The authors thank P.L. Kapitza for interest in the work. We are sincerely grateful to A.S. Borovik-Romanov for directing the work and for a discussion of the results.

[1] I.E. Dzyaloshinskii, Zh. Eksp. Teor. Fiz. 32, 1547 (1957) [Sov. Phys.-JETP 5, 1259 (1957)].
[2] A.S. Borovik-Romanov and V.I. Ozhogin, ibid. 39, 27 (1960) [12, 18 (1961)].
[3] S.A. Alikhanov, ibid. 39, 1481 (1960) [12, 1028 (1961)].
[4] S. Foner, Rev. Scient. Instrum. 30, 548 (1959).
[5] P.J. Flanders, Preprint, Laboratory for Research on the Structure of Matter, Philadelphia, Pennsylvania, 1971.

DESTRUCTION OF A SOLID BY SUPERDENSE EXCITATION OF ITS ELECTRONIC SUBSYSTEM

D.I. Vaisburd and I.N. Balychev
Tomsk Polytechnic Institute
Submitted 2 March 1972; resubmitted 4 April 1972
ZhETF Pis. Red. 15, No. 9, 537 - 540 (5 May 1972)

1. The processes occurring in the track of a heavy ionizing particle were simulated in macroscopic solid volumes. The samples were irradiated for a short time ($\sim 10^{-8}$ sec) by a powerful flux of electrons in such a way that the average excitation-energy density reached, as in the center of the track, $W \sim 10^{20} - 10^{22}$ eV/cm^3 [1]. For this purpose, we prepared and adapted an accelerator with the following parameters of the electron momentum: upper particle energy 0.3 MeV, duration in the interval $(7 - 30) \times 10^{-9}$ sec, and current density in the range $(0.01 - 1) \times 10^3$ A/cm^2. The accelerator was developed by Mesyats and Koval'chuk; it employs the phenomenon of explosive field emission from a sharply pointed cathode in strong electric fields [2]. We observed that irradiation by single pulse causes destruction of the solid if the average energy density absorbed during the time of the pulse exceeds a threshold W_{des} characteristic of this substance. The effect becomes manifest in the following manner:

1) Thin plates (0.01 - 0.5 mm) of ionic (LiF, NaF, NaCl, KCl, KBr, CaF_2) and covalent (Ge, Si) crystals experience brittle damage and break apart. The number of fragments is large and depends on the beam density Φ. The values of Φ_{des} and W_{des} were determined from the condition required to break the sample into two fragments.

2) In thick samples, Lichtenberg figures consisting of cracks 0.1 - 1 μ thick are produced.

3) In plastic bodies, tracks of explosive radiolysis are observed, namely gas bubbles and swelling or erosion of the surface. The electrons employed for the irradiation transfer practically the entire energy lost in the medium directly to its electronic subsystem (ES) and only an insignificant fraction $\sim 10^{-4}$ directly to the nuclear subsystem (NS). Our experiments have thus demonstrated that direct excitation of only the ES of a solid can produce brittle damage, and established the threshold W_{des} necessary for this purpose.

	Ge	LiF	NaF	NaCl	KCl
Φ_{des}, 10^{13} electron/cm^2	3,0	1,7	1,3	1,1	0,7
W_{des}, 10^{20} eV/cm^3	15,0	3,0	2,3	2,0	1,1

2. The very lowest W_{des} are observed in alkali-halide crystals (AHC). At such excitation levels no damage is produced in either metals, or semiconductors, or glasses, or organic dielectrics. Destruction of solids under the influence of power radiation is usually associated with electric breakdown or heating [3]. The experiments have shown that neither of them cause the destruction of the AHC in this case.

1) The charge transferred to a sample of thickness larger than the electron mean free path (0.45 mm in NaCl) is $\sigma = e\Phi_{des} = 10^{-6} - 10^{-5}$ C/cm^2 per pulse. According to the Poisson equation, the field reaches in this case $2\pi\sigma/\kappa \approx 10^6 - 10^7$ V/cm and can cause breakdown (κ is the dielectric constant). Actually a large number of channels of incomplete breakdown were produced in thick plates of lucite and other dielectrics. There are no breakdown traces in thin plates of the same substances, since they absorb fewer electrons. However, the damage effect remains. Direct measurements of the charge of an electron beam before and after passing through an NaCl sample have shown that when the sample thickness is decreased from 0.45 to 0.01 mm the absorbed charge is decreased by a factor of more than 10, while W_{des} and Φ_{des} change by less than 20%. Placing platinum electrodes on the surface and wrapping the grounded aluminum foil does not prevent the damage. The thin AHC plates were obtained by dissolution and chemical polishing.

2) Even total conversion of W_{des} into heat would heat the NaCl by only 20°. We have demonstrated by a direct experiment that the mechanical stresses due to the temperature gradients in such heating cannot cause damage. We used a beam of 5 mm diameter. The intensity at the center and at the edges differed by not more than 25%. The sample size, 4 × 4 × 0.1 mm, guaranteed the absence of significant temperature gradients both on the surface and in the interior of the sample. The measurements have shown that not more than 30% of the electron beam is absorbed in NaCl plates 0.1 mm thick. Part of the sample was then covered with a crystal plate. The cleanliness of the cleavage surfaces of the latter ensured a sharp boundary, within 1 μ, between the irradiated and non-irradiated parts. This produced the maximum temperature gradient possible at the value of W_{des}. However, the damage cracks were produced in the center of the sample, where the beam density was higher.

