

⁷K. P. Belov, Упругие, тепловые и электрические явления в ферромагнитных металлах (Elastic, Thermal, and Electrical Phenomena in Ferromagnetic Metals), GITTL, 1951.

⁸V. L. Ginzburg, J. Exptl. Theoret. Phys. (U.S.S.R.) **17**, 833 (1947).

Translated by W. F. Brown Jr.

115

SOVIET PHYSICS JETP

VOLUME 6 (33), NUMBER 3

MARCH, 1958

*INVESTIGATION OF THE CHARACTERISTIC ENERGY LOSSES OF ELECTRONS AND
THE SECONDARY ELECTRON EMISSION FROM GeO₂*

N. B. GORNYI and A. IU. REITSAKAS

Submitted to JETP editor March 1, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 571-575 (September, 1957)

The characteristic energy losses of electrons reflected from the surfaces of two germanium plates of the n and p types covered with GeO₂ are investigated. The spectra of the characteristic losses for both types of plates are similar. If the difference in the lattice constants is taken into account, the spectra of the characteristic energy losses for GeO₂ and MoO₂, which have identical (tetragonal) lattices, are found to be similar. Secondary electron emission has been investigated for the indicated GeO₂ samples. The secondary electron yield from GeO₂ is almost twice as large as the yield from germanium.

CHARACTERISTIC ENERGY LOSSES OF ELECTRONS

IN an earlier work on the characteristic energy losses in reflection from a MoO₂ surface¹ one of the authors has showed that these losses can be determined by the formula

$$W = (h^2 / 8m) (n/d)^2.$$

For MoO₂ which crystallizes in a tetragonal lattice $(n/d)^2 + (h^2 + k^2)/a^2 = (\ell/c)^2$ where h, k, and ℓ are the Miller indices, and a and c are the lattice constants. Thus, the spectra of the characteristic energy losses of electrons must depend on the structure and size of the crystal lattice of a given material. Therefore, different substances with the same crystal structure must have similar spectra. This conclusion was arrived at in one of the recent works of Marton and co-workers.²

To test the above conclusion we undertook to investigate the characteristic energy losses of electrons in GeO₂, which has the same crystal lattice as MoO₂. We treated two thin plates of germanium (thickness 0.5 mm), one type n and the other type p, with a solution of nitric acid; this, as is known, forms a layer of GeO₂ on the surface of germanium. After treating with nitric acid the sample was washed in distilled water, then treated in a solution of NaOH, and once again washed in distilled water and in pure alcohol. As a result there remained on the surface of the germanium a layer of GeO₂, "insoluble" in water, and crystallized in a tetragonal lattice.³ The lattice constants of GeO₂ are a = 4.39 Å and c = 2.859 Å.

The method of electrical differentiation in a spherical capacitor^{4,5} circuit was used to investigate the characteristic energy losses of electrons reflected from the surfaces of the above two GeO₂-coated germanium plates. The vacuum apparatus was as that used in Ref. 6. The two targets were arranged on a cylindrical table made of tantalum inside the spherical vacuum apparatus. By means of a magnet outside the vacuum it was possible to turn the table so that either one of the specimens could be placed in the beam. After long adjustment and degassing of the apparatus the pressure, measured with an ionization

gauge prior to firing the getter and unsoldering the apparatus, was less than 5×10^{-7} mm. The earth's magnetic field was compensated by two coils 1 m in diameter.

For both specimens there were obtained curves of the distribution of scattered electrons vs energy. The curves obtained for these two specimens at equal primary electron energy were very much the same. On Fig. 1 are shown the distribution curves obtained with GeO_2 layers on n-germanium for an emitter

