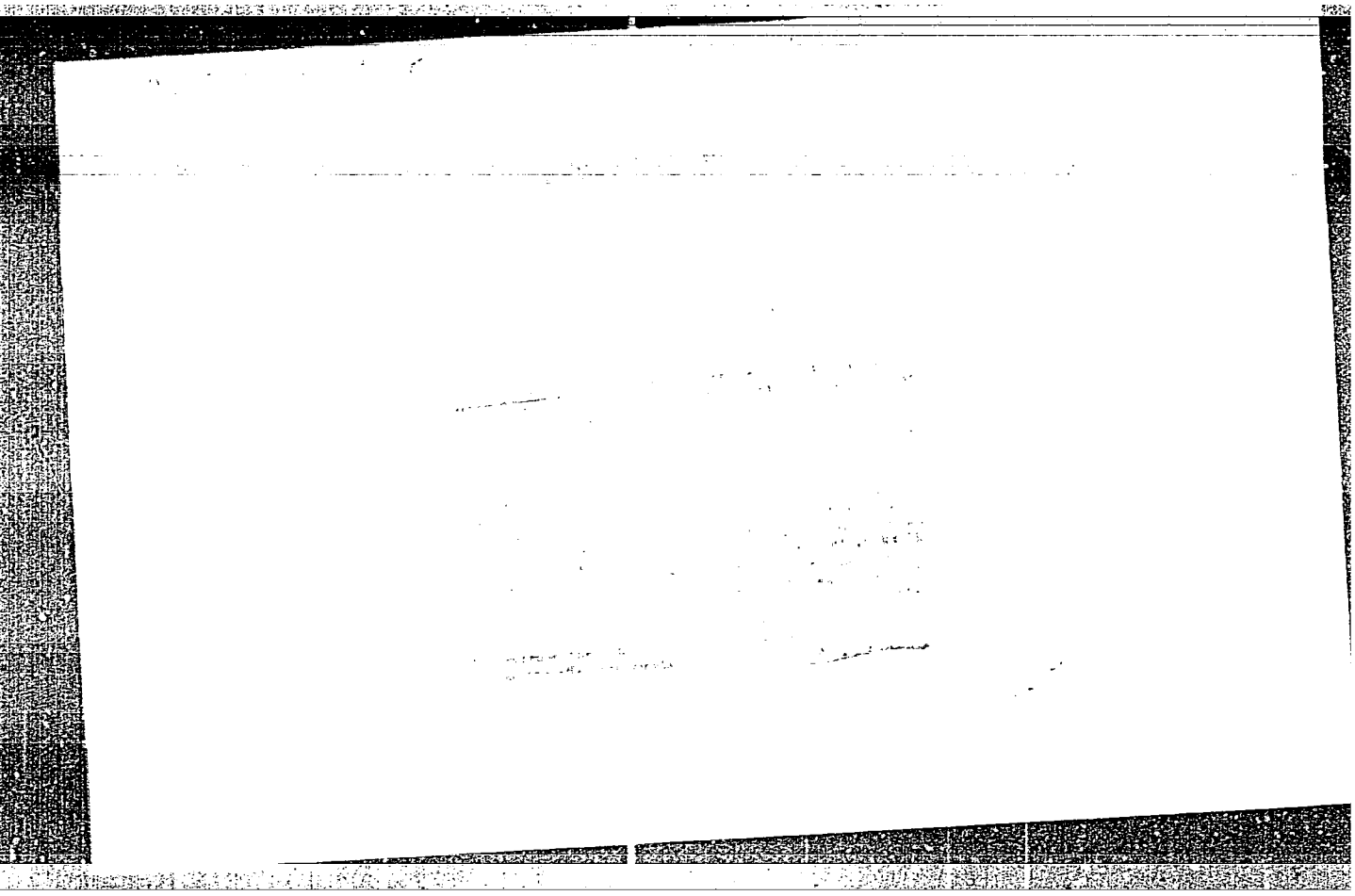
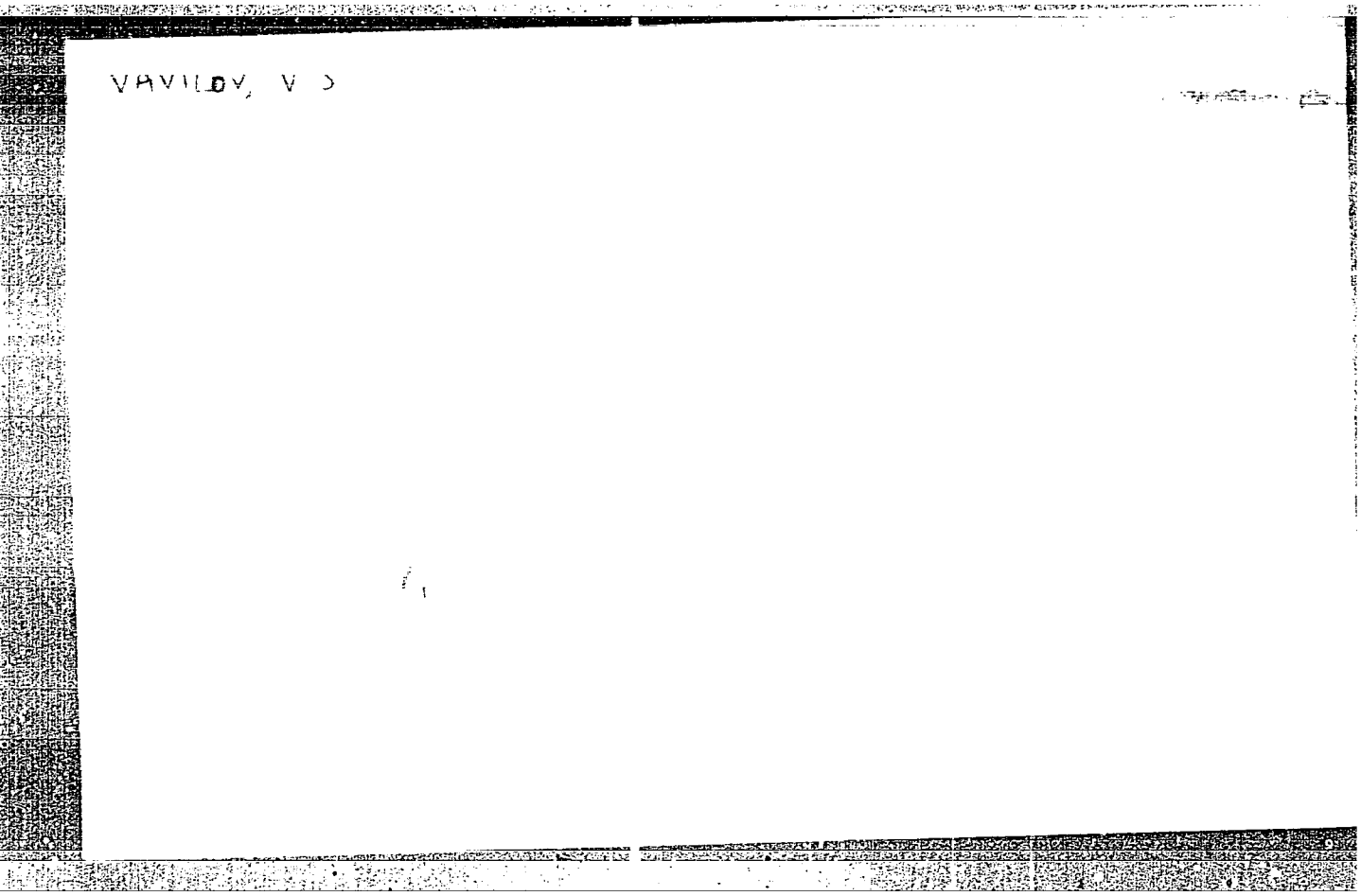
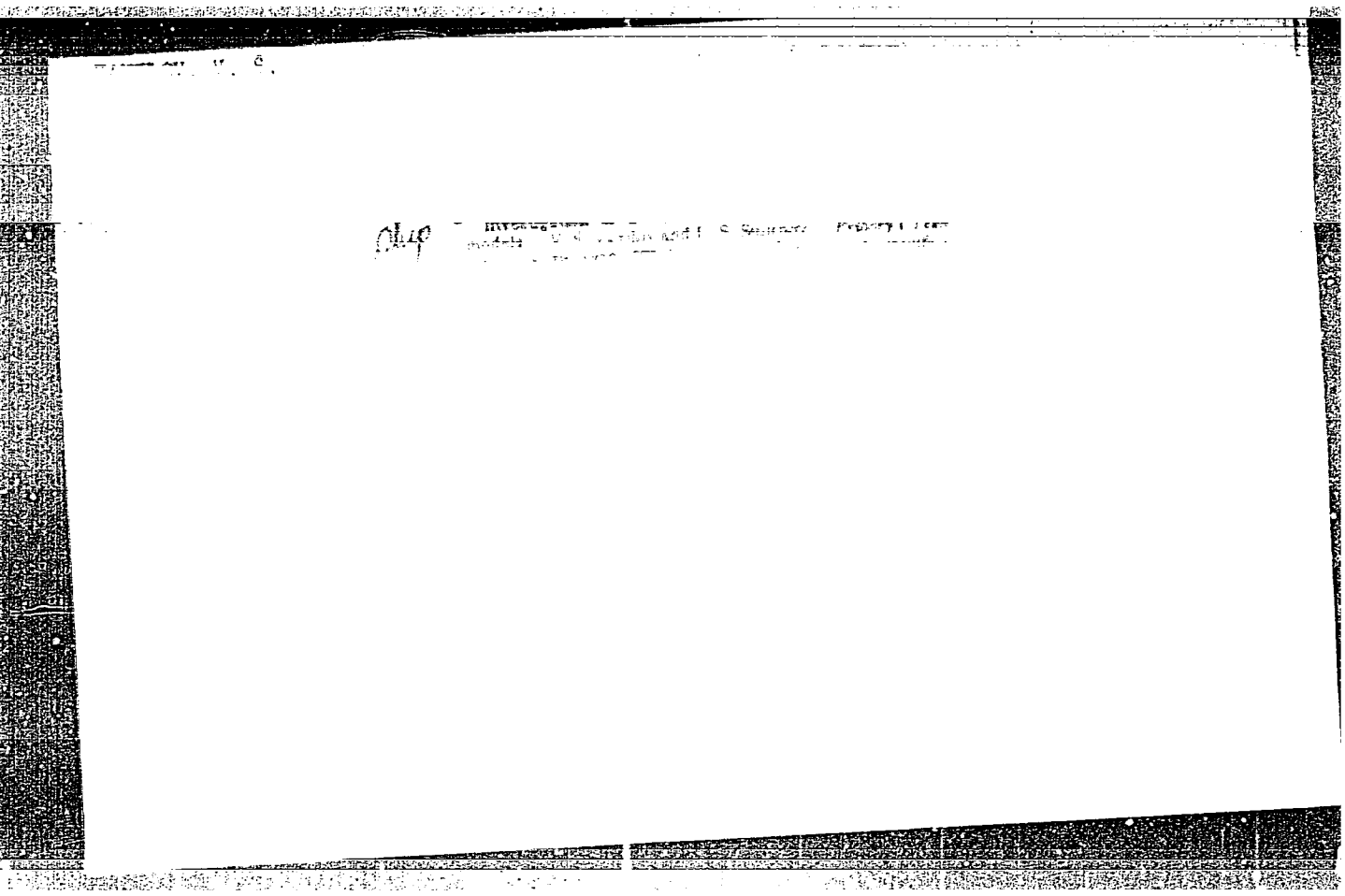
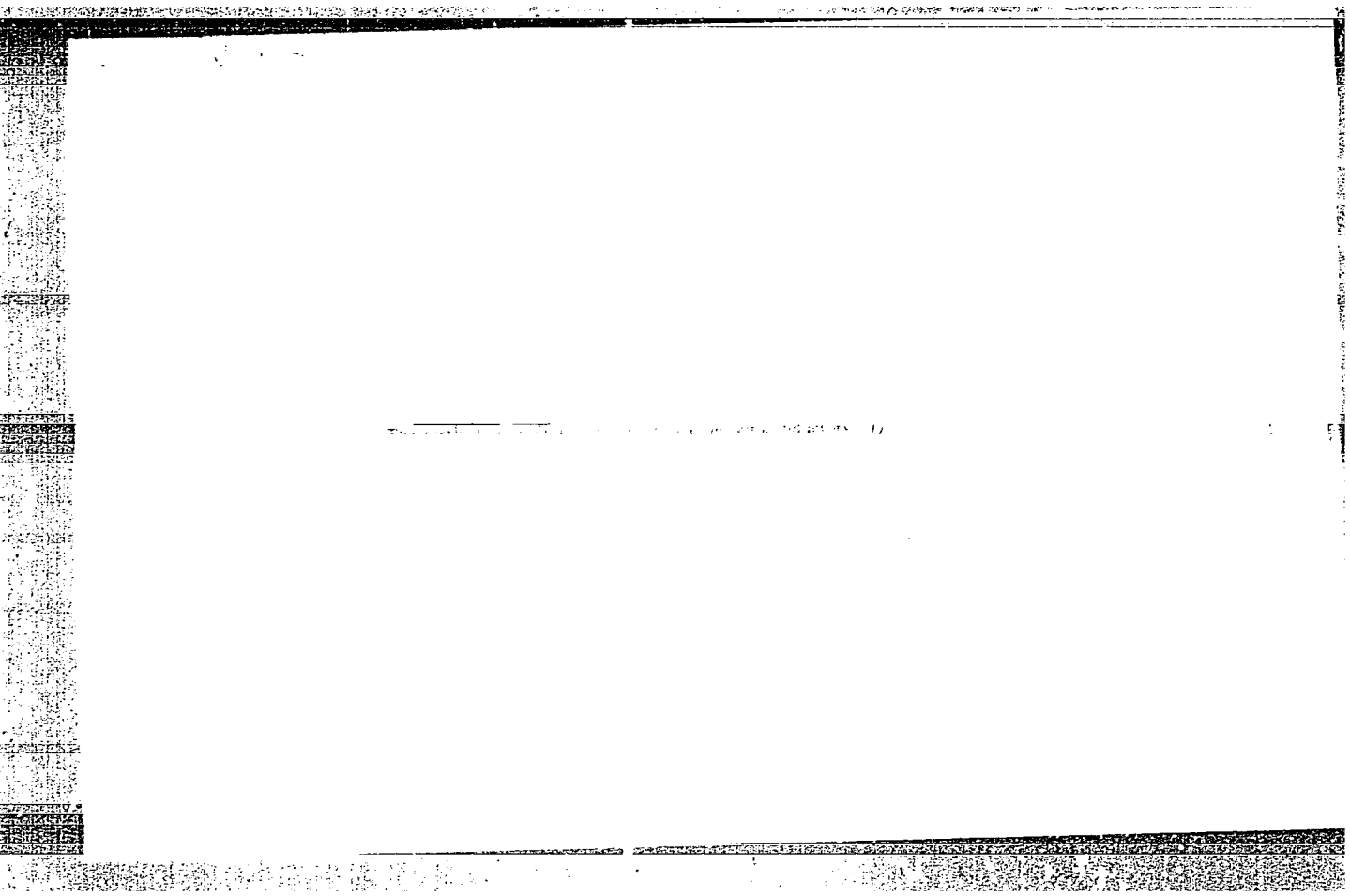


