ELECTRIFICATION OF DUST PRODUCED FROM $Cd_x Hg_{1-x}Te$ AND $CdTe_x Se_{1-x}$ ALLOYS

By J. Malcher

Institute of Technical Physics, Technical University, Wrocław*

The electrification of dusts produced from CdTe, HgTe, CdSe and the $Cd_xHg_{1-x}Te$ and $CdTe_xSe_{1-x}$ alloys, with $0 < x < 1$, have been measured. The conductivities of dust layers of the same materials have also been measured. $Cd_xHg_{1-x}Te$ alloys form mixed crystals, whereas $CdTe_xSe_{1-x}$ alloys form a mixture of crystals. It was found that a change in crystal structure arising with a change in alloy composition bears a bigger effect on dust electrification than do changes in conductivity.

Investigations of the electrification of dust produced from CdTe, HgTe and CdSe, and also from alloys of varying composition — $Cd_xHg_{1-x}Te$ and $CdTe_xSe_{1-x}$ with $0 < x < 1$ — had the purpose of finding the influence of the material's crystal structure on dust electrification. The CdTe, HgTe and CdSe compounds are semiconductors. CdTe and HgTe crystallize in the regular system, and their structural type corresponds to that of sphalerite. The lattice constants are $a = 6.423$ Å [1] for CdTe and $a = 6.429$ Å [2] for HgTe. The crystal structure of CdSe is like that of wurtzite, with $a = 4.309$ Å and $c = 7.034$ Å [1]. The energy gap is $E_g = 1.41$ to 1.47 eV for CdTe [2], $E_g = 0.01$ eV for HgTe [3] and $E_g = 1.74$ eV for CdSe [2]. The resistivities of bulk materials are: $\varrho = 10^6$ to 10^8 ohm-cm for CdTe [4], $\varrho = 10^{-2}$ to 10^{-3} ohm-cm for HgTe [5], and $\varrho = 10^7$ to 10^8 ohm-cm for CdSe [6]. It follows from these data and from a number of other properties of these compounds that CdTe and CdSe are typical semiconductors, whereas HgTe is a compound defined by some authors as a semi-metal [3]. The $Cd_xHg_{1-x}Te$ and $CdTe_xSe_{1-x}$ alloys may be regarded as binary alloys, *i.e.* alloys of CdTe with HgTe and CdTe with CdSe. Since in the case of the $Cd_xHg_{1-x}Te$ alloys the initial compounds have the same crystal structure, these are single--phase alloys, that is, in the entire range of concentrations mixed crystals appear. On the other hand, the initial compounds of the $CdTe_xSe_{1-x}$ alloy have different crystal structures and because of this these alloys are two-phase alloys within a broad range of concentrational changes, that is, a mixture of crystals exists in them [1].

The electrification of the dust was measured by the Kunkel and Hansen technique [7]. With this technique the magnitudes of the charges on the individual dust particles and

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* Address: Instytut Fizyki Technicznej, Politechnika Wrocławska, Wrocław, Wybrzeże Wyspiańskiego 27, Polska.

the particle diameters were measured. In accord with the applied method of interpreting the results [8, 9], the measure of the electrification process was assumed in the form of the standard deviation σ, which is the fundamental parameter determining the shape of the statistical charge distribution curve for a dust cloud. If the charge distribution is a normal one, the electrification process may be described by means of the formula

$$\frac{\Delta N}{N} = \frac{1}{\sigma \sqrt{2\pi}} \exp\left[-\frac{q_i - \bar{q}}{2\sigma^2} \right].$$

The standard deviation σ is given by the formula

$$\sigma = \sqrt{\frac{\sum\limits_{1}^{N} (q_i - \bar{q})^2}{N}}$$

where q_i is the charge of the individual dust particles, $\bar{q}$ is the arithmetic mean of the charges, and N and ΔN are the numbers of all particles and particles within a given charge interval, respectively.