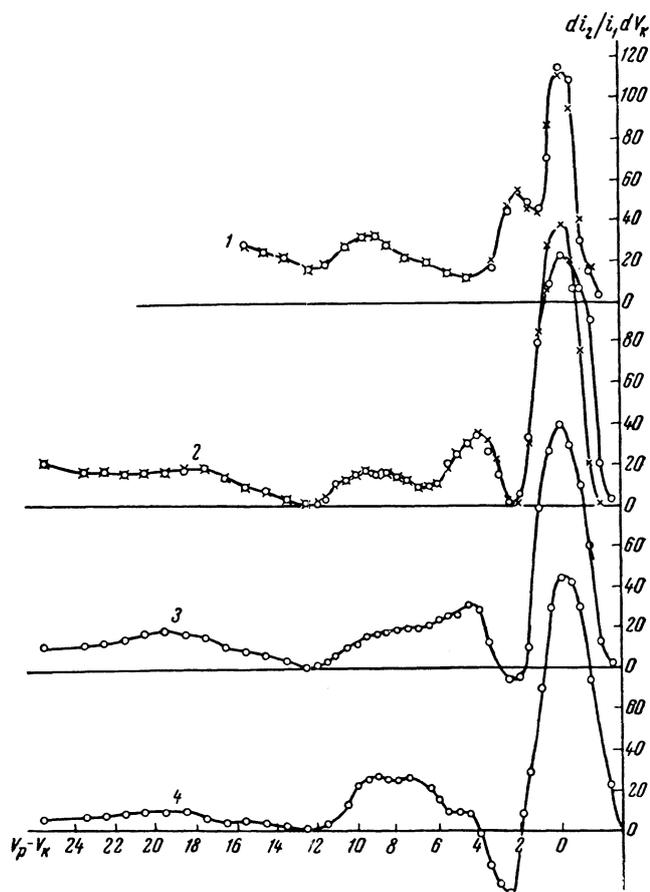


FIG. 1. (1) $V_p = 30$ v, (2) $V_p = 50$ v, (3) $V_p = 70$ v, (4) $V_p = 100$ v.

with an energy loss $W = 3.2$ ev and the other with $W = 4.8$ ev, for h, k and l (110) and (001) respectively. Further, the 12.8 ev MoO_2 characteristic energy-loss peak coincides exactly with a minimum in

h	k	l	W, ev	$V_p - V_k, \text{v}$
1	0	0	1.96	2
0	0	1	3.1	3
1	1	0	3.9	4.4
1	0	1	6.6	7
1	1	1	8.6	9
1	2	1	14.3	14.5
0	0	2	18.5	19
2	2	1	20.3	

all the curves of Fig. 1,¹ and the presence of this peak is therefore difficult to observe. However, the flattening of this minimum in the curves with increasing V_p (in particular in the curve for $V_p = 260$ volts) may be explained by the presence of a characteristic energy loss peak with $W = 12.8$ ev and by the increase in the probability of this loss with increasing energy of the incident electrons.

From the data obtained we may conclude: (1) that for GeO_2 the spectra of characteristic electron energy losses are determined by the structure of its crystalline lattice; (2) that the spectra of the electron characteristic energy losses are similar in GeO_2 and MoO_2 ,

which have the same crystalline lattice, and the difference in the spectra depends only on the difference in their lattice constants.

SECONDARY ELECTRON EMISSION

As far as we know, the literature contains no information concerning the secondary electron emission

temperature of 400°C and for several values of incident electron energy. The table lists the values of energy loss calculated by the above formula for a series of values of h, k and l , and also the experimentally-obtained characteristic energy losses $V_p - V_k$. We first note the good agreement between the experimental and the calculated values. If we compare the curves of Fig. 1 and the table with Fig. 1 and the table of Ref. 1, we see that the fundamental inelastic-loss peaks obtained for MoO_2 for h, k and l equal to (111), (002) and (221) manifest themselves just as pronouncedly in the case of GeO_2 . Further, by comparing the curves of Fig. 1 it is possible to note that, just as for MoO_2 (Ref. 1) and Cu_2O (Ref. 7), increasing of the incident electron energy increases the probability of characteristic losses of large energy (for $V_p - V_k$ equal to 7 and 9 ev), and decreases the losses at values of $V_p - V_k$ equal to 3.2 and 4.4 ev. The characteristic losses for $V_p - V_k = 2$ ev are clearly visible only for $V_p = 30$ v.

However, there are certain discrepancies between the results obtained for GeO_2 and for MoO_2 . For GeO_2 we have two peaks of characteristic losses for h, k and l equal to (110) and (121) with values of energy W equal to 3.9 and 14.3 ev, respectively, which we do not find for MoO_2 . The corresponding energies W for MoO_2 have the values 3.2 and 12.8 ev. Upon careful examination of the curves of inelastic loss for MoO_2 (Ref. 1) we may assume that the peak for $V_p - V_k = 4.5$ ev is the result of the superposition of two peaks, one

of GeO_2 . We therefore present the results of our investigation of the secondary electron emission, obtained with the same apparatus and from the same two GeO_2 samples as used for the investigation of the characteristic electron energy losses.