APPROVED FOR RELEASE: 08/31/2001 CIA-RDP86-00513R001859030006-9"







APPROVED FOR RELEASE: 08/31/2001 CIA-RDP86-00513R001859030006-9"

SUBJECT USSR / PHYSICS CARD 1 / 6 PA - 1251
AUTHOR VAVILOV, V.S.
TITLE Sun Piles. (On the Direct Transformation of Radiation Energy into Electric Energy with the Help of Photoelements).
PERIODICAL Atomaja Energija, 1, fasc. 3, 107-116 (1956)
Publ. 3 / 1956 reviewed 9 / 1956

Semiconductor thermopiles are mentioned which were suggested by the academician A.I.IOFFE and were successfully developed in the USSR without, however, being discussed on this occasion. Semiconductor photoelements with barrier layer have been known since the valve photoelements have been invented by W.A.ULIANIN (Wied.Ann. 34, 241 (1888)), but until recently the efficiency of these photoelements has never been more than some tenths of a %. By investigating the main properties of semiconductors, like those of the mechanism of electrons and the hole conductivity, the life of current carriers in semiconductor crystals, and the rectification of the current at the contacts between semiconductors, it was possible to predict the properties of photoelements from Ge and Si and to attain efficiencies in practice of up to 11%. Thus it is now possible to obtain more than 100 watt of electric energy per 1 m^2 of a surface directly irradiated by the sun.
Some properties of semiconductors used in sun piles: The basis of the element of the sun pile is a semiconductor crystal which contains two domains separated by a sharp boundary and having different mechanisms of electric conductivity. This boundary is called - not quite correctly - "electron-

hole-transition". Like their "relative", the diamond, pure Germanium and silicon without admixtures or structural blemishes act as insulators at room temperature and at low temperatures. By the addition of extremely small quantities (10^{-5}%) of atoms of the III. and V. group of the periodic system, it is possible to control the mechanism of electric conductivity and the specific resistance in the various domains of the crystal.
If a silicon crystal in one of its nodes contains an arsenic atom with 5 valence electrons, then 4 of them are occupied by the "bindings" keeping the atom in the node, but one of them remains free and wanders about in the crystal.
If admixtures with 3 valence electrons are used, Si- or Ge-crystals are obtained in which the electric current is transmitted as by positive charges. ("Hole conductivity"). This conception of holes is well suited for the description of the drive- and diffusion processes.
The semiconductors of sun piles are unbalanced by the absorption of solar radiation, on which occasion an excess of holes or electrons will be found to exist. Photons with more than 1,12 eV (i.e. with a wave length that is shorter than 1,1 micron), give up their energies to the silicon crystal and thereby liberate bound valance electrons. These electrons diffuse in the crystal until recombination occurs. The average "diffusion length" covered by the electrons or holes amounts to $L = \sqrt{L_\tau} = \sqrt{\mu kT/q}$. Sufficiently great

diffusion lengths (several mm) are found only in very perfect monocrystals of semiconductors.
Next, the electron-hole-contacts (transitions) between the domains which are enriched with donors and acceptors are described. On the occasion of the artificial production of crystals with electron-hole-transition it is not necessary to do away with the admixture of one of the conductor types in order, by adding the other admixture, to obtain the necessary conductivity for the corresponding part of the crystal, for it is quite sufficient to introduce the admixture necessary for the neutralization of the admixture of the other type plus a certain surplus. To one donor or acceptor there correspond 10^7 to 10^8 atoms of the basic material.
The main property of electron-hole-transitions is the capacity of rectifying the electric current. This property is based on the existence of a domain with space charge which forms a potential step for the electrons and holes. Here a qualitative explanation for the phenomena occurring on the occasion of the rectification of the current by a semiconductor crystal with electron-hole-transition is given. The number of liberated "holes" and therefore also the inverse current declines with declining temperature and with an increase of the energy E_g which is necessary for the liberation of an electron bound within the system of "valence binding". This energy amounts to 0,75 eV for Ge and to -1,12 V for Si.

Atomaja Energija, 1, fasc. 3, 107-116 (1956) CARD 4 / 6 PA - 1251

Sun piles - silicon photoelements with electron-hole-transitions. By the absorption of photons and production of electron-hole-couples solar energy is transformed direct into electric energy, i.e. into the energy of the electrons in the crystal. However, without electron-hole-transitions only the concentration of these charge carriers in the semiconductor (i.e. photoconductivity) would increase near this absorption. On the basis of a diagram the phenomena taking place in a semiconductor near the electron-hole-transition are discussed. Apparently the electrons and the holes are "separated" by the potential barrier of the electron-hole-transition, i.e. there is free transition of electrons into the domain of electronic conductivity, which is thus charged negatively, while the holes wander into the hole-domain which they charge positively. In consequency of the concentration of the charge carriers the potential barrier V_k diminishes. If the outer circuit is open, a dynamical equilibrium of the primary diffusion current of the surplus current carriers and of the inverse current which is caused by the accumulation of the space charge of the holes in the P-domain and of the electrons in the N-domain, is established, If the outer circuit is short-circuited the entire diffusion current passes through and in the case between these two extremes the current is distributed over the outer circuit and over the interior of the crystal.
Next, the equivalence scheme of the sun pile is discussed on the basis of a drawing and computed. The diffusion current I_D is equal to the short

circuit current, and the latter is forked in that one part, namely I, enters the load circuit with the load R, and the other, namely I_n, is caused by the inverse passing through of the carriers. The corresponding part of liberated energy is lost. For the maximum potential difference it applies that $V_o = (kT/q)\ln((qI_DR_o/kT) + 1)$. Here the null resistance R_o is connected with the saturation current of the electron-hole-transition as follows: $I_o = kT/qR_o$ (q denotes the charge of an electron).

Electron-hole-transitions are in considerably more intense in silicon than in germanium. This difference is due above all to the greater width of the forbidden zone of Si (1,12 eV) in comparison with Ge (0,75 3V). The theoretical efficiency of Si-photocells may, in the case of a direct incidence of solar radiation and at 25° C, attain 18%. Slight cooling down (as e.g. to 0° C) increases the degree of efficiency.

Such "sun piles" were constructed in 1954-1955; they consist of large silicon monocrystals (4-5 cm per element). The electron-hole-transitions of these crystals are located rather close to and under the surface to be irradiated. The production of sufficiently large Si-monocrystals is still very difficult. A further technical difficulty is presented by the problem of mounting the electrode which is transparent for visible and infrared light on the surface of the crystal. This and the establishment of the electron-hole-transition in the desired depth was brought about by the thermal diffusion of the admixture

Atomaja Energija, 1, fasc. 3, 107-116 (1956) CARD 6 / 6 PA - 1251

electrons. According to D.CHAPIN et al. J.Appl.Phys. 25, 676 (1954) the best results are obtained by the diffusion of boron (as acceptor) in N-silicon at a temperature that is near the melting point of Si (1400° C). Different varieties and details of this procedure are described.