The hypothesis of the normality of the statistical distributions of charges in the examined clouds of dust were checked by the χ^2 test. The condition which enables the acceptance of the normality of the examined statistical distributions is the fulfilment of the inequality $\chi^2 < \chi_p^2$, where χ^2 is the value calculated for the given distribution, and χ_p^2 is the critical value for the assumed importance level at a given number of degrees of freedom 1. The electric charges on the grains of dust are generated during the pulverization of the material. At the same time, thanks to many mutual contacts of the dust grains between each other, there is partial neutralization 10 of the charges on them. It may be presumed that the neutralization of charge will depend on the conductivity of the material. As the dust is submitted to the pressure of a pestle during crushing, the contact of dust grains with each other and, hence, the neutralization of charges, occurs under a certain pressure. Therefore the measurements of the conductivities of dust layers were performed at a pressure corresponding to that during pulverization.

Result of measurements

The electrification of dust was measured by the Kunkel and Hansen technique for CdTe, CdSe, HgTe and alloys of the following compositions: $Cd_{0.75}Hg_{0.25}Te$, $Cd_{0.5}Hg_{0.5}Te$, $Cd_{0.25}Hg_{0.75}Te$, $CdTe_{0.8}Se_{0.2}$, $CdTe_{0.5}Se_{0.5}$ and $CdTe_{0.156}Se_{0.844}$. CdTe, CdSe and HgTe were obtained by synthesis of zonally refined substrates. The alloys were obtained by heating pulverized CdTe, CdSe and HgTe in quartz ampoules under a pressure of 10^{-5} torr. The refinement of the materials, the synthesis of the compounds and the production of the alloys was done in the Semiconductor Laboratory of the PAS Institute of Physics in Warsaw.

The dust was obtained by crushing bulk material in a mill with a porcelain mortar and a porcelain pestle [11]. The time during which every material was crushed equalled 10 minutes, and the pestle crushing force was 50 to 70 N. Because the conditions under which the materials were crushed were rigorously maintained the same, dusts of a similar

range of particle sizes were obtained from all samples. The diameters of the dust particles were contained within the range from 3.0 to 4.4 μ. The results of electrification measurements reveal a linear dependence of mean positive and negative charge on dust particle diameter. Owing to this dependence the results of the individual series of measurements were compared within the mutual range of diameters. Indeed, it is for these particles comprised within
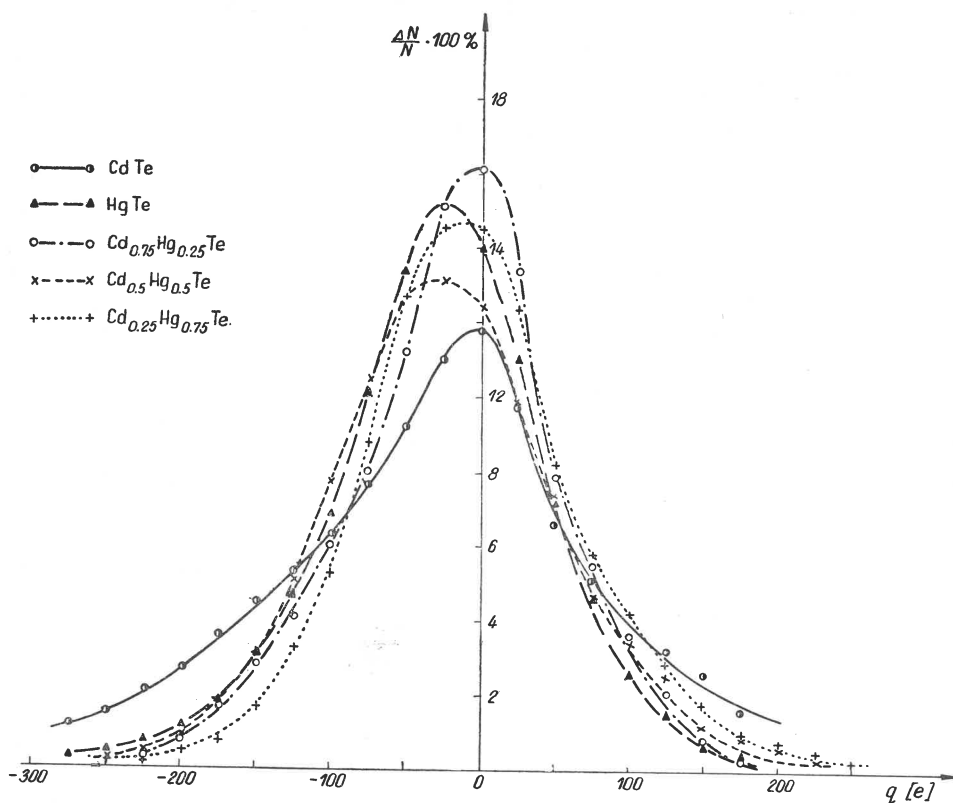