The investigation of the secondary electron emission was in accordance with the usual scheme.⁸ The dependence of the secondary electron coefficient δ on the energy of the primary electrons, $\delta = f(V_p)$, was obtained for both specimens (layer of GeO_2 formed on n-germanium and p-germanium). Figure 2 shows the curves of $\delta = f(V_p)$ obtained for GeO_2 on n-germanium. Curve 1, obtained at room temperature, gives the maximum value $\delta_{\text{max}} = 2.06$ for $V_p = 400$ volts. The curves obtained for the second specimen were identical.

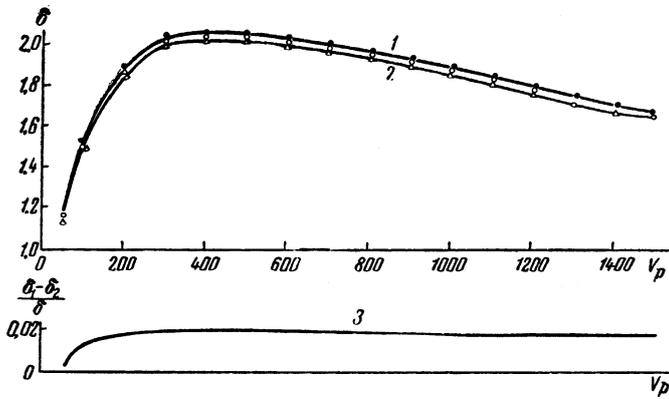


FIG. 2. (1) Room temperature, (2) $t = 400^\circ\text{C}$, (3) Increased temperature.

The yield of secondary electrons from GeO_2 is approximately $1\frac{1}{2} - 2$ times greater than the yield from Ge.⁹⁻¹¹ One cannot assume that the considerable increase of δ in the dioxide of Ge is due to the oxygen atoms, since in a number of cases the yield of secondary electrons not only did not increase for the oxidized substance, but actually decreased (for example, MoO_2 and Cu_2O). It is therefore necessary to assume that the variation of secondary emission characteristic of oxides is connected with the change in the crystal lattice, and consequently also in the energy levels.

From the curve of $\delta = f(V_p)$ obtained for for $t = 400^\circ\text{C}$ it is seen that the yield of secondary electrons is somewhat reduced with increased temperature. The character of the relative variation of δ for increased temperature, $(\delta_1 - \delta_2)/\delta_1 = f(V_p)$, shows⁸ that the decrease in δ is not caused by an increase in the work function but results from the change in thickness of the emitter. A similar character and an approximately equal reduction in δ with increasing temperature was observed for Ge;¹⁰ in those investigations the same variation in δ was observed in samples differing in the free-electron concentration by more than three orders. It was therefore concluded that the energy loss of the secondary electrons is due not to the free electrons, but to the interaction between the electrons and the lattice. It is necessary to assume that also in the case of GeO_2 this same mechanism is responsible for the reduced yield of secondary electrons with increasing temperature.