In the silicon photoelements the maximum of the transformation is about $\lambda = 0,75\ \mu$, on the boundary of the red and infrared spectral domains. To this wavelength there corresponds nearly exactly the maximum number of photons in the spectrum of solar radiation. Thus, a silicon photpelement with electron-hole-transition near the surface causes a nearly perfect transformation of solar energy. Because of the relatively good transmissivity of clouds and fog for infrared light, sun-piles operate also in dull weather, although, of course, their efficiency will be somewhat lower.

The dependence of the electromotoric force and of the short-circuit current of a silicon photoelement on light conditions as well as the load characteristic of such photoelements are shown in a diagram. The load characteristics have their maxima at $\sim 0,3$ V in the case of an illumination of 1 milliwatt per cm^2 and less. Therefore, receivers necessitating a constant voltage at the input (e.g. accumulators) may be used in connection with sun piles within a wide range of illumination strength. - Within the coming years simple and sufficiently inexpensive methods for the production of semiconductor photoelements with large surface and high degree of efficiency will probably be worked out, so that the direct transformation of solar energy will be able to occupy the place it deserves within the framework of "low power economy".

INSTITUTION:

VAVILOV, V.S.

USSR/Electricity - Semiconductors G-3

Pub Jour : Referat Zhur - Fizika, No 5, 1957, 12183

Author : Vavilov, V.S., Smirnov, L.S., Galkin, G.N., Spitsyn, A.V., Patskevich, V.M.

Inst : Physics Institute, Academy of Sciences, USSR, Moscow.

Title : Formation of Defects of Crystalline Lattice in Germanium Upon Bombardment by Fast Electrons.

Orig Pub : Zh. tekhn. fiziki, 1956, 26, No 9, 1865-1869

Abstract : Thin (50 microns) platelets of single-crystal n-germanium with bombardment of monoenergetic electrons with energies from 400 to 1000 kev. The concentration of the lattice defects arising thereby was calculated from the variation in the specific resistivity ρ of the specimens before and after the irradiation. The threshold value of the energy W_{min}, starting with which ρ increases upon

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VAVILOV, V.S.

"The Structural Defects in Germanium Monocrystals Irradiated by Beta-Particles and Fast Neutrons and the Influence of These Defects on Electron-Hole Recombination," V.S. VAvilov, L.S. Smirnov, A.V. Spitsyn, V.M. Patskevich, M.V. Chukichev, Moscow, USSR

Paper submitted for presentation at the International Conference on Radioisotopes in Scientific Research, Paris 9-20 Sep 1957.

USSR Acad. of Sciences, Moscow

Presented at Conf. by V S Vavilov

VAVILOV, V.S.

120-4-14/35

AUTHORS: Galkin, G.N. and Vavilov, V.S.

TITLE: Measurement of the Lifetime of Charge Carriers and their Drift Mobility in Silicon. (Izmereniye vremeni zhizni nositeley zaryada i ikh dreyfovoy podvizhnosti v kremnii)

PERIODICAL: Pribory i Tekhnika Eksperimenta, 1957, No.4, pp. 52 - 56 (USSR)

ABSTRACT: Apparatus is described by which the lifetime and mobility of electrons and holes in mono-crystallic silicon can be measured. The pulse method is used and traps are filled by illumination of the crystal. The apparatus can be used for measurement of lifetimes from 1 μsec.
The method is based on the drift under the action of an applied electric field, of minority carriers introduced into the semi-conductor by a point contact (emitter) to which is applied s short pulse (0.3 μsec). After a time lag, a rectangular pulsed electric field is applied to the specimen. The introduced non-base carriers move along the specimen and on passing the collector, create an opposition pulse (collector response) which is displayed on an oscillograph. The block diagram is given in Fig.1 and the oscillograph display in Fig. 2. By changing the time lag, a different height of the collector response H can be obtained,

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Measurement of the Lifetime of Charge Carriers and their Drift Mobility in Silicon.

depending on the maximum concentration of the non-base carriers at the instant they pass near the collector. For a short emitter pulse and with small deviation from equilibrium concentration, H is given by:

$$H \sim (1/\sqrt{t}) \exp(-t/\tau).$$

The first factor corresponds to diffusion and the second to recombination. Here, τ is the lifetime of the minority carriers. Log $(H\sqrt{t})$ is plotted against t giving a straight line with a slope equal to $-1/\tau$. The presence of traps can be detected by the shape of the collector response (Fig.3). The specimen is illuminated until asymmetry of the collector response is eliminated.
The injection level can also be judged by the shape of the collector response, since a large quantity of minority carriers changes the conductivity of the material and causes asymmetrical distortion of the pulse (Fig.4). Thus the method indicates when the traps are filled and when the concentration of the minority carriers is sufficiently low.
Card2/4 To avoid non-linearity of the collector, contact with small

Measurement of the Lifetime of Charge Carriers and their Drift Mobility in Silicon.

concentrations of the non-base carriers near the collector, the intensity is increased by illumination of the surface near the collector by white light (Granville and Gibson method, Refs. 7 and 13).
The mobility u_d was determined by the formula:

$$u_d = L/t \cdot E$$

where L is the distance between the emitter and the collector, t is the time between the application of the pulse and the reception of the response, E is the applied field.
The time t is found by extrapolation of the graph of H against t to H= 0 (Fig.7). L is measured by a measuring microscope, and E is found by backing off an oscillograph displaying the voltage.
The table shows that for measurements $\tau > 3$ μsec., the error does not exceed 10%, and down to 0.2 μsec. 100%. The errors of u_d do not exceed 10% and compare well with values given in the literature. There are 9 figures and 13 references, 5 of which are Slavic.

120-4-14/35

Measurement of the Lifetime of Charge Carriers and their Drift Mobility in Silicon.

ASSOCIATION: Physics Institute imeni P.N. Lebedev Ac.Sc. USSR. (Fizicheskiy institut im. P.N. Lebedeva AN SSSR)

SUBMITTED: March 2, 1957.

AVAILABLE: Library of Congress

Card 4/4

V.S. VAVILOV,

"Energy of Ionization by Beta-Particles in Crystals of Germanium and Silicon," V.S. Vavilov, L.S. Smirnov, V.M. Patskevich, Moscow, USSR.

Paper submitted for presentation at the International Conference on Radioisotopes in Scientific Research, Paris, 9-20 Sep 195[illegible].

Acad. Sci. USSR, Moscow

Paper presented at Conf by V S Vavilov

VAVILOV, V.S.

Semiconductor converters of radiation energy. Dok. akad. fiz. no.5:209-226 '57. (MIRA 16:6)

(Transistors)

VAVILOV, V.S.

USSR/Electricity - Semiconductors G-3

Abs Jour : Ref Zhur - Fizika, No 1, 1958, 1303

Author : Vul, B.M., Vavilov, V.S., Smirnov, L.S., Gelkin, G.N., Patskevich, V.M., Spitsyn, A.V.

Inst : -

Title : Transformation of the Energy of β Particles Into Electric Energy in Germanium Crystals with P-N Junctions.

Orig Pub : Atomn. energiya, 1957, 2, No 6, 533-536

Abstract : The authors report results of an investigation of the direct transformation of the energy of β particles into electric energy in germanium crystals of the n-type with p-n junctions, obtained by melting-in indium. The sources of the β particles were the compounds $Sr^{90} - Y^{90}$ with activities of 50, 100, and 200 millicurie. The experiments were also performed with artificially-accelerated electrons with energies from 400 to 1150 kev, the intensity of the electron beam reaching values corresponding

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USSR/Electricity - Semiconductors G-3

Abs Jour : Ref Zhur - Fizika, No 1, 1958, 1303

a secondary role. It is indicated that it is possible to restore the initial properties of crystals by heating them. Other possible types of semiconducting energy transformations to transform the energy of radioactive decay into electric energy are considered.

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Probability of Charge Carriers by Frenkel Defekts in N-Germanium.

restitution of the original life. If the number of defects occuring in the chrystal lattice is compared with the attendant circumstance of reduction of life the capture cross-section of the carriers (holes) can be estimated (by the new-formed recombination-centers). The formula for the capture cross-section is derived on the assumption that the number of new recombination-centers is equal to the number of Frenkel-defects and that all these centers are filled with electrons. Experimental result for this domain which must be considered to be the lowest of the actual value, were approximatively $7 \cdot 10^{-17} cm^2$. (1 image).

ASSOCIATION: Physical Institute "P.N.Lebedev", Moscow.
PRESENTED BY:
SUBMITTED: 1.10.1956
AVAILABLE: Library of Congress.

G-3

VAVILOV, V.S

USSR/Electricity - Semiconductors

Abs Jour : Ref Zhur - Fizika, No 1, 1958, 1325

Author : Vavilov, V.S., Spetsyn, A.V., Smirnov, L.S., Chukichev, M.V.

Inst : Physics Institute, Academy of Sciences, USSR, Moscow

Title : Effect of Fast Neutron Irradiation on Recombination of Electrons and Holes in Germanium Crystals.

Orig Pub : Zh. eksperim. i teor . fiziki, 1957, 32, No 4, 702-705

Abstract : On the basis on the transverse cross sections for the interaction of fast neutrons with germanium nuclei, using the Snyder and Neufeld method (Referat Zhur Fizika, 1956, No 7, 19840, No 12, 35072), the authors calculate the number of germanium atoms, shifted from their lattice points as a result of scattering of fast neutrons. It was established experimentally that the irradiation of germanium

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VAVILOV, V.S

AUTHORS Patskevich, V.M., Vavilov, V.S., Smirnov, L.S. 56-3-43/59

TITLE Electron Ionization Energy in Silicon Crystals. (Energiya ionizatsii elektronami v kristallakh kremniya) (Letter to the Editor)

PERIODICAL Zhurnal Eksperim.i Teoret.Fiziki,1957,Vol 33,Nr 3,pp 804-805(USSR)

ABSTRACT The "multiplication coefficient" ß of the charge carriers was measured on a silicon monocrystal of the P-type with P-N-transitions. Irradiation by electrons with an energy of from 10 to 30 keV took place vertically to the N-type side of the crystal,but parallel to the P-N-transitions.From the coefficient ß measured the quantity $\mathcal{E}$ was determined as $4,2 \pm 0,6$ eV.
There are 2 figures and 5 Slavic references.

53-1a-8/18

AUTHOR VAVILOV, V.S., MALOVETSKAYA, V.M., GALKIN, G.N., LANDSMAN, A.P.

TITLE Silicon Solar Batteries as Sources of the Electric Feeding of Artificial Earth Satellites
(Kremniyevyye solnechnyye batarei kak istochniki elektricheskogo pitaniya iskusstvennykh sputnikov zemli. Russian)

PERIODICAL Uspekhi Fiz. Nauk, 1957, Vol 63, Nr 1a, pp 123 - 129 (U.S.S.R.)