Fig. 1. Statistical distributions of charges in clouds of dust produced from CdTe, HgTe and Cd_xHg_{1-x}Te alloys, q — mean charge of dust particle, in electrons, $\Delta N/N$ — ratio of number of dust particles ΔN with charge comprised between q and $q+\Delta q$ to total number of particles N

the mutual range of diameters that the statistical distributions of charges in the investigated dust clouds were plotted. The statistical distributions of charges in dust clouds made from CdTe, HgTe and their alloys, and CdTe, CdSe and their alloys, are represented by the Figures 1 and 2. The parameters σ determining the shape of the distribution curves and, at the same time, characterizing the electrification process, together with the values of χ^2, χ^2_p and l, which make it possible to state that with the assumed importance level these distributions satisfy the normality condition, are given in Tables I and II.

The conductivities of layers of dust were also measured. The dust was placed in a quartz tube terminated by brass electrodes. The measurement was accomplished by means of a valve
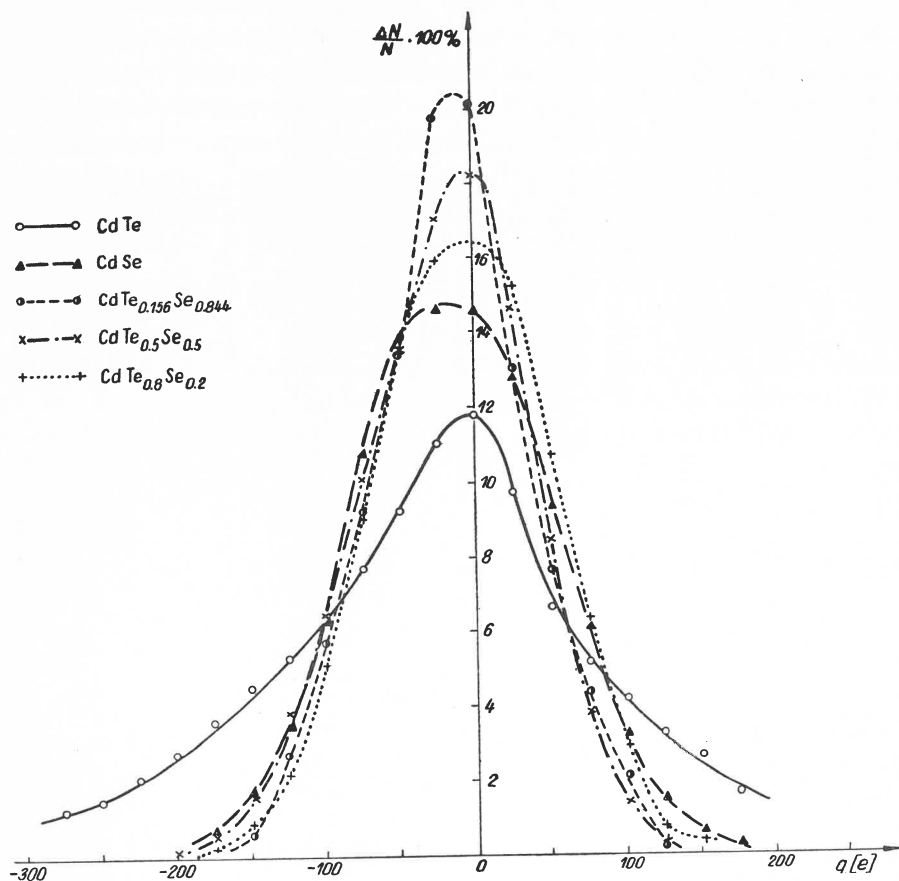
Fig. 2. Statistical distributions of charges in clouds of dust produced from CdTe, CdSe and CdTe$_x$Se$_{1-x}$ alloys q — mean charge of dust particles, in electrons, $\Delta N/N$ — ratio of number of dust particles N with charge comprised between q and $q+\Delta q$ to total number of particles N

