

We feel that this technique furnishes a useful tool for the study of the intermediate state, and we are pressing the work with a view to contributing to the understanding of both the statics and dynamics of the transition.

¹ See D. Shoenberg, *Superconductivity* (Cambridge University Press, Cambridge, 1952), for a full discussion.

Distribution of the Mass Transported from a Collector into a Germanium Crystal by the Forming Process*

M. W. AARONS, M. POBERESKIN, J. E. GATES,
AND E. B. DALE

Battelle Memorial Institute, Columbus, Ohio

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A MAJOR problem in transistor physics is the elucidation of the effects of the forming process in point contact crystal triodes. An hypothesis for the high α 's observed in formed collectors is the "hook" theory of Shockley.¹ The combination of mass transfer and thermal effects during the forming pulse have been proposed as a possible mechanism for "hook" formation. The purpose of this note is to report preliminary results of experiments measuring the distribution of the transported mass in the crystal.

Rough estimates of the number of atoms expected to be transferred indicated 10^9 atoms into a volume of 10^{-8} cm³. In order to detect so small a quantity of matter, carrier-free radio isotopes were considered. A survey of available isotopes resulted in the selection of gold 199 as a suitable tracer material.

Very briefly, the experiments proceeded as follows: Gold 199 and 197 were separated from irradiated platinum and plated on a tungsten needle. The plated needle was used to "form" single crystals of 7 ohm-cm *n*-type germanium. The amount of gold transferred was measured by counting with an end-window Geiger tube, and the area of gold distribution was measured from an autoradiograph. Microphotographs of the autoradiographs were subsequently analyzed by a photodensitometer to obtain the area and distribution of the gold at that level. The surface was then precisely lapped and counted and an autoradiograph taken. By repeating this procedure to a depth in the crystal

TABLE I. The distribution of Au in crystal 1 after forming. The forming pulse was 0.053 seconds long, with an average current of 65 ma at 240 volts. A total of 1.6×10^9 Au atoms was transferred into a volume of about 10^{-7} cm³. There was no visible damage to the crystal surface.

Thickness of layer lapped off, microns	Diameter of formed region at top of layer, microns	Average Au concentration in formed region of layer, atoms/cm ³
5	180	1.9×10^{16}
2.5	72	8.9×10^{14}
2.5	72	2.8×10^{15}

TABLE II. The distribution of Au in crystal 2 after forming. The forming pulse was 0.053 seconds long, at a peak voltage of 400 volts. A total of 7.4×10^{10} Au atoms was transferred into a volume of about 10^{-6} cm³. A crater 230 microns in diameter and about 15 microns deep was observed in the crystal surface after forming. A conical protuberance was noted in the center of the crater.

Thickness of layer lapped off, microns	Diameter of formed region at top of layer, ^a microns	Average Au concentration in formed region of layer, atoms/cm
5	Broad and diffuse	3.3×10^{17}
10	232	1.3×10^{15}
9	198	1.6×10^{15}
9	153	5.7×10^{14}

^a The diameter of the active region on the crystal surface after the last lap was 108 microns.

at which no activity could be detected, the concentration of gold atoms as a function of depth was obtained. The results of two forming experiments are presented in Tables I and II.

No activity remained in crystal 1 after the third lap. To compute the concentration of gold in the third layer, the formed region in that layer was assumed to be conical, with a base equal to the exposed active area after the second lap, and a height equal to the thickness of the third layer.

Crystal 2 was destroyed after the fourth lap. At that time 4.6×10^7 foreign atoms remained in the crystal.

From these results, it appears that the distribution in depth of the transferred gold atoms was as follows: a high concentration region at the surface, followed by a region of diminished concentration, terminating in a region of somewhat higher concentration than the minimum. The concentration drops abruptly beyond this point.

Experiments on the effects of emitter current flowing in the crystal during the forming of the collector are in progress.

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¹ W. Shockley, *Electrons and Holes in Semiconductors* (D. Van Nostrand Company, Inc., New York, 1950), p. 108.

Effect of Chemical Combination on the Characteristic Energy Loss of Electrons*

LEWIS B. LEDER AND L. MARTON

National Bureau of Standards, Washington, D. C.

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IN a recent note we presented measurements of the characteristic energy loss of 30-keV electrons passing through thin films of solids.¹ There have been some attempts to explain these losses by associating them with secondary electron emission,² by electron plasma oscillation,³ and by comparison with x-ray absorption data.^{4,5} The data available are not complete enough to verify any of the possible explanations. We have, there-

TABLE I. Characteristic energy losses (in ev) of 30-kev electrons passing through thin films of Si, Te, Pb, Sb, Mg, and compounds of these metals.

Material	Energy loss (ev)		
	E_1	E_2	E_3
Si	4.8	16.9	
SiO ₂	5.4	19.4	
Te	4.6	16.0	
TeO ₂	9.5	17.5	
Pb	5.1	12.1	21.8
PbS	6.8	14.7	21.9
Sb	4.3	14.9	30.6
Sb ₂ S ₃	6.3	18.0	35.4
Mg	9.7	20.3	
MgO ^a	11.4	25.0	

^a H. Watanabe (private communication).

fore, been engaged in determining the properties of these losses.