ABSTRACT For artificial earth satellites it is of advantage to use solar batteries in connection with buffer accumulators because they are effective during the whole time of flight of the satellite (outside of the earth's shadow).

The principle of the effect of a semiconductor transformer with P-N-transitions. In the course of this process the energy of solar radiation is transformed into electric energy as follows: A photon is absorbed and an "electron-hole" pair is produced. In the case of lacking P-N-transition, however, the concentration of the electrons and holes in the semiconductor would increase in the vicinity of the absorption domain of light. The authors here investigated the diagram of the energy states of the electrons and holes in the semiconductor in the vicinity of the artificial produced P-N-transition. This diagram then supplies information concerning the mode of operation of the photoelement. Within the domain of the P-N-transition there exists a potential barrier,

Silicon Solar Batteries as Sources of the Electric Feeding of Artificial Earth Satellites 53-2a-8/18

the height V_k of which can be nearly as great as the width E_g of the forbidden zone (in the case of silicon 1,1 eV). The electrons and holes produced on the occasion of the absorption of light diffuse to P-N--transition. The potential barrier of the P-N-transition then probably "separates" the electrons and holes so that the electrons advance freely to the domain of the electronic (N)-conduction of the crystal to which they then give a negative charge. On the occasion of transition into the domain of the hole-conditioned conduction line the holes charge the crystal positively. As a result of the change of the concentrations of the charge carrier the height of the potential barrier decreases. A diagram shows the dependence of the effective coefficient of a perfect semiconductor transformer with P-N-transition upon the width of the forbidden zone. The effective coefficient at first increases considerably, attains its maximum value at a width of 1,3 eV, and then gradually decreases again. In none of the known cases was the ideal effective useful coefficient of about 22 % attained. The authors developed a method for obtaining P-N-transitions in monocrystals of P-silicon by the thermal diffusion of phosphorus from the gaseous phase. Various details

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Silicon Solar Batteries as Sources of the Electric Feeding of Artificial Earth Satellites

of this method are discussed. The construction of an experimental silicon photoelement is shown in an illustration.

The Volt-ampère characteristics and the charge characteristics:
The volt-ampère characteristic of a photoelement with a surface of 0,95 cm^2 irradiated by sunlight is shown in a diagram. For the darkness volt-ampère characteristic in the domain of the direct current a formula is written down. The optimum load resistance R_B can be determined from the load characteristic as well as by computation. The authors here point to the following means of further increasing the effective coefficient of transformation:

1.) Increase of the effective useful coefficient α to one,
2.) Decrease of the resistance $R_{ser} \ll R$ which is connected in series (?).
3.) Transillumination (making transparent ?) of the surface at R = 0.
4.) Improvement of the shape of the load characteristic by the application of material of a lower resistance (without changing α).

The evaluation of the fourth possibility requires further experimental investigations. The simultaneous increase from α up to a value near 1 as well as the reduction of the reflection and of R_{ser} to a minimum make it

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Silicon Solar Batteries as Sources of the Electric Feeding of Artificial Earth Satellites

possible to attain an effective useful coefficient of ~15 %

The behavior of temperature in solar batteries. According to theory the electromotoric force developed by a silicon-photoelement must increase on the occasion of the reduction of temperature, a preliminary investigation resulted in $dV/dT = -0,00252$ V/°C. A diagram attached shows the dependence of V on temperature within the domain of from - 70 up to + 90°. If the solar battery is to yield the highest possible efficiency during the flight of the earth satellite, a sufficiently low equilibrium temperature of the solar battery is necessary. Possibilities for the decrease of equilibrium temperature are given. The experimental results for silicon solar batteries obtained at conditions prevailing on the earth confirm their applicability to earth satellits. (With 6 illustrations).

ASSOCIATION Not given
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VAVILOV, V.S., MALOVETSKAYA, Z.M., GALKIN, G.M., and LANDSMAN, A.P.

"Silicon Solar Batteries as Electric Power Sources for Artificial Earth Satellites," Uspekhi Fizicheskikh Nauk, Vol. 63, No. 1-2, p. 181, September 1957.

SO: JPRS Report No. 187

Vavilov, V.S

PA - 2332

AUTHOR: VAVILOV,V.S., SMIRNOV,L.S., PATSKEVICH,V.M.

TITLE: Energy of Ionization by Electrons in Germanium crystals (Energyya ionisatsii elektronami v kristallakh germaniya, Russian).

PERIODICAL: Doklady Akademii Nauk SSSR, 1957, Vol 112, Nr 6, pp 1020 - 1022, (U.S.S.R.)

Received: 4 / 1957 Reviewed: 5 / 1957

ABSTRACT: The authors carri i out experiments on the determination of the average ionization energy in germanium on the occasion of excitation by electrons with 5 - 15 keV. For these experiments N-Type crystals with P - N - transitions, into which indium was melted, were used. Irradiation occurred on the side opposite to the indium electrode. The electronscompletely lost their energies within the domain of the N-type. The authors used the following denotations: N_o - the number of carrier pairs actually created in the unit of time, N_1 - amperage of the electrons, N_2 - amperage of the holes. It holes that $\beta_1 = N_2/N_1 = I_2/I_1$, where I_1 corresponds to the primary current corresponding to the flux of the fast electrons. Up to very high intensities of the inciting bundle it further holds that $N_2 = \alpha N_o$. Due to recombination on the surface and in the interior of the crystal it always holds that $\alpha < 1$. For the multiplication factor β it holds that $\beta = N_o/N_1 = \beta_1/\alpha = I_2/\alpha I_1$. In the case of the crystals examined here did not depend on the wave length of the light. This holds good up to such wave

Card 1/3

Energy of Ionization by Electrons in Germanium crystals.

wave lengths in the case of which a considerable part of the light does not pass through the crystal but is absorbed in it. For the measuring of α the authors used light with λ = 1,05 μ which for the most is absorbed in layers with a maximum thickness of 1,0 μ. α depends greatly on the conditions prevailing on the surface of the crystals and changes on the occasion of the pumping out of the device and of bombardment with electrons. For the purpose of a continuous control of α in the course of measurements, the electrons were at the same time irradiated with electrons and light. The tests were carried out at pressures of 10^{-4} - 2.10^{-6} torr. No dependence of ε (i.e. of the energy which must be used for the production of a carrier pair) on pressure (within the limits 2.10^{-6} - 10^{-4} torr) was noticed. The series of measurements on the crystals, which were subjected to different surface treatments, furnished the same value for ε. The mean value ε = 3,7 $\pm$ 0,4 eV was obtained from 4 series of measurements. In the case of V " 5 to 15 keV ε does not change. This indicates slight energy losses of the primary electrons in the superficial oxide film which occurs on the occasion of the pickling of the germanium. The considerable similarity of the amounts of ε on the occasion of ionization by electrons and α particles may apparently be ex-

PA - 2332

Energy of Ionozation by Electrons in Germanium Crystals.

plained by the fact that in the second case a considerable part of the charge carrier pairs occurs under the effect of relatively fast δ-electrons. (1 illustration)

ASSOCIATION: Not given.
PRESENTED BY: Member of the Academy D.V.SKOBEL'TSYN.
SUBMITTED: 24.10.1956
AVAILABLE: Library of Congress.

Card 3/3

VAVILOV, V.S.; LANDSMAN, A.P.; SUBASHIYEV, V.K.

Solar batteries. Isk.sput.Zem. no.2:75-80 '58. (MIRA 12:5)

(Artificial satellites)
(Solar batteries)

AUTHORS: Vavilov, V.S., Galkin, G.N., Malovetskaya, V.M. SOV/89-4-6-9/30

TITLE: Investigation of Silicon Photoelements as Converters of Solar Radiation (Issledovaniye kremniyevykh fotoelementov kak preobrazovateley solnechnogo izlucheniya)

PERIODICAL: Atomnaya energiya, 1958, Vol 4, Nr 6, pp. 571-575 (USSR)

ABSTRACT: The P-N-transitions are investigated which are produced in silicon of the P-type by the thermal diffusion of phosphorus from the gaseous phase.
It was found that P-silicon with P-N-transitions can be used as converter of solar radiation. These photoelements have the following properties:
1.) The current in the outer circle is produced by the forming of electrons and holes by the light in the N-type and in the P-type along the P-N-transitions
2.) The diffusion length of the electrons in the P-range diminishes after P-N transitions have been obtained to from 20 to 35 μ.
3.) The surface layer produced by phosphorthermodiffusion reduces the reflection coefficient within the most important

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Investigation of Silicon Photoelements as Converters of Solar Radiation

range of operation from 36 to 30% to 12 to 15%. The collective coefficient, on the other hand, is not reduced very much. The result is that the short-circuit current is comparatively high.

4.) Silicon photoelements operate with an insolation of up to 0.5 W/cm^2.

There are 7 figures and 7 references, 3 of which are Soviet.

SUBMITTED: December 14, 1957

1. Silicon--Electrical properties 2. Silicon--Applications
3. Photoemission--Test results 4. Sun--Radiation

Card 2/2

VAVILOV, V.S.

AUTHORS: Vavilov, V. S., Gippius, A. A., Gorshkov, M. M. 57-3-9/32

TITLE: On the Reflection Coefficients of Germanium and Silicon Crystals (O koeffitsiyentakh otrazheniya kristallov germaniya i kremniya).

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol 28, Nr 2, pp. 295-299 (USSR)

ABSTRACT: The integrating sphere (reference 4) was here used for measuring the diffusion-(as well as the specular) reflection of the light of Ge or Si within the range of wave-lengths from 0,4 to 1,1 μ. A description of the apparatus is given. The errors in the measurement of R according to this method are determined by the relation of the three apertures to the surface of the sphere (reference 7) and by the accuracy of the measurement of the intensities I. Here the error amounted to less than 2% of the value of R to be determined. (Reflection coefficient). The dependence of the reflection coefficient R on the wave-length λ is given here: 1) for a polished germanium monocrystal of the n-type, $\varrho \approx$ 'o ohm.cm, which was not etched; 2) for the same germanium-sample after a deep-etching in H_2O_2; 3) for a polished silicon-monocrystal of the p-type, ϱ ~ to ohm.cm. 4) for a [illegible]

Card 1/2

On the Reflection Coefficients of Germanium and Silicon Crystals. [illegible]/32

lished silicon-monocrystal of the N-type, alloyed with phosphorus (surface-concentration p of the order of magnitude [illegible]) The obtained data prove a marked dependence of the reflection coefficient on the nature of the surface-treatment. In investigations whose results depend on the values of the reflection coefficient the simple method described here makes it possible to avoid essential errors. E. N. Alentsev and L. L. Lasitsa helped in the work. There are 1 figure, and 7 references, 2 of which are Slavic.

ASSOCIATION: Moscow State University, Physics Department, (Moskovskiy gosudarstvennyy universitet Fizicheskiy fakul'tet).

