OSCILLATIONS OF THE CONDUCTIVITY OF TUNNEL CONTACTS CONTAINING URACIL IN THE BARRIER LAYER

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The presence of impurity molecules in the barrier layer of tunnel junctions leads to the occurrence of additional channels for the penetration of the electrons through the potential barrier; these channels open up at definite values of the voltage. For the cathode electrons whose energy corresponds to localized electronic energy levels of the impurity molecules, resonant passage through the barrier is possible, and the probability of such processes can greatly exceed the probability of ordinary tunneling [1]. The energy of the electron is conserved in this case, and consequently the tunneling transition is elastic. These processes are manifest on the current-voltage characteristic in the form of jumps of the current at voltages corresponding to the system of electronic levels of the impurity molecules. In the present paper we report observation of oscillations of the conductivity of tunnel junctions containing uracil[1] in the barrier layer. It is assumed that the periodic structure of the tunnel characteristics is the result of tunneling of the electrons through localized levels, which are nearly equidistant in the energy, in the barrier.

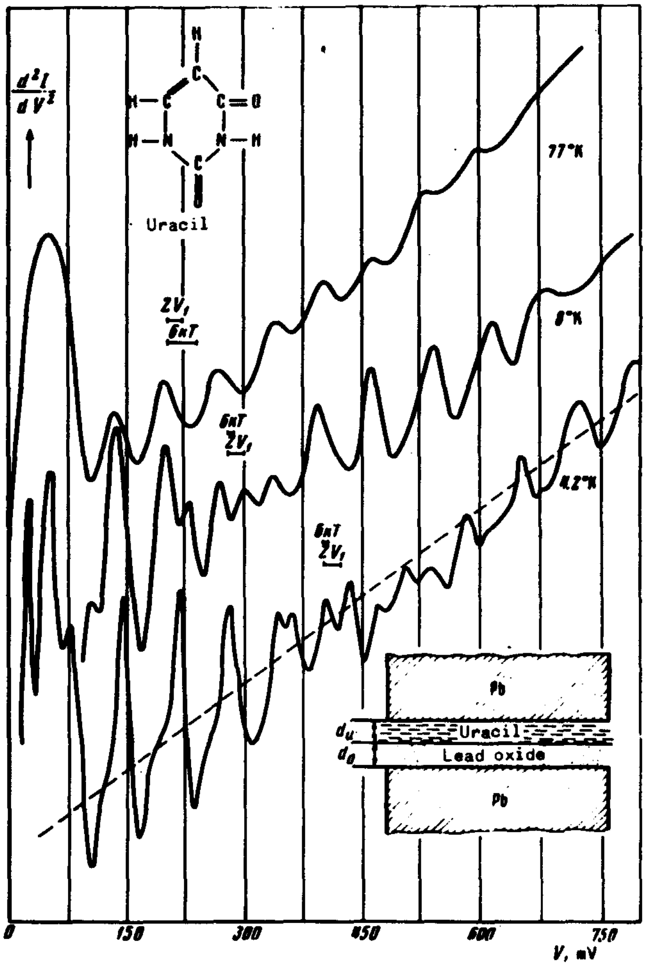

Fig. 1. Tunnel characteristics of sample No. 2 at different temperatures. The position of the origin on the ordinate axis is different for the different curves.

We used in the experiments tunnel contacts of lead and its oxide. It was shown earlier [2] that the tunnel spectra of Pb - PbO - Pb junctions do not contain bands at voltages exceeding 75 mV. A thin layer of uracil was deposited on the oxidized lower film by sputtering in vacuum immediately prior to the deposition of the upper film. The average thickness of the layer was monitored against the exposure time at a known rate of condensation. At an evaporation temperature 140 - 150°C, the uracil becomes sublimated without decomposition,

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[1] Uracil is a nitrogenous base entering in the composition of RNA molecules and less frequently in DNA (Fig. 1).