megohmmeter or R.L.C. bridge. Next, measurement of the thickness of the dust layer and the area of the electrodes enabled calculation of the conductivity of the dust layer. The instrument in which the resistance measurements were done, made it possible to determine

TABLE I

Participation in alloy of		σ (electrons)	γ ($\Omega^{-1}\,cm^{-1}$)	l	χ^2	χ_p^2
CdTe	HgTe					
1.00	—	99.13	3.08×10^{-11}	17	20.93	33.40
0.75	0.25	84.02	1.10×10^{-8}	12	12.96	26.21
0.50	0.50	80.13	2.56×10^{-5}	14	9.06	29.14
0.25	0.75	77.51	7.00×10^{-3}	13	22.74	27.68
—	1.00	74.22	2.89×10^{-2}	12	13.51	26.21

TABLE II

Participation in alloy of		σ (electrons)	γ ($\Omega^{-1}\,cm^{-1}$)	l	χ^2	χ_P^2
CdTe	HgTe					
1.00	—	99.13	3.08×10^{-11}	17	20.93	33.40
0.80	0.20	56.64	5.75×10^{-11}	10	3.59	23.20
0.50	0.50	56.06	8.85×10^{-10}	10	11.14	23.20
0.156	0.814	51.58	2.63×10^{-8}	9	14.77	21.66
—	1.00	64.07	6.62×10^{-8}	11	1.21	24.72

the dependence of the dust layer conductivity on pressure. Figures 3 and 4 present the dependence of the conductivity of the dust layer on applied pressure for CdTe, HgTe and their alloys and CdTe, CdSe and their alloys. All of the conductivity *versus* pressure curves
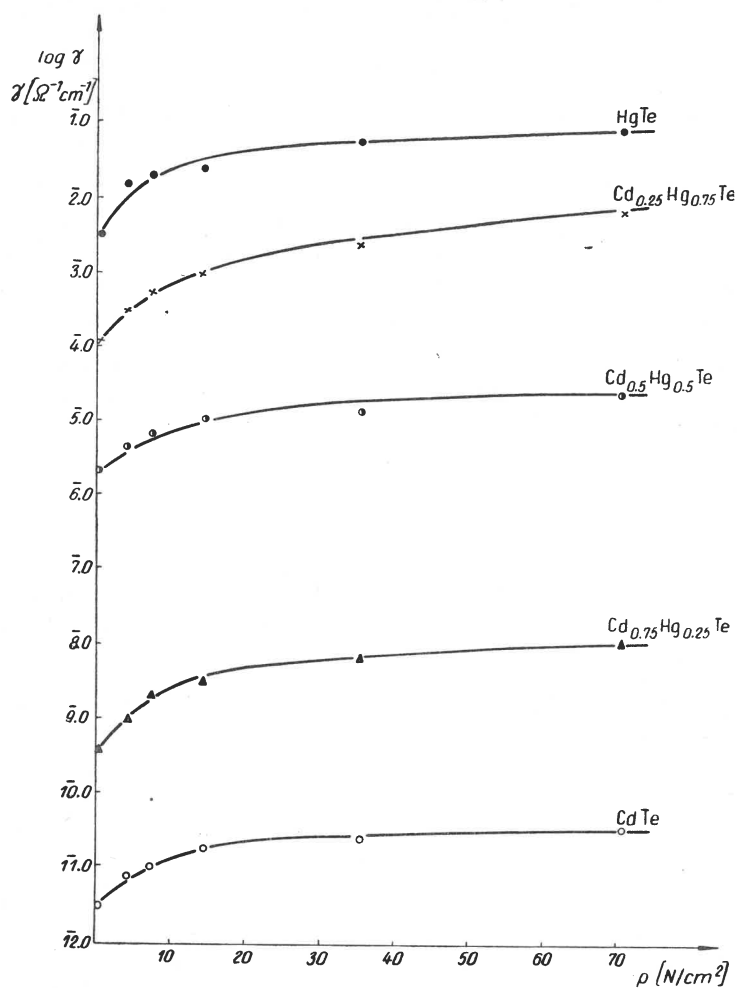