SUBMITTED: June 27, 1957

AVAILABLE: Library of Congress

1. Single crystals 2. Crystals-Reflective effects

Card 2/2

AUTHORS: Vavilov, V. S., Smirnov, L. S., Spitsyn, A. V., 57-28-5-6/36
Patskevich, V. M., Galkin, G. N.

TITLE: On Defects in a Crystal Lattice in n-Germanium (O defektakh kristallicheskoy reshetki v germanii N-tipa)

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 28, Nr 5, pp. 960-961 (USSR)

ABSTRACT: In the previous paper the authors communicated the investigation results of germanium crystals of the n- type subjected to an electron bombardment with energies ranging from 0,4 to 1 MeV (Ref 1). There, the experimentally determined modifications of the specific resistance with respect to the energy and the amount of fast electrons, was opposed to the theory of defect formation because of an electron dispersion by means of germanium nuclei by Frenkel'. V. V. Galavanov to whom the authors are indebted, indicated a numerical error. This error was committed in the computation of the integral cross-sections $\sum_{\theta min}^{\pi}$ of electron dispersion on a nucleus at all angles from π to the angle θ_{min} at which the electron transfers the minimum energy to the nucleus necessary for the formation of a defect. The newly computed theoretical values of $\sum_{\theta min}^{\pi}$ corresponding to

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a threshold energy of 500 keV as well as the experimentally determined sections Σ of center formation, which remove the electrons from the conduction zone are given in the table. From this follows, that the experimental values, which have been obtained in the mentioned paper and which were verified by subsequent experiments, do not correspond to the conception that at energies W varying from the threshold energy (W = 0,5 MeV) to W = 0,96 MeV the constant defects in n-type germanium are produced according to the law $\sum_{\theta_{min}}^{\pi} = f(W)$

It is intended to conduct in the near future experiments with n-type crystals with strongly differing Fermi levels and to determine, whether the difference between theory and experiment is dependent upon the low degree of filling of the capture centers. There are 1 table and 1 Soviet reference.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva AN SSSR, Moskva(Physical Institute imeni P. N. Lebedev AS USSR, Moscow)

SUBMITTED: January 18, 1958

1. Germanium crystals--Analysis

AUTHORS: Vavilov, V. S., Britsyn, K. I.

TITLE: On the Quantum Yield of the Atomic Photo-Effect in Germanium (O kvantovom vykhode vnutrennego fotoeffekta v germanii)

PERIODICAL: Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki, 1958, Vol. 34, Nr 2, pp. 521 - 523 (USSR)

ABSTRACT: First the authors shortly refer to earlier works dealing with the same subject. The authors carried out measurements of the quantum yield of the atomic photo-effect in germanium of the N-type within the range of wave lengths of from 1,5 to 0,254 μ. The quantum yield Q is defined as the ratio (number of excess free carriers / number of absorbed photons). In the experiments germanium monocrystals with the specific resistance from 9 10 to 20Ω were used. The original diffusion length was about 1,5 mm. The plate-shaped crystals (0,3 - 0,6 mm thick and 1 cm^2 surface) were irradiated with monochromatic light from one side. At the opposite side of the plates there was an N-P-transition which had been pro-

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56-2-40/51

On the Quantum Yield of the Atomic Photo-Effect in Germanium

duced by the melting of indium. Also the light sources used are given. Within the ultraviolet range the luminescent compound Lumogen (with a constant yield of luminescence) as well as the photomultiplier ФЭУ-25 were used as recorders for the bands 366, 313, 289 and 254 m μ. Also the formula for the calculation of the quantum yield is given. The total reflection coefficient occurring in this formula was measured by means of integral photometer sphere. A diagram shows the curve R(hν) as well as the values of the quantum yield for the photo-energies from 0,83 to 4,9 eV computed by means of the above formula. This curve clearly shows the important increase of Q, which, however, does not begin with the double minimum work function of the electron (~1,4 eV), but at higher energies. The increase of the quantum yield becomes slower with great hν ; i.e. the mean energy ε , which must be expended for the production for an electron-hole pair, increases. A certain increase of ε was also observed in the investigation of the propagation of fast electrons in germanium with increasing energy of the electrons. There are 1 figure, and 8 references, 7 of which are Slavic.

Card 2/3

56-2-42/51

On the Quantum Yield of the Atomic Photo-Effect in Germanium

ASSOCIATION: Moscow State University
(Moskovskiy gosudarstvennyy universitet)

SUBMITTED: November 21, 1957

AVAILABLE: Library of Congress

1. Germanium-Atomic photo effect 2. Quantum yield-Measurement

Card 3/3

Vavilov V. S.

56-2-47/51

AUTHORS: Spitsyn, A. V. , Vavilov, V. S.

TITLE: On the Recombination Capturing of Minority Carriers in n-Type Germanium by Lattice Defects Caused by Irradiation With Quick Neutrons (O rekombinatsionnom zakhvate neosnovnykh nositeley v germanii n-tipa defektami reshetki, obrazuyushchimisya pri obluchenii bystrymi neytronami)

PERIODICAL: Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki, 1958, Vol. 34, Nr 2, pp 530 - 531 (USSR)

ABSTRACT: In a previous work by V. S. Vavilov et al. (reference 1) the cross section of the recombination capture θ of the minority carriers by radiation-caused defects of the crystal structure in n-type germanium (caused by irradiation with quick neutrons) was estimated. The formulae used for the calculation are given. For the estimation of the magnitude θ the values of the mean number $\overline{N}_d$ of displaced germanium atoms per scattering of a neutron were used, which had been recalculated by a formula of H. Fan and K. Lark-Horovitz (re-

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On the Recombination Capturing of Minority Carriers in n-Type Germanium by Lattice Defects Caused by Irradiation With Quick Neutrons

ference 2). In order to prove the correctness of the calculation of N_d the authors carried out additional experiments on the irradiation of n-germanium with neutrons. With increasing dosage of the neutron irradiation measurable changes of the specific resistance $\rho - \rho_0 = \Delta\rho$ were found which were compared with the changes of life in the same samples. With the dosages of the neutron irradiation with neutrons used here it can be assumed that the movability does not change. The change Δn of the concentration of carriers with given $\Delta\rho$ was determined from the theoretical dependence $\rho = f(n)$ mentioned by M. Prince. These dependences are well satisfied by the germanium monocrystals used. Using the data of J. Cleland (reference 4) on the values of Δn, the concentration n_d of defects in all irradiated samples were estimated. From one of the above-mentiond formulae the quantity N_d was determined for the samples irradiated with monoenergetic neutrons. The values of the quantity are close to 260. The data obtained are given in a table. The values of θ obtained here are greater by one order of magnitude

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56-2-47/51

On the Recombination Capturing of Minority Carriers in n-Type Germanium by Lattice Defects Caused by Irradiation With Quick Neutrons

than the cross sections of the capture of carriers by single Frenkel' defects forming in the irradiation of electrons. The increase of θ obviously is connected with the fact that one of the recombination levels is situated in the upper half of the forbidden band. There are 1 table, and 6 references, 2 of which are Slavic.

ASSOCIATION: Institute of Physics imeni P. N. Lebedev AS USSR
(Fizicheskiy institut im. P. N. Lebedeva Akademii nauk SSSR)

SUBMITTED: November 29, 1957

AVAILABLE: Library of Congress

1. Germanium crystals-Defects 2. Neutron irradiation-Applications

Card 3/3

SOV/56-34-5-66/61

AUTHORS: Vavilov, V. S., Britayn, K. I.

TITLE: On the Quantum Yield of the Photo-Ionisation in Silicon (O kvantovom vykhode fotoionizatsii v kremnii)

PERIODICAL: Zhurnal eksperimental'noy i teoreticheskoy fiziki, 1958, Vol. 34, Nr 5, pp. 1354 - 1355 (USSR)

ABSTRACT: It was shown in two previous works (Refs 1,2) that the quantum yield of the internal photo effect in germanium crystals in the case of sufficiently high photon energies can reach considerably higher values than unity. This increase of the quantum yield can be explained by collision ionisation by primary electrons or holes (which on occasion of the absorption of the photon have become free and have the necessary excess momentum). A similar phenomenon could also be expected in silicon. For the investigation of the photo effect in silicon the author used crystals with P-N-transitions which could be expected to occur by thermo-diffusion of phosphorus in silicon of the P-type. To obtain a sufficient sensitivity in the short-wave range crystals were produced in which the depth of the P-N-transition under the

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On the Quantum Yield of the Photo-Ionisation in Silicon

illuminated surface did not exceed over 2μ. The same experimental arrangement served in these measurements and in those with germanium. Reference is made concerning a complication, which occurs as compared to germanium. In the range of the photon energies of $E_g < \hbar\nu < 2E_g$ ($E_g \sim 1,1$ eV denoting the width of the forbidden band of silicon) the quantum yield was set equal to 1. The experimental dependence of the reflection coefficient R and of the product of the quantum yield Q with the collective coefficient (koeffitsiyent sobiraniya) on the photon energy $\hbar\nu$ is illustrated in a diagram. At about $\hbar\nu \sim 3,25$ eV a remarkable increase of this quantity begins. The course taken by the curve tends to show an increase of the quantum yield and thus a presence of ionisation by collision by the carriers liberated in the absorption of the photons. The results resemble those from the measurements by McKay (Ref 6). The authors express their gratitude to V.M. Malovetskiy, V.M.Patskevich and L.V.Belova for their assistance in the production of the crystals with the P-N-transitions.

Card 2/3 There are 1 figure and 6 references, 4 of which are Soviet.

On the Quantum Yield of the Photo-Ionisation in Silicon SOV/56-34-5-60/61

ASSOCIATION: Moskovskiy gosudarstvenny universitet (Moscow State University)

SUBMITTED: February 27, 1958

1. Silicon crystals--Photoconductivity 2. Electrons--Properties
3. Photons--Properties

Card 3/3

SOV/53-65-3-11/11

AUTHOR: Vavilov, V. S.

TITLE: Bibliography (Bibliografiya)

PERIODICAL: Uspekhi fizicheskikh nauk, 1958, Vol. 65, Nr 3, pp. 547-548 (USSR)

ABSTRACT: This is a detailed discussion of a reference work published under the title: "Problems of Semiconductor Physics" (Problemy fiziki poluprovodnikov); the book was compiled from the translation of articles published in German periodicals under the editorship of V. L. Bonch-Bruyevich. It was published in 1957 at Moscow and contains 628 pages; price: Rubles 36,20.

1. Physics 2. Semiconductors--Bibliography

Card 1/1

VAVILOV, V.S.

21(0),24(0) PHASE I BOOK EXPLOITATIO' SOV

Akademiya nauk SSSR. Fizicheskiy institut

Issledovaniya po eksperimental'noy i teoreticheskoy fizike: [sbornik] (Studies on Experimental and Theoretical Physics; Collection of Articles) Moscow, Izd-vo AN SSSR, 1959. 304 p. Errata slip inserted. 2,300 copies printed.