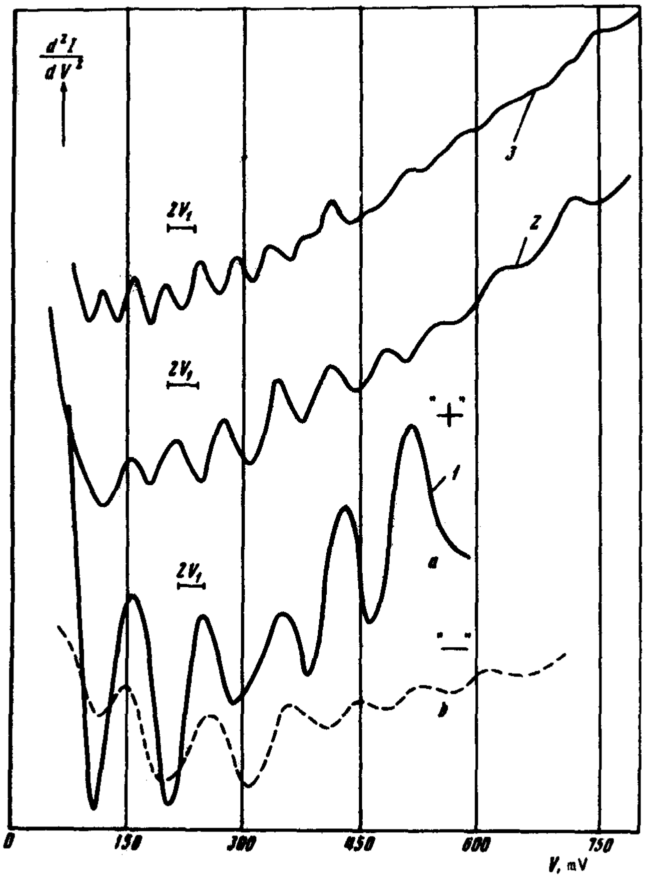

Fig. 2. Tunnel characteristics of junctions containing different amounts of uracil. The numbers next to the figures correspond to the numbers of the samples in the table. T = 4.2°K. Curve 1b was plotted at T = 77°K. The polarity indicated near curves 1 corresponds to the lower oxidized film. For the remaining curves, the polarity of the lower film is negative.

as is confirmed by the absorption spectra in the ultraviolet and infrared regions. As a rule, in one experiment we prepared several junctions containing different amounts of uracil, making it possible to compare the characteristics of the junctions that differ with respect to this parameter in a sufficiently wide range, but having the same oxide layer. For the measurements we chose only junctions with good tunnel characteristics. At small voltages at $T < T_c(Pb)$ there was always observed on the current-voltage characteristics and its derivatives a distinct gap singularity at $eV = 2\Delta$. At large voltages, phonon singularities were observed in the superconducting Pb [3], and also inelastic tunneling with production of optical phonons in the PbO [4] under the condition that the stronger peaks connected with the resonant tunneling did not overshadow them. In addition, in the entire investigated range of voltages (0 - 750 mV), the current-voltage characteristics of the different contacts were similar and could be approximated over a large section by a cubic polynomial, while the d^2I/dV^2 characteristic could be approximated by a linear relation (disregarding the oscillations) in accordance with the theory [5] (see the dashed line on Fig. 1, T = 4.2°K, and other curves). Consequently, there were no space-charge-limited conduction currents [6]. Since the conductivity oscillations amounted to 0.1 - 1.0% of the background level, they began to be manifest mostly on the $d^2I/dV^2(V)$ characteristics, which are shown in Figs. 1 and 2. Near each curve are indicated the doubled amplitude of the modulating signal $2V_1$ and the thermal spread of the lines $\sim 6\ kT$, which limits the resolving power. Both factors influence the shape of the curve in approximately the same manner, as can be seen from the comparison of the curves at T = 77°K on Fig. 1 and curve 2 on Fig. 2, which pertain to the same sample. It is seen from Fig. 1 that the shapes of at least several lines (V = 150, 225 mV, T = 4.2°K) definitely correspond to bursts of conductivity dI/dV at the jumps of the currents on the current-voltage characteristics. The periodic structure of the characteristics is not connected with the superconductivity of the lead (T_c = 7.2°K) and remains in force even at temperatures of liquid nitrogen (Fig. 1). Figure 2 shows the characteristics of three junctions with different thicknesses of the uracil layer (see the table). There are no oscillations on the characteristics of the junctions containing small amounts of uracil (sample No. 4). It is important to note that the period ΔV of the oscillations increases with increasing thickness d_u of the uracil layer (Fig. 3). This makes it impossible