Fig. 3. Conductivity *versus* pressure curve for dust produced from CdTe, HgTe and Cd_xHg_{1-x} Te alloys
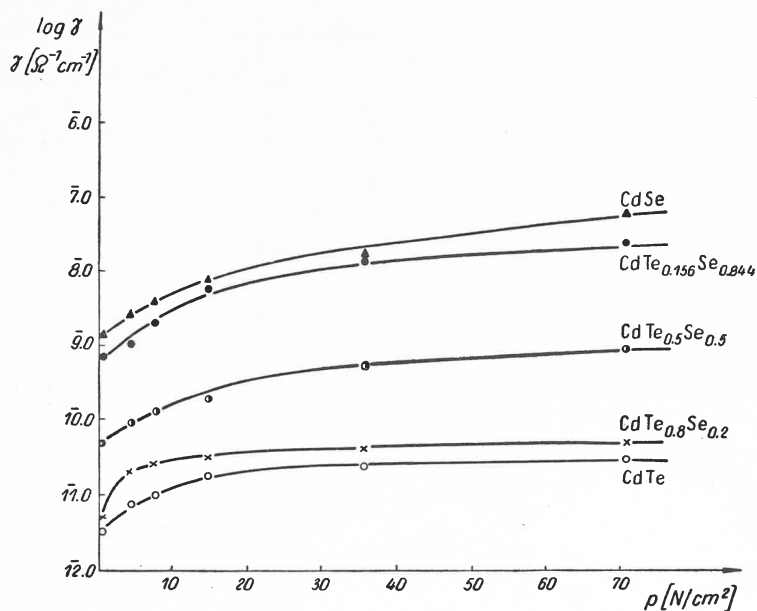
Fig. 4. Conductivity *versus* pressure curve for dust produced from CdTe, CdSe and CdTe$_x$Se$_{1-x}$ alloys

are shaped similarly. At first, at low pressures, the layer conductivity increases, then starting from a pressure of about 35 N cm^{-2} the dependence of conductivity on pressure is already weak. Since charges are neutralized during the crushing process, when the dust is submitted to the force of the pestle, the most reliable value of conductivity is that at the pressure corresponding to the pressure during the crushing of the material. Tables I and II give the values of conductivity of the dust corresponding to a pressure of 70 Ncm^{-2}. These values differ substantially from the values of conductivity of bulk materials cited in the literature.

Discussion of results

A comparison of the results indicates that the highest electrification is had by the CdTe dust ($\sigma = 99.13e$), somewhat lower by the HgTe dust ($\sigma = 74.22$ e) and the least by the CdSe dust ($\sigma = 64.07$ e).

On the other hand, the results of conductivity measurements should be lined up differently, *viz.*, CdTe ($\gamma = 3.8 \times 10^{-11}$ ohm^{-1} cm^{-1}), CdSe ($\gamma = 6.62 \times 10^{-8}$ ohm^{-1} cm^{-1}) and HgTe ($\gamma = 2.89 \times 10^{-2}$ ohm^{-1} cm^{-1}).

Owing to the high conductivity of the HgTe dust, as compared with the CdTe dust, a much lower electrification of the dust produced from mercury telluride could be expected. This supposition is aroused when comparing the results of conductivity and electrification measurements of dusts produced from CdTe and CdSe. The conductivity of the CdSe dust is higher by only three orders of magnitude than that of the CdTe dust, whereas the conductivity of the HgTe dust is higher by nine orders than that of the CdTe dust. Despite this the electrification of the dust produced from HgTe is greater than that of the CdSe dust.