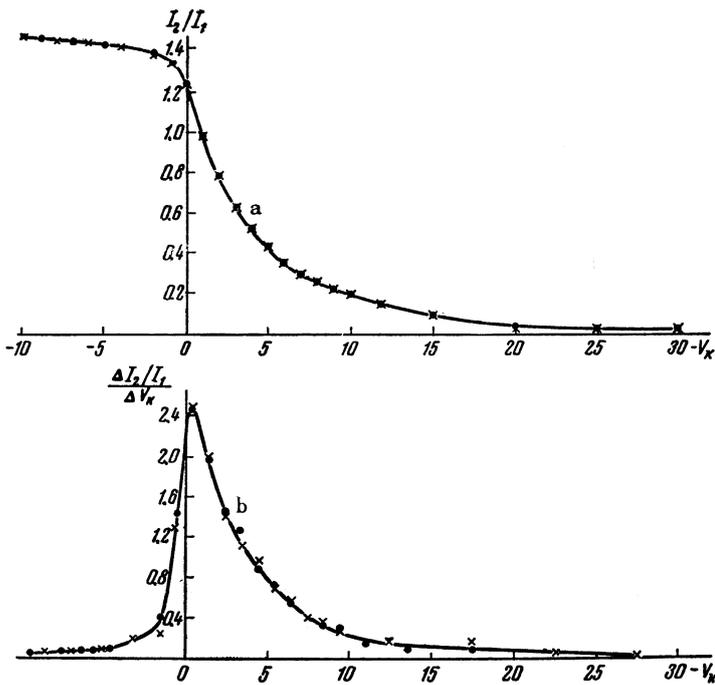


FIG. 3

The distribution of secondary electrons with respect to energy was investigated by the retarding field method. Figure 3a shows the retarding curve for GeO_2 on n-germanium obtained for $V_p = 100$ v and $t = 400^\circ\text{C}$. Differentiation of the retarding curve gives the energy distribution of the secondary electrons (Fig. 3b). The curves are not corrected for contact potential difference between the GeO_2 and the aquadag on the collector since we do not know the work function of GeO_2 . In the same way curves were obtained for 20°C , and also for $V_p = 500$ v at the above two temperatures. Analogous curves were obtained for GeO_2 on p-germanium. Curves obtained for the same value of V_p but for different

temperatures (20 and 400°C) were identical. The ordinate of the retarding curve I_2/I_1 obtained for $V_p = 500$ v becomes negative values starting with $V_k = 11$ v. The position of the peak of secondary electrons in the distribution curve was also obtained for $V_p = 100$ v (Fig. 3b), but the half-width of the peak of the distribution curves for $V_p = 500$ v is narrower (3 ev) than that of the curve obtained for $V_p = 100$ v (3.5 ev). The range of secondary-electron energies of the distribution curves for GeO_2 , is characteristic of semiconductors.

The absence of saturation in the retarding curves in the region of positive values near zero, which leads to the appearance of electrons with "negative" energy, is explainable by tertiary electrons knocked out of the collector by the reflected primary or secondary electrons.¹²

In conclusion we regard it our agreeable duty to express thanks to V. P. Zhuze for making the germanium, and we also are thankful to B. F. Zhuravskii for his help with the measurements.

¹N. B. Gornyi, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 132 (1956); Soviet Phys. JETP **4**, 131 (1957).

²Leder, Mendlowitz, and Marton, Phys. Rev. **101**, 1460 (1956).

³O. H. Johnson, Chem. Rev. **51**, 431 (1952).

⁴N. B. Gornyi, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 171 (1954).

⁵N. B. Gornyi and L. M. Rachovich, J. Exptl. Theoret. Phys. (U.S.S.R.) **26**, 454 (1954).

⁶N. B. Gornyi, J. Exptl. Theoret. Phys. (U.S.S.R.) **26**, 88 (1954).

⁷N. B. Gornyi, J. Exptl. Theoret. Phys. (U.S.S.R.) **30**, 160 (1956); Soviet Phys. JETP **3**, 175 (1956).

⁸N. B. Gornyi, J. Exptl. Theoret. Phys. (U.S.S.R.) **26**, 79 (1954).

⁹L. R. Koller and J. S. Burgess, Phys. Rev. **70**, 571 (1948).

¹⁰J. B. Johnson and J. R. McKay, Phys. Rev. **93**, 668 (1954).

¹¹H. Gobrecht, F. Speer, Zeits. Phys. **135**, 602 (1953).

¹²N. B. Gornyi, J. Tech. Phys. (U.S.S.R.) **26**, 723 (1956), Soviet Phys. JTP **1**, 702 (1956).

Translated by L. B. Leder

116

CHANGE IN THE ISOTOPIC COMPOSITION OF MERCURY BY EVAPORATION

V. N. GRIGOR'EV, IA. S. KAN, N. S. RUDENKO, and B. G. SAFRONOV

Physico-Technical Institute, Academy of Sciences, Ukrainian S.S.R.

Submitted to JETP editor March 13, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 576-580 (September, 1957)

Evaporation-induced changes in the isotopic composition of mercury are investigated under various conditions. It is found that the kinetics of evaporation plays a large role at slow distillation rates. The upper limits of $\Delta p/p$ are evaluated for mercury isotopes.

INTRODUCTION

THE determination of the relative saturated vapor pressures for isotopes is important both for studying the influence of isotopic composition on the properties of matter and for isotope separation techniques. This measurement is often performed by evaporation of isotope mixtures at constant temperature. The change in the composition of a two-component mixture is then given by

$$\frac{c}{c_0} = \left(\frac{1-c_0}{1-c} \right)^{1/\alpha} \left(\frac{v_0}{v} \right)^{\frac{\alpha-1}{\alpha}}, \quad (1)$$