instant when the electron current is interrupted a certain number of plasma ions is accelerated in the direction of motion of the electron beam, i.e., in opposition to the externally applied potential difference. The acceleration is effected in the gap ℓ and in the electrode cavity (3) by the self-consistent fields. The ion energies increase with V and can exceed eV by 10 - 100 times. In particular, at V = 200 - 300 kV we obtained protons with energy up to 4 - 5 MeV and carbon ions with energy up to 15-20 MeV. The average number of accelerated protons or deuterons reached 10^{11} - 10^{12} per pulse.

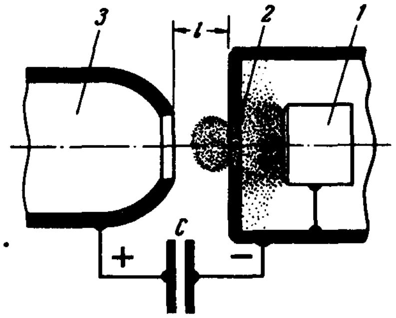

Fig. 1. Schematic diagram of experiment.

It follows from the mass spectrograms of the ions (parabola method) that the averaged energy spectrum of the ions is quite broad (Fig. 2). The maximum ion energies do not depend on the multiplicity of the charge.

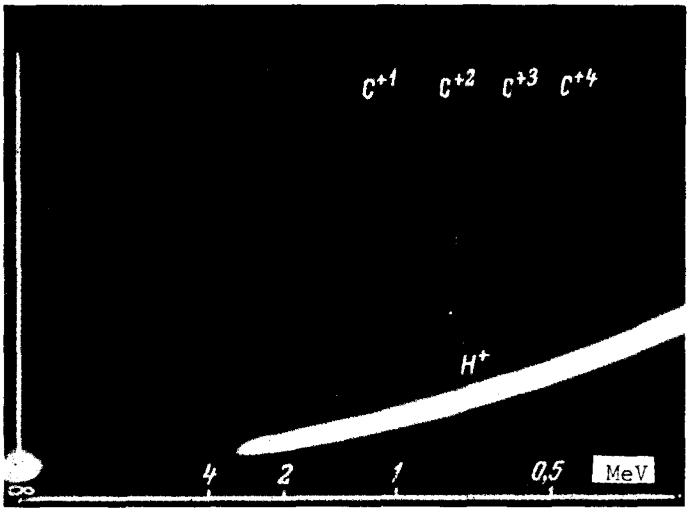

Fig. 2. Mass spectrogram of ions accelerated in electron beam. The indicated energy scale pertains to protons.