The surmise, hence, is that the result of electrification of dust produced from CdTe, HgTe and CdSe is affected, apart from conductivity, by yet another factor associated with the crystal structure of the examined materials. CdSe has the structure of wurtzite, whereas CdTe and HgTe have the structure of sphalerite. The supposition that the crystal structure
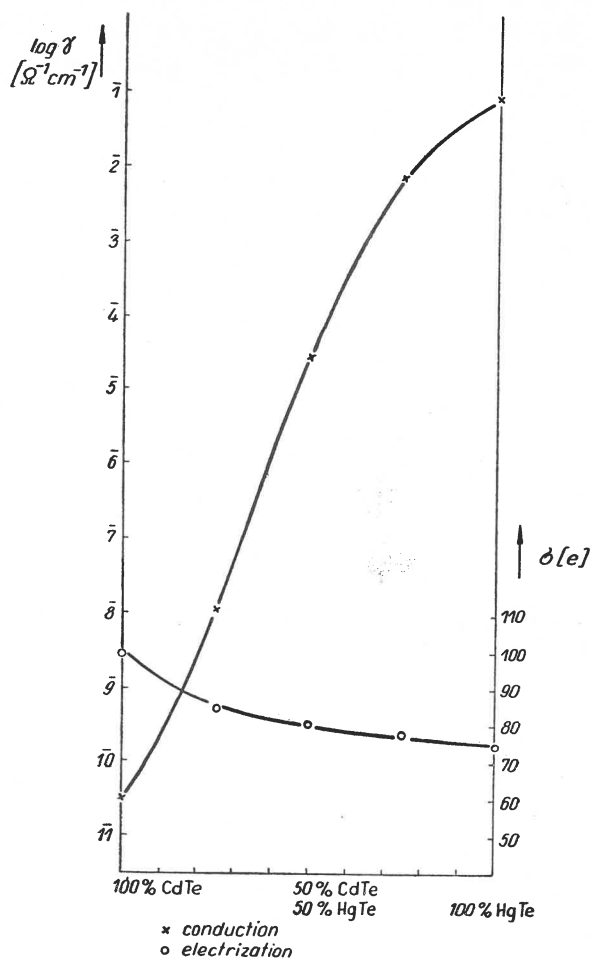

Fig. 5. Logarithm of conductivity γ (in ohm^{-1} cm^{-1}) — left-hand ordinate axis — and electrification σ (e) → right-hand ordinate axis — as a function of composition of Cd$_x$Hg$_{1-x}$Te alloy

bears an effect on the electrification of dust is confirmed by the results of measurements of the electrification of dust produced from the Cd$_x$Hg$_{1-x}$Te and CdTe$_x$Se$_{1-x}$, alloys.

In order to make the changes of electrification and conductivity of the dusts with a change in alloy composition more apparent, the σ and γ data are plotted in Figs 5 and 6.

The standard deviation σ for the Cd$_x$Hg$_{1-x}$Te alloys (Fig. 5) decreases with increased HgTe concentration in the alloy. On the other hand, the dust conductivity rises. The decreased electrification with increased conductivity is not strange, for an increase in dust

conductivity enhances the possibility of neutralization of charges on the particles. The effect of perturbations in the crystal structure is small, for there are mixed crystals within the entire range of composition changes. The two initial components have an identical structure (sphalerite), and the lattice constants differ only slightly.

The dependence of electrification on composition changes for the $CdTe_xSe_{1-x}$ has a different character than that for the $Cd_xHg_{1-x}Te$ alloys. The standard deviation for the $CdTe_xSe_{1-x}$ alloys (Fig 6) assumes lower values than for the pure components, *i.e.* CdTe
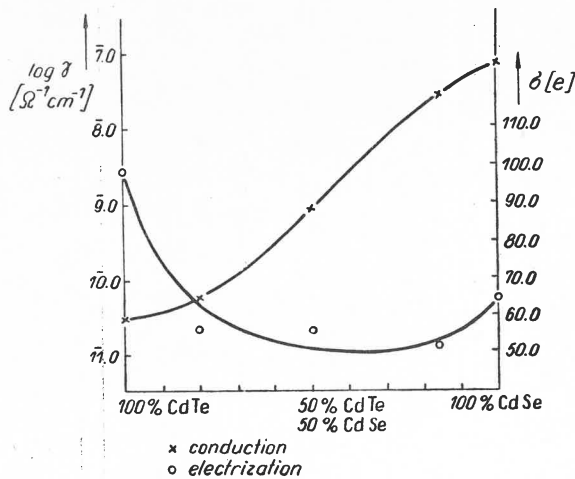