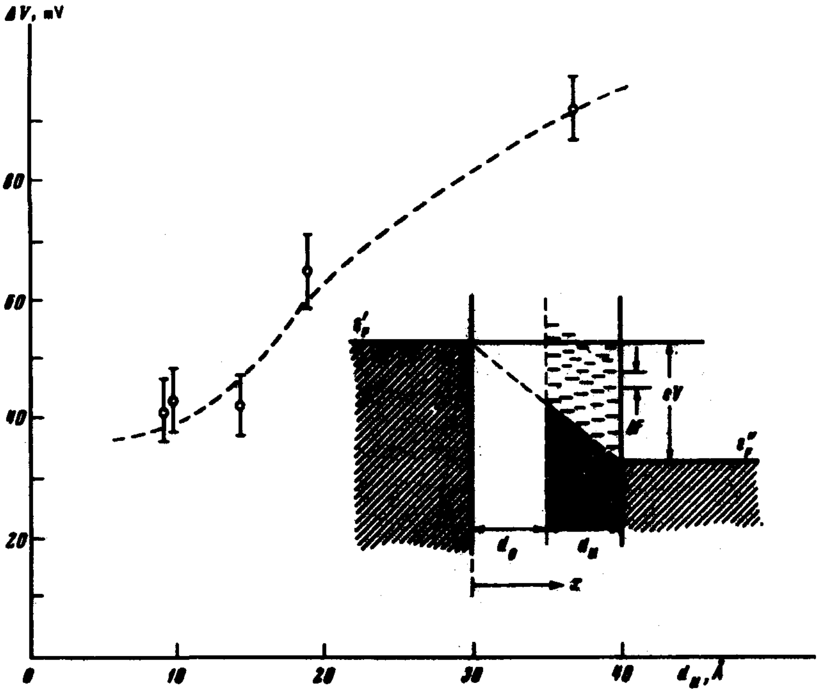

Fig. 3. Dependence of the oscillation period on the thickness of the uracil layer. The insert shows the proposed energy diagram of the junction.

No.of contacts	1	2	3	4
d_u, Å	37	19	14	5
R_N, kΩ	140	81	25	0.73
Contact area, mm^2	0.56 × 0.58	0.88 × 0.5	0.87 × 0.5	0.87 × 0.5
film thickness, Å	870 1100	2000 1000	1100 1100	1500 1000
ΔV period, mV	90	64	41	No oscillations

to relate the observed singularities with any size effect in the uracil film, for then an increase of the dimension should lead to a decrease of the period. It can also be noted from Fig. 2 that the amplitude of the oscillations increases with increasing d_u. The position of the singularities on the V axis does not depend on the polarity of the applied voltage. The characteristics shown in Figs. 1 and 2 correspond to negative polarity of the lower oxidized film, for at this polarity the background conductivity is almost constant in the voltage interval 0 - 750 mV.

It if is assumed that the observed oscillations are connected with the mechanism of resonant tunneling proposed at the beginning of the article, then the observed $dV(d_u)$ dependence can be easily understood. Indeed, let the distance between the localized energy levels be ΔE. The observed period of oscillations ΔV will be a function of the coordinate x that determines the position of the levels inside the barrier: $\Delta V = \Delta E(L/x)$, where $L = d_0 + d_u$ is the width of the barrier (Fig. 3). The probability of resonant tunneling is maximal for the levels located at the center of the barrier, and decreases exponentially when they are shifted towards the edges of the barrier [1]. Therefore the main contribution to the tunnel current is made by levels located closer to the center of the barrier. Consequently, at small amounts of uracil, $\Delta V \simeq \Delta E$ and depends little on d_u:

$$\Delta V = \Delta E(1 + d_u / d_0); \quad x = d_0,$$

and with decreasing d_u the period should approximately double

$$\Delta V(x = L/2) = 2\Delta E,$$

as is indeed observed in the experiment (Fig. 3). The picture is symmetrical with respect to reversal of the voltage, if account is taken of the levels located both above and below the Fermi energy. The most interesting question, namely the origin of such a system of levels, remains open. Generally speaking, these levels may be connected with the energy spectrum of the uracil itself, its complexes with the metal or the oxide, or with the properties of the barrier as a whole. An investigation of the tunnel spectra of uracil in junctions consisting of different metals and oxides, and also the spectra of other bases, will help answer this question.

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LOW-TEMPERATURE QUENCHING OF THE PHOTOMECHANICAL EFFECT IN γ-IRRADIATED NaCl CRYSTALS

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As is well known [1, 2], the mechanical characteristics of alkali-halide crystals with F color centers can change under the influence of light, and previously there were observed the so-called photomechanical effect, i.e., the change of the plastic-flow stress [1], and the photomobility of the dislocations, i.e., the changes of the dynamic properties of the dislocations [2] upon illumination. At the instant of illumination of the deformed crystal by light with wavelength λ_F, corresponding to the maximum optical F-absorption, the electron structure of the F center changes, and this leads to additional slowing down of the moving dislocations, a fact manifest by the growth of the flow stress [1] and a decrease of the dislocation velocity [2]. The equality of the spectral characteristics of the photomechanical effect, the photomobility of the dislocations, of optical absorption, and photoconductivity in colored alkali-halide crystals demonstrates that all these phenomena should be connected with one stage, namely the transition of the F-center electron from the ground to the excited state. It is therefore important to obtain additional information concerning such an excited state, and a feature of the mechanical properties is their selective sensitivity precisely to local changes directly near the dislocation line.