Ed.: I. L. Fabelinskiy, Doctor of Physical and Mathematical Sciences; Ed. of Publishing House: A. L. Chernyak and V. G. Berkaut; Tech. Ed.: Yu. V. Rylina; Ye. Yam

Commission for Publishing Scientific Works in Memory of Grigoriya Samuilovich Landsberg: I. Ye. Tamm (Chairman), Academician; M. A. Leontovich, Academician; P. A. Bazhulin, Doctor of Physical and Mathematical Sciences; S. L. Mandel'shtam, Doctor of Physical and Mathematical Sciences; I. L. Fabelinskiy, Doctor of Physical and Mathematical Sciences; P. S. Landsberg-Baryshanskaya, Candidate of Physical and Mathematical Sciences; and G. P. Motulevich (Secretary), Candidate of Physical and Mathematical Sciences.

PURPOSE: This book is intended for physicists and research engineers engaged in the study of electromagnetic radiations and their role in investigating the structure and composition of materials.

COVERAGE: The collection contains 30 articles which review investigations in spectroscopy, optics, semiconductor physics, nuclear physics, and other branches of physics. The introductory chapter gives a biographical profile of G. S. Landsberg, Professor and Head of the Department of Optics of the Division of Physical Technology at Moscow University, and reviews his work in Rayleigh scattering, combat gases, spectral analysis of metals, etc. No personalities are mentioned. References accompany each article.

VAVILOV, V.S.

24(4) PHASE I BOOK EXPLOITATION SOV/3140

Akademiya nauk Ukrainskoy SSR. Institut fiziki

Fotoelektricheskiye i opticheskiye yavleniya v poluprovodnikakh; trudy pervogo vsesoyuznogo soveshchaniya po fotoelektricheskim i opticheskim yavleniyam v poluprovodnikakh, g. Kiyev, 20-26 noyabrya 1957 g (Photoelectric and Optical Phenomena in Semiconductors; Transactions of the First Conference on Photoelectric and Optical Phenomena in Semiconductors...) Kiyev, 1959. 403 p. 4,000 copies printed.

Additional Sponsoring Agency: Akademiya nauk SSSR. Prezidium. Komissiya po poluprovodnikam.

Ed. of Publishing House: I. V. Kisina; Tech. Ed.: A. A. Matveychuk; Resp. Ed.: V. Ye. Lashkarev, Academician, Ukrainian SSR, Academy of Sciences.

PURPOSE: This book is intended for scientists in the field of semiconductor physics, solid state spectroscopy, and semiconductor devices. The collection will be useful to advanced students in universities and institutes of higher technical training specializing in the physics and technical application of semiconductors.

COVERAGE: The collection contains reports and information bulletins (the latter are indicated by asterisks) read at the First All-Union Conference on Optical and Photoelectric Phenomena in Semiconductors. A wide scope of problems in semiconductor physics and technology are considered: photoconductivity, photoelectromotive forces, optical properties, photoelectric cells and photoresistors, the actions of hard and corpuscular radiations, the properties of thin films and complex semiconductor systems, etc. The materials were prepared for publication by E. I. Rashboy, O. V. Snitko, K. B. Tolpygo, A. P. Lubchenko, and M. K. Sheynkman. References and discussion follow each article.

Photoelectric and Optical Phenomena (Cont.) SOV/3140

VAVILOV, V.S.; VUL, B.M.; GALKIN, G.N.; FRIDMAN, S.A.

Performance of "atomic" sources of current with double transformation of energy. Fiz.tver.tela 1 no.5:826-827 My '59. (MIRA 12:4)

1. Fizicheskiy institut im. P.N. Lebedeva.
(Semiconductors)

VAVILOV, V.S.; PLOTNIKOV, A.F.; ZAKHVATKIN, G.V.

Infrared absorption of silicon having high specific resistance and containing radiation defects. Fiz. tver. tela 1 no.6:976-979 Je '59. (MIRA 12:10)

1.Fizicheskiy institut im. P.N. Lebedeva Akademii nauk SSSR, Moskva.
(Silicon--Optical properties)

9.4160 24.2600 67303

~~9 (6)~~

AUTHORS: Malovetskaya, V. M., Vavilov, V. S., Galkin, G. N. SOV/181-1-8-8/32

TITLE: On the Reflection Coefficients of a Clarified Surface of Silicon Photocells

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 8, pp 1201-1204 (USSR)

ABSTRACT: The efficiency of solar energy transformation may be considerably increased if the surface reflection of a photocell is reduced by clarifying and if in this case surface the recombination rate is not raised. For this clarifying a film of the required optical properties is applied to the surface. Reflection is reduced by interference of the light reflected from the film and from the material under the film. The conditions for a removal of light reflection at the dielectric are given. For this clarifying of optical materials mainly oxides like TiO_2, ZrO_2, ThO_2, SiO_2, SnO_2, etc are used. The refractive indices of these compounds are listed in a table. Various reasons explained in the paper justify the application of SiO_2 films in clarifying although these films because of their high refractive index must have somewhat worse clarifying

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On the Reflection Coefficients of a Clarified Surface of Silicon Photocells

properties than the other substances mentioned above. The SiO_2 film is usually applied from the ethyl ether of octosilicic acid. Because of the lacks of this method, however, the authors prepared the SiO_2 film from oxidation of a pure silicon surface. The reflection coefficient was measured in the range 0.45-2.2 μ by means of a reflecting monochromatic illuminator with glass prism. In the range of wavelengths from 1.00 to 2.00 μ reflection coefficients were determined by direct measurement of the regular reflection for small angles of incidence. In both cases measurement was carried out with modulated light. The reflection coefficient curves taken in the spectral ranges 0.45-1.00 μ and 1.00-2.20 μ fit well to one another. The maximum error was 3% of the quantity measured. In the range 0.45-2.2 μ reflection on silicon with film is considerably less than on pure silicon. The minimum value of the reflection coefficient is 7% instead of 30 to 32%. By varying the film thickness by proper choice of the working method, the minimum may be shifted into the desired spectral range. Two figures show the

On the Reflection Coefficients of a Clarified Surface of Silicon Photocells

families of reflection curves on silicon with a film produced by oxidation in air and with another one produced by oxidation in an oxygen atmosphere. No difference between these spectral curves could be found. SiO which forms by reduction of SiO_2 is unstable under the conditions investigated. Since the SiO_2 film is transparent for the spectral range under investigation, reduction of silicon-photocell surface reflection increases carrier pair production which in turn raises the photoelectric current. The second table contains the values of the short-circuit current of the photocells with and without film. In order to attain a successful operation of silicon solar-energy transformers it is necessary for the clarifying film to remain constant over a long period. The properties of this film practically do not vary for six months. There are 4 figures, 2 tables, and 6 references, 5 of which are Soviet.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva AN SSSR, Moskva (Physics Institute imeni P. N. Lebedev of the AS USSR, Moscow)

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On the Reflection Coefficients of a Clarified Surface of Silicon Photocells

SOV/181-1-8-8/32

SUBMITTED: July 26, 1958

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67401
SOV/181-1-9-25/31

AUTHORS: Vavilov, V. S., Smirnov, L. S., Patskevich, V. M.

TITLE: On the Diffusion Length of Charge Carriers in Silicon Photoelements

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 9, pp 1465 - 1467 (USSR)

ABSTRACT: The thermal procedure applied in the production of silicon photoelements leads to a decrease in the diffusion length L of the carriers. Certain difficulties, discussed in the introduction, occur in the determination of L and the carrier lifetime in the case of a p-type layer being situated below an n-type layer. The authors therefore made other experiments in order to determine the diffusion lengths, offering results which are independent of the method, the influence of the traps, and the surface recombination. A semiconductor crystal with p-n junction and nonrectified contacts A and B (cf. figure 1) is considered. The light incident upon the surface is characterized by its reflection coefficients R and the surface recombination rate s; it induces electron-hole pair production in the crystal. If $k^{-1} \ll d$ (k - absorption coefficient, d - thickness of the p-type layer), practically all

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66345
SOV/181-1-10-20/21

~~24(5)~~ 24,5400

AUTHORS: Vavilov, V. S., Britsyn, K. I.

TITLE: On the Spectral- and the Temperature Dependence of the Quantum Yield in Silicon

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 10, pp 1629 - 1631 (USSR)

ABSTRACT: Already in an earlier paper the authors showed that the absorption of photons with an energy exceeding e.g. 3 ev in silicon is accompanied by a carrier production with a yield that exceeds unity. This was assumed to be due to an impact ionization by carriers having kinetic energy excess. An increase of the quantum yield with the energy of the absorbed photons was observed also in germanium, indium antimonide and other semiconductors. It was the aim of the present paper to obtain more accurate data concerning photoionization in silicon. For the investigation of the process of photoionization the changes of steady photoconductivity are used. In the case of a sufficiently high concentration of the adhesion centers a considerable increase of the photocurrent may, however, occur, which renders interpretation

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SOV/181-1-10-20/21

On the Spectral- and the Temperature Dependence of the Quantum Yield in Silicon

of experimental results more difficult. For their investigation the authors used silicon single crystals of the p-type with P-N transitions. The depth of the position of the P-N transition fluctuated in the various crystals between 2 and 40 μ. For these samples the spectral and the temperature dependence of the photoionization quantum yield was investigated for a photon energy up to 4.9 ev. The investigations were carried out by employment of a method which permitted excluding the influence of adhesion centers and also permitted separation of the phenomena directly connected with photon absorption and impact ionization by carriers with kinetic energy excess. Some of the results are shown in the two diagrams. Figure 1 shows the dependence of the so-called "effective quantum yield" Qα on hν (in ev) at 100, 300, and 400°K. The curves take a similar course: at low (ν 1 ev) quantum energies the yield increases slightly, after which Qα remains constant over a range of nearly 2 ev, and then increases more or less steeply with further increasing hν. Figure 2 shows the function Q=f(hν) for the same temperatures. After the plane part of the curve the

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On the Spectral- and the Temperature Dependence of the Quantum Yield in Silicon

ascending branches begin; the yield increase begins the sooner, the higher the temperature: at 400°K the ascending branch begins at 2.95 ev, at 100°K only at 3.4 ev. This temperature dependence of the quantum yield is within the range of impact ionization. This dependence is considered to be due to a temperature-dependent decrease of the widths of the forbidden band. An additional shift of the impact ionization range towards lower photon energies may be connected with an increase of the relative number of "indirect" electron transitions with photon participation with rising temperature. The authors finally thank S. G. Kalashnikov, B. M. Vul, M. N. Alentsev, and V. A. Chuyenkov for valuable comments. There are 2 figures and 6 references, 4 of which are Soviet.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva AN SSSR Moskva (Physics Institute imeni P. N. Lebedev of the AS USSR, Moscow). Moskovskiy gos.Universitet, Fizicheskiy fakul'tet (Moscow State University, Department of Physics)

SUBMITTED: March 24, 1959

Card 3/3

SOV/56-37-1-3/64

21(7)
AUTHORS: Vavilov, V. S., Gippius, A. A., Gorshkov, M. M., Kopylovskiy, B. D.