Fig. 6. Logarithm of conductivity γ (in ohm^{-1} cm^{-1}) — left-hand ordinate axis — and electrification $\sigma(e)$ — right-hand ordinate axis — as a function of composition of $CdTe_xSe_{1-x}$ alloy

and CdSe. The conductivity of the dust increases with higher concentrations of CdSe in the alloy. The lesser electrification of alloys compared to that of the substrates may be explained on the basis of the crystal structure of the alloys. In the case of $CdTe_xSe_{1-x}$ alloys we are dealing with a fine crystalline structure consisting of crystals of two different structures. Hence, during pulverization there is no breaking up of crystals but only separation of grains sintered to each other. This involves less electrification than in the case of bulk material (single crystal or polycrystal). During pulverization of the bulk material there is electrification due to the unequal distribution of charges between the surfaces being separated. On the other hand, when a fine crystalline material is crushed, there is a separation of individual grains rather than a rupture of the space lattice. These grains are not as closely united as a mono- or polycrystalline material. It is plausible that the area of contact between grains is smaller than area of surfaces newly uncovered during pulverization of bulk material. As the electrification of dust depends primarily on the area of the fracture, there is less electrification in the case of fine crystalline substances than in the case of mono- or polycrystalline substances. This explanation of the smaller electrification of $CdTe_xSe_{1-x}$ alloys compared with CdTe and CdSe appears to be in accord with the assumed mechanism of electrification of dust which relates the electrification phenomenon with the exposure of new surfaces during pulverization of the material.

A comparison of the relation of electrification of dust with conductivity for $Cd_xHg_{1-x}Te$ and $CdTe_xSe_{1-x}$ alloys shows that a change of composition of the $Cd_xHg_{1-x}Te$ alloy brings about a large change in conductivity (by nine orders of magnitude) and a slight change in electrification. The crystal structure in the entire range of changes in composition is identical. On the other hand, for the $CdTe_xSe_{1-x}$ alloy the change in electrification is pronounced whereas that of the conductivity of the dust is relatively small (three orders of magnitude).

On the basis of the presented results of alloy electrification it may be ascertained that fusion of materials of different structures bears a larger effect on electrification than does a change in conductivity brought about by a change in composition with the crystal structure being preserved.

REFERENCES

[1] J. Litwin, *Phys. Status Solidi*, **5**, 551 (1964).
[2] N. A. Goriunowa, *Chemia półprzewodników typu diamentu*, WNT, Warszawa 1965 (in Polish).
[3] H. Rodot, M. Rodot, R. Triboulet, *C. R. Acad. Sci* (France), **256**, 26 (1963).
[4] P. Höschl, *Phys. Status Solidi*, **13**, 101 (1966).
[5] T. C. Herman, M. J. Logan, H. L. Goering, *J. Phys. Chem. Solids*, **7**, 228 (1958).
[6] Hirosi Tubota, Hiromichi Suzuki, Kazayoski Hirakawa, *J. Phys. Soc. Japan*, **15**, 1701 (1960).
[7] W. B. Kunkel, I. W. Hansen, *Rev. Sci. Instrum.*, **21**, 308 (1950).
[8] A. Szaynok, *Acta Phys. Polon.*, **32**, 801 (1967).
[9] A. Szaynok, *Acta Phys. Polon.*, **32**, 819 (1967).
[10] J. Malcher, *Acta Phys. Polon.*, **A37**, 000 (1970).
[11] J. Malcher, A. Sycińska, A. Szaynok, *Acta Phys. Polon.*, **29**, 103 (1966).