As shown in the data of our previous communication these losses have been observed in insulators (collodion and quartz) as well as in metals, and in examining these results we noticed that the spectrum for quartz (SiO₂) was in all respects similar to that of silicon, except that the positions of the peaks were shifted to higher energy losses. In view of this we felt it would be of interest to pursue this line of investigation, and therefore, measured the energy losses in several other compounds. The resulting data are given in Table I. In Fig. 1 a representative set of spectra are shown. These are the superimposed microphotometer tracings of the Sb and Sb₂S₃ spectra. It is seen from the figure that the characteristics of the spectrum remain the same with the peaks shifted to higher energies. This trend was observed in all four pairs.

It has been known for a long time that a shift, such as we have observed, occurs in the *K* and *L* x-ray emission or absorption edge.⁶ The shift in the *K* x-ray absorption edge of Si has been attributed to the effect of crystal structure by Barton and Lindsay;⁷ and on the other hand, Das Gupta⁸ has shown some correlation of the *K*-valence emission band shift with the heat of formation. While we are not prepared at present to discuss the source of the shift or to subscribe implicitly to Das Gupta's hypothesis, in Table II we have tabu-

TABLE II. The shift, ΔE , of the characteristic energy loss of Si, Te, Pb, Sb, and Mg as a result of chemical combination. In the fourth column are given the values calculated using the formula of Das Gupta.

Material	Shift of the energy loss (ev)			
	ΔE_1	ΔE_2	ΔE_3	calc. ΔE_4
Si	0.6	2.5		3.7
Te	5.0	1.5		1.6
Pb	1.7	2.6	0	1.9
Sb	2.0	3.1	4.8	2.2
Mg	1.7	4.7		4.7

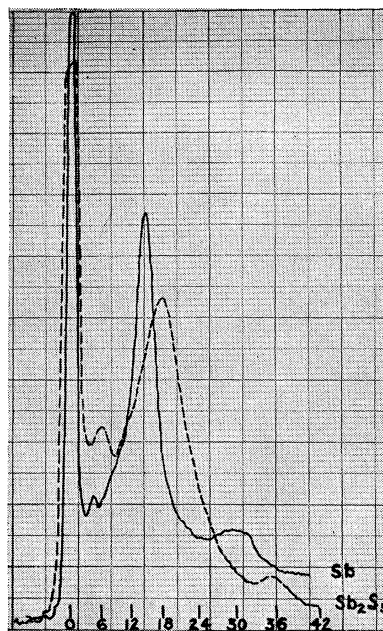


FIG. 1. Superimposed microphotometer tracings of the energy loss spectra of Sb and Sb₂S₃. The solid line is the spectrum of Sb, and the dashed line that of Sb₂S₃. The scale shown on the bottom is in electron volts. The ordinates are relative intensities.

lated our observed shifts and in column four have given the shift expected using the formula of Das Gupta. These latter appear to be at least of the right order of magnitude.

We have also measured the energy losses in several alkali halides. However, the results are difficult to analyze because (1) although the alkali metals Na and K were evaporated directly in the vacuum of the analyzer, they may have oxidized during the time of observation, (2) in all cases the materials were deposited on a substrate and the effect of the substrate is as yet an unknown factor, (3) the spectra are more complex than for the other materials, and (4) the intensities of some of the peaks are radically different in the alkali metal and the alkali halide and thus make it difficult to correlate the various loss lines. Nevertheless, a shift of the peaks is indicated.

This evidence suggests that some of the characteristic energy losses that we are observing are not due to electron plasma interaction,³ since there would be no plasma in the compound, but are rather due to excitations of some outer orbit electrons.

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¹ L. Marton and L. B. Leder, Phys. Rev. **94**, 203 (1954).

² O. W. Richardson, Proc. Roy. Soc. (London) **A128**, 63 (1930).

³ D. Bohm and D. Pines, Phys. Rev. **92**, 609 (1953); D. Pines, Phys. Rev. **92**, 626 (1953); and preceding papers.

⁴ Y. Cauchois, Acta Cryst. **5**, 351 (1952).

⁵ A. Nilsson, Arkiv Fysik **6**, No. 6 (1953).

⁶ M. Siegbahn, *Spektroskopie der Röntgenstrahlen* (Verlag Julius Springer, Berlin, 1931), second edition, pp. 278-306.

⁷ V. P. Barton and G. A. Lindsay, Phys. Rev. **71**, 406 (1947).

⁸ K. Das Gupta, Phys. Rev. **80**, 281 (1950).

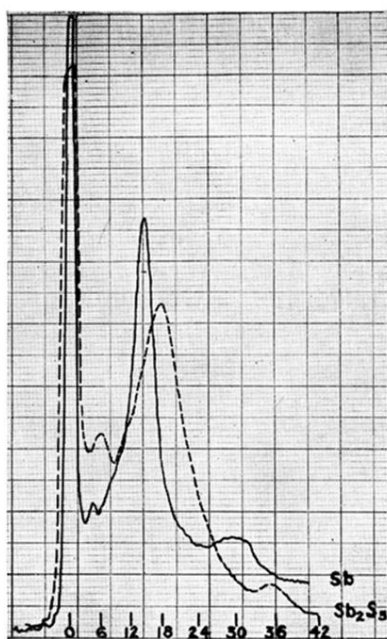


FIG. 1. Superimposed microphotometer tracings of the energy loss spectra of Sb and Sb_2S_3 . The solid line is the spectrum of Sb, and the dashed line that of Sb_2S_3 . The scale shown on the bottom is in electron volts. The ordinates are relative intensities.