3) It is known that the interaction of the excited ES and NS leads not only to heating but also to the formation of radiation defects. After $10^{-15} - 10^{-11}$ sec, all the high-energy excitations of the ES are converted into low-energy ones, namely electrons and holes, which produce effectively, following nonradiative recombination, F centers and interstitial atoms in the AHC. A pair of such effects consumes 40 - 100 eV [4]. Thus, W_{des} cannot account for more than 5×10^{18} cm^{-3} defect pairs in NaCl. By proton bombardment of NaCl we raised the concentration of these defects to 5×10^{19} cm^{-3}, but the crystals were not destroyed thereby [5]. An impression is gained that the destruction of the crystals has little probability when an absorbed energy equal to W_{des} is uniformly distributed. Calculation of the random (Poisson) fluctuations of the number of incident electrons, of the secondary excitations, and of the radiation defects show that they are not significant. Indeed, in tracks of high-energy ions the density of the electron excitations can greatly exceed W_{des} [1]. This, however, does not lead to brittle damage of the sample, but only to strong local changes. For destruction it is necessary that the smallest linear dimension of the excited region ℓ_{des} be much larger than the track dimension 0.001 - 0.01 μ [1]. We have assumed $\ell_{des} \sim 0.1 - 1$ μ; this is of the order of the crack thickness. Random fluctuations in such regions are negligible.

At W_{des} there is produced in AHC a dense grid of interacting electrons and holes with spacing 30 - 50 Å. We assume that their condensation leads to the formation in the AHC of macroscopic regions with an excitation-energy density greatly exceeding the average value. Keldysh [6] was the first to consider the occurrence of "electron-hole drops" in semiconductors, where the exciton has a large radius, $a \sim 100$ A, and a low binding energy, $\varepsilon \sim 0.02$ eV. Therefore the electrons and holes combine into one Wannier-Mott-Keldysh condenson with equilibrium particle density 10^{17} - 10^{18} cm^3, which are stable at low temperature. In AHC, a is of the order of the interatomic distance and $\varepsilon \sim 1$ eV. We therefore assume that the system of electrons and holes at room temperature is capable of contracting into Frankel condensons with equilibrium density 10^{21} - 10^{22} cm^{-3}. W can then reach the binding-energy density, which is certainly sufficient for destruction.

[1] D.I. Vaisburd, N.S. Kravchenko, L.A. Melikyan, and P.D. Alekseev, Izv. AN SSSR, ser. fiz. 35, 1364 (1971); D.I. Vaisburd, A.A. Vorob'ev, and L.A. Melikyan, Atomnaya Energiya 30, 538 (1971).
[2] G.A. Mesyats et al., Izv. Vuzov. Fizika, No. 5, 153 (1969).
[3] S.I. Anisimov et al., Deistvie izlucheniya bol'shoy moshchnosti na metally (Effect of High-power Radiation on Metals), Moscow, 1970.
[4] M. Hirai, Y. Kondo, T. Yoshinari, and M. Ueta, J. Phys. Soc. Japan 30, 1071 (1971).
[5] D.I. Vaisburd, S.M. Minaev, and N.L. Terent'ev, Izv. AN SSSR, ser. fiz. 33, 870 (1969).
[6] L.V. Keldysh, Proceedings, Ninth International Conference on Semiconductor Physics, Moscow, 1969.

BEHAVIOR OF LARGE-CURRENT ELECTRON BEAM IN A DENSE GAS

L.I. Rudakov, V.P. Smirnov, and A.M. Spektor
Submitted 17 February 1972
ZhETF Pis. Red. 15, No. 9, 540 - 544 (5 May 1972)

It was observed in [1] that a 50-kA beam of 3-MeV electrons traverses a distance of 30 cm in air at atmospheric pressure before it spreads apart. This is larger than the mean free path of one electron by more than one order of magnitude.

We have investigated this effect in different gases in the pressure interval from 10^{-2} Torr to 1.6 atm. A beam of electrons from the "Neptune" accelerator passed through the anode foil into a dielectric chamber of 18 cm diameter and 80 cm length. The bulk of the experiments were performed at an electron energy 660 keV and a beam current 12 kA and duration 40 sec. The beam parameters in the drift chamber were measured with a calorimeter that could be moved along the axis. At the same time, we photographed the glow of the plasma produced by the beam. Figure 1 shows photographs in air and in helium. Figure 2 shows the energy distribution, along the chamber, of an electron beam incident on the calorimeter with a diameter equal to the chamber diameter. A comparison of these curves shows that the plasma glow intensity agrees with the calorimetric measurements. We see that in air at atmospheric pressure the beam breaks up at a length ~12 cm. The penetration length L of the beam in air decreases from 20 to 10 cm when the pressure is changed from 0.4 to 1.6 atm. At lower pressures, L increases rapidly. In helium we were unable to measure L, since it turned out to be larger than the length of the drift chamber in the pressure interval up to 1.6 atm.

These phenomena are apparently connected with the appearance of a unique beam instability in a strongly dissipative medium. Under the conditions