TITLE: Radiation Combination in Germanium Crystals Subjected to a Bombardment by Fast Electrons (Izluchatel'naya rekombinatsiya v kristallakh germaniya, podvergnutykh bombardirovke bystrymi elektronami)

PERIODICAL: Zhurnal eksperimental'noy i teoreticheskoy fiziki, 1959, Vol 37, Nr 1, pp 23-26 (USSR)

ABSTRACT: The authors describe the results obtained by investigations of the infrared spectra accompanying the recombination of electrons and holes in germanium monocrystals. Three samples were investigated, in which radiation was excited by the injection of holes by means of various indium contacts; the third sample was irradiated with 0.7 Mev electrons. The concentration of the effective acceptor levels of the defects, formed in irradiation, was calculated as amounting to $5.10^{13} cm^{-3}$ near the surface, and as decreasing towards zero at ~ 0.3 mm. In first approximation it may be assumed that the concentration of recombination centers formed in irradiation is equal to that of the effective acceptor levels. The spectra of all

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Radiation Combination in Germanium Crystals
Subjected to a Bombardment by Fast Electrons

samples showed an emission band (Fig 1) with a maximum at 1.85 μ (0.67 ev) at room temperature and at 1.67 μ (0.74 ev) at 78° K. The displacement of the long-wave edge of this band corresponds well to the variation of the width of the forbidden band of germanium. The temperature coefficient β was determined as amounting to $3.2 \cdot 10^{-4}$ ev/degrees, which agrees well with the results obtained by other authors (Refs 1,7). Figure 1 shows the shifting of the natural radiation band of Ge in the case of a temperature variation of 300 per 78° K. Figure 2 shows the spectra of the impurity- and natural radiation of the Ge-samples at 78° K, figure 3 the spectrum of impurity radiation of a Ge-sample of the N-type without treatment at 78° K. The curve has a maximum at 2.35 μ (0.53 ev). Figure 4 shows the spectrum of a N-germanium sample, irradiated by 0.7 Mev electrons at 78° K (irradiation occurred at room temperature); also the curve for the sensitivity of the PbS photoresistor within the same λ-range is shown. The intensity B of radiation near the maximum of the natural radiation dpends on the injection current J (100 μa):

$B \sim J^m$, $m \approx 1.7$. The experiments, among other things,

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Radiation Combination in Germanium Crystals
Subjected to a Bombardment by Fast Electrons

showed that an increase in the concentration of the Frenkel defects caused by fast electron bombardment causes an increase in the concentration of the relative intensity of the emission band (maximum at 2.35 μ). The authors finally thank B. M. Vul for his interest in this investigation, and M. V. Fok and M. N. Alentsev for their critique and valuable remarks; they also thank L. N. Silonov for his assistance. There are 4 figures and 9 references, 1 of which is Soviet.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva Akademii nauk SSSR (Physics Institute imeni P. N. Lebedev of the Academy of Sciences, USSR)

SUBMITTED: January 29, 1959

SOV/53-68-2-2/7

21 (1), 24 (0)

AUTHOR: Vavilov, V. S.

TITLE: Radiating Recombination in Semiconductors (Izluchatel'naya rekombinatsiya v poluprovodnikakh)

PERIODICAL: Uspekhi fizicheskikh nauk, 1959, Vol 68, Nr 2, pp 247-260 (USSR)

ABSTRACT: The author gives a survey of fundamental theoretical concepts concerning the radiating recombination in semiconductors and shows the experimental results obtained until the end of 1958. Recombination of electrons and holes in semiconductors is one of the most important processes giving information as to the properties and range of applicability of semiconductors, e.g. in electronics. The present survey consists of six sections, the content being chiefly taken from Western publications. 1) Introduction, brief enumeration of the forms of recombination, general phenomena. 2) Theory of direct recombination of electrons and holes with emission of a photon; consideration of the process as a reversion of the pair formation process in the absorption of a photon (Refs 2, ?); evaluation of the recombination rate, investigation of the dependence of the recombination probability on the photon

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energy and the temperature according to Van Roosbroeck and Shockley (Fig 1, Refs 3, 4) in the case of germanium; investigation of light absorption in different semiconductors, evaluation of the recombination life time according to Burshteyn and Eggli (Table 1). 4) Experimental methods of excitation and investigation of the spectra of recombination radiation; data taken from American publications; figure 2 and 3 show schemes of analytical apparatus (for germanium investigation). 4) Spectra of eigen- and impurity recombination radiation of germanium; representation according to Hall, Nash, Newman et al: figure 4 shows a characteristic spectrum of eigen-recombination radiation of a thin Ge plate; illustration of impurity radiation phenomena according to Newman (Ref 23), some figures being taken from his publications. 5) Radiation recombination in silicon; taken from Haynes, Westphal, McFarlane, Morin et al; discussion of the steep peak in 1.1μ (Fig), investigation of the influence exerted by the impurities introduced into the Si upon the recombination spectrum; reproduction and discussion of a table by Morin et al. 6) Radiating recombination in semiconductor combinations (InSb, GaSb, InP, PbS); InSb-investigation [illegible] by gas and

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Hawkins (Fig 10), GaAs, GaSb and InP - Braunstein; investigation of PbS made by L. N. Galkin and N. V. Korolev (Ref 35) on thin polycrystalline layers; more recent investigations made by Scanlon. There are 10 figures, 2 tables, and 37 references, 8 of which are Soviet.

SOV/53-69-1-7/11

24(3)
AUTHOR: Vavilov, V. S.

TITLE: Modern Semiconductor Physics (Sovremennaya fizika poluprovodnikov)

PERIODICAL: Uspekhi fizicheskikh nauk, 1959, Vol 69, Nr.1, pp 149-156 (USSR)

ABSTRACT: As a member of the Delegation of the AS USSR, the author took part in the International Conference on Semiconductors (August 1958) at Rochester (USA), about which the present is a report. Of the Russian delegates, Academician A. F. Ioffe spoke about a theoretical analysis and survey of research results obtained with respect to the electrical and thermal properties of semiconductors which were investigated at the Institut poluprovodnikov AN SSSR (Institute of Semiconductors, AS USSR). He mentioned the particularly successful investigation and application of valence crystals and showed that the electrical properties of most semiconductor materials cannot be dealt with within the framework of the generally recognized zone theory. The electron motion in these substances cannot be described by a modulated plane wave, because these waves are extinguished within very small periods, which are in some cases smaller than the lattice constant. In such a case the conception of the

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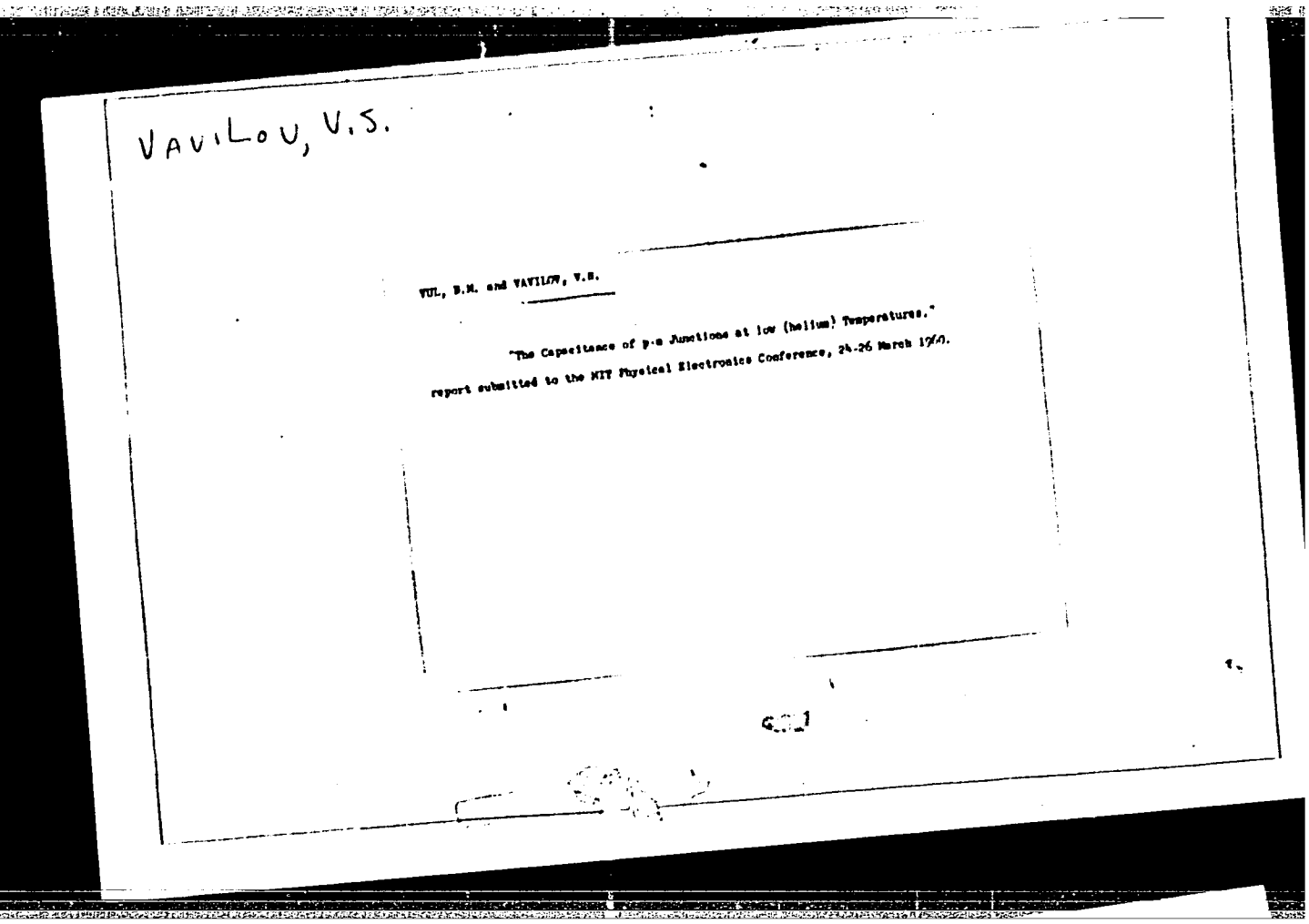
wave-like motion of electrons must be substituted by that of a successive jumping over from one atom to another. This conception also satisfies the law of the exponential growth of mobility with increasing temperature (experiments by V. P. Zhuze). L. S. Stil'bans (Institute for Semiconductors, AS USSR) showed on the basis of experimental data concerning the dependence of the mobility of the charge carriers upon degeneration and temperature that two-phonon processes play the main part in the scattering of electrons on thermal lattice oscillations within the range of high temperatures. In the case of the scattering of electrons on impurities, the scattering cross section is to a considerable extent dependent on temperature.
S. G. Kalashnikov (Institut radioelektroniki AN SSSR - Institute of Radioelectronics, AS USSR) lectured on the investigation of the recombination of electrons and holes in germanium. The author spoke about results obtained by more recent investigations of the dependence of the life time upon carrier concentration in equilibrium, and on temperature. Ye. F. Gross (Leningradskiy fiziko-tekhnicheskiy in-tut AN SSSR - Leningrad Physico-technical Institute AS USSR) spoke about optical absorption spectra correlated with the production of excitons,

as well as about the magneto-optical properties of excitons. - In the second part of this article the author speaks about scientific work carried out in the USA in the field of semiconductor physics.

VAVILOV, V. S., Doc Phys-Math Sci -- (diss) "Action of radiations on germanium and silicon." Moscow, 1960. 17 pp; (Academy of Sciences USSR, Physics Inst im P. N. Lebedev); 200 copies; free; list of author's work on pp 15-17; (KL, 22-60, 130)



VAVILOV, V.S.

VUL, B.M. and VAVILOV, V.S.

"The Capacitance of p-n Junctions at low (helium) Temperatures."

report submitted to the MIT Physical Electronics Conference, 24-26 March 1960.

81783

S/181/60/002/02/31/033
B006/B067

24,2600
24,7700

AUTHOR: Vavilov, V. S. [redacted]

TITLE: Absorption of Infrared Radiation by Free Carriers in Silicon

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No.2, pp. 374-377

TEXT: By means of an ИКС-12 (IKS-12) spectrograph the author investigated infrared absorption in the range 1-11 μ in p-type and n-type silicon single crystals with free carrier concentrations of 10^{14} to $5 \cdot 10^{17}$ cm^{-3} at 295°K. Boron was the main impurity in the p-type samples and phosphorus in the n-type samples. The samples had a thickness of up to 3 cm because of strong opaqueness. The reflection coefficients R of the polished silicon surfaces were measured individually, and the absorption coefficient was calculated for each wavelength from formula $I_\lambda / I_{o\lambda} = (1-R)^2/(e^{ad} - R^2 e^{-ad})$ by taking into account multiple reflection. Fig. 1 shows the typical function $\alpha = f(\lambda)$. The peak at 8.9 μ is due to vibrations of oxygen atoms, further small peaks were observed at

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Absorption of Infrared Radiation by Free Carriers in Silicon

λ = 6.85 and 7.65 μ; these bands were independent of the type of conductivity, and are probably connected with lattice or inactive impurities vibrations (not oxygen). For p-type crystals with hole concentrations of $8 \cdot 10^{15}$ to $3 \cdot 10^{17}$ cm^{-3} the absorption coefficient increases with the wavelength as $\lambda^{3/2}$. On the basis of experimental results, the effective hole mass is estimated as $m_+^* = 3.6 \cdot 10^{-28}$ g. In the range of high hole concentrations α increases for p-type crystals (ρ = 0.007 ohm.cm) with the wavelength as $\lambda^{1.85}$. Considerable deviations from the $\lambda^{3/2}$-law were observed in p-type samples with hole concentrations $< 5 \cdot 10^{15}$ cm^{-3}. None of the n-type crystals showed a behavior corresponding to this law. Curve 2 in Fig. 1 shows the spectral dependence on α that is characteristic of such a crystal; the sample had an electron concentration of $4 \cdot 10^{17}$ cm^{-3}. Also in these samples the absorption coefficient increased with given wavelength with the carrier concentration. Fig. 2 shows the ratio between absorption and carrier concentration of p-type and n-type

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Absorption of Infrared Radiation by Free Carriers in Silicon

crystals at $\lambda = 4\ \mu$. The fact that the absorption coefficient of n-type samples was a linear function of the electron concentration led to the conclusion that the absorption is due to electronic interaction in the conduction band. In conclusion, the author thanks B. M. Vul and V. A. Chuyenkov for discussions, and Yu. A. Kolotov for assistance. There are 2 figures and 7 references: 2 Soviet, 2 British, and 2 American.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva Moskva (Institute of Physics imeni P. N. Lebedev, Moscow)

SUBMITTED: September 11, 1959

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VAVILOV, V.S.

82534

S/181/60/002/007/009/042
B006/B070

21.5300
24.7700

AUTHORS: Vavilov, V. S., Patskevich, V. M., Yurkov, B. Ya., Glazunov, P. Ya.

TITLE: The Effect of Fast Electron Bombardment on the Electrical Conductivity of Silicon and the Dependence of the Rate of Defect Formation on the Orientation of the Crystal Relative to the Electron Beam

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 7, pp. 1431-1433

TEXT: A determination of the minimum kinetic energy of electrons, necessary for the production of stable structural defects in crystals, is of importance for the possible application of semiconductors as particle counters, and for transformation of nuclear radiation energy. To obtain new data on defect formation, the authors investigated it in p-type silicon by bombarding rectangular single crystals oriented at different angles relative to the incident beam of 500-kev electrons. Before their radiation, the samples had a homogeneous resistivity ρ of 160 ohm.cm.

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B006/B070

The Effect of Fast Electron Bombardment on the Electrical Conductivity of Silicon and the Dependence of the Rate of Defect Formation on the Orientation of the Crystal Relative to the Electron Beam

Bombardment and the subsequent measurement of potential distribution were done at room temperature. The crystals were water-cooled during the bombardment. Measurements of the Hall effect showed that the carrier mobility changed only slightly as a result of bombardment. To investigate the depth distribution of the defects produced, a comparison was made between the potential distribution curves along the direction of the incident beam for irradiated and unirradiated samples. Fig. 1 shows the curves $\rho(x)$ for three samples bombarded in the directions ⟨111⟩, ⟨110⟩, and ⟨100⟩, respectively, x denoting the depth of penetration of the electron beam. The maximum depth of penetration for which a change in ρ could be established, was 0.6 mm irrespective of the orientation. On bombardment in the ⟨111⟩ direction, the surface of the sample showed a larger change in resistivity than for the other two directions. Further, the experimental and theoretical values of the minimum electron energy are compared. Two theoretical values are investigated:

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The Effect of Fast Electron Bombardment on the Electrical Conductivity of Silicon and the Dependence of the Rate of Defect Formation on the Orientation of the Crystal Relative to the Electron Beam

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E'_{min} = 280 kev (Ref. 3) and E''_{min} = 145 kev (Ref. 2 and the present paper). A comparison with the experiments of the authors (Fig. 2) shows that there is a much better agreement with the E''_{min} curve. For E''_{min} = 145 kev, the rate of defect formation is $A_d(0) \simeq 2.9$ cm^{-1}, and the rate of removal of the holes is $A_p(0) \simeq 1.4 \cdot 10^{-3}$cm^{-1}. Hence, $A_p/A_d \simeq 5 \cdot 10^{-4}$ is the average number of trapped carriers corresponding to the theoretically calculated value of defect concentration. The effects observed are finally discussed. The authors thank T. M. Kopylova for her calculations. There are 2 figures and 10 references: 3 Soviet and 7 US.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva AN SSSR Moskva (Institute of Physics im. P. N. Lebedev of the AS USSR, Moscow)

82534

S/181/60/002/007/009/042
B006/B070

The Effect of Fast Electron Bombardment on the Electrical Conductivity of Silicon and the Dependence of the Rate of Defect Formation on the Orientation of the Crystal Relative to the Electron Beam

SUBMITTED: December 21, 1959

4

Card 4/4

83014
S/181/60/002/008/033/045
B006/B063

24.2600

AUTHORS: Vavilov, V. S., Britsyn, K. I.

TITLE: The Effect of a Strong Electric Field on Light Absorption in Silicon

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 8, pp. 1937 - 1939

TEXT: The effect of strong fields on light absorption and the field-induced shift of the main absorption band was first mentioned by F. F. Vol'kenshteyn, and a theory was developed by L. V. Keldysh. The authors of the present paper made experiments concerning the effect of strong fields on light absorption in polycrystalline silicon. Silicon has a forbidden band width of not much more than 1 ev, and the effective carrier mass is much smaller than m_e. The silicon sample used for these experiments had a resistivity of about 10^{11} ohm.cm at T = 100°K (experimental temperature). This had been effected by neutron bombardment in a reactor ($\sim 10^{18}$ n/cm^2). Previous experiments had shown that near the absorption edge a new band with a maximum at 1.8 μ appeared due to

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The Effect of a Strong Electric Field on Light Absorption in Silicon

defects. The experimental arrangement is shown in Fig. 1 and briefly described. In the spectral region corresponding to phononic transitions from the valency band to the conduction band there was a considerable shift of the absorption edge by 150 A at $E = 5 \cdot 10^4$ v/cm (Fig. 2). It may be seen from Fig. 2 that the application of a field entails a considerable increase in the absorption coefficient in the wavelength range of 0.8 - 0.9 μ. The amount of the shift observed, $\Delta\lambda$, and its dependence on the field strength in the sample are in good agreement with theoretical predictions. The strength of the effect and the slight change in conductivity seem to justify the assumption that this is a pure field effect. The measurements were made at E = const. The authors thank L. V. Keldysh, M. N. Alentsev, S. G. Kalashnikov, and B. M. Vul for their discussions. There are 2 figures and 5 Soviet references.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet Fizicheskiy fakul'tet Kafedra poluprovodnikov (Moscow State University, Department of Physics, Chair of Semiconductors)

SUBMITTED: January 25, 1960

Card 2/2

84061

S/181/60/002/009/002/036
B004/B056

26.1631
26.1512

AUTHORS: Galkin, G. N., Rytova, N. S., Vavilov, V. S.

TITLE: Volume Recombination of Current Carriers in n-Type Silicon Containing Radiative Structural Defects

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 9, pp. 2025-2030

TEXT: The authors experimentally checked G. K. Wertheim's data (Refs. 3,4). According to a method suggested by S. G. Kalashnikov and N. A. Penin (Ref. 6), the change in the parameters of the p-n junction, caused by the changed lifetime of the minority carriers, was investigated in dependence on the alternating voltage applied. Fig. 1 shows the shape of samples made from n-type silicon single crystal, into which aluminum had been melted. The samples were irradiated with beta particles of an $Sr^{90} - Y^{90}$ preparation at room temperature. The lifetime τ was obtained as a function of the injection level $\delta p/n_o$ within the range of 150 - 440°K. $\tau(1+\delta p/n_o)=f(\delta p/n_o)$ develops linearly within a large injection-level range (Fig.2). From $\ln(\tau_o/T^{3/2})=f(1/T)$ at high temperatures, the distance ΔE

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of the recombination level E_t from the edge of one of the bands was determined. ΔE was found to be 0.16 ± 0.01 ev. By investigating the temperature dependence of τ_∞ / τ_o it was determined in which half of the forbidden band the recombination level was located. If the latter is found to be in the lower half, it is necessary that, at a critical temperature $p_1 = n_o$ and $E_t - E_v = E_c - F$ (F = Fermi level). In the samples investigated $E_c - F$ is about 0.16 ev at 240°K, τ_∞ / τ_o at this temperature equaled 10. Thus, this temperature was not the critical one. The recombination level of the radiative defects was in the upper half of the forbidden band. From the values τ_{no} and τ_{po} the trapping cross sections for electrons (σ_n) and holes (σ_p) were calculated as functions of T (Fig. 3), and from these the dependence of τ_o on 1/T was determined (Fig. 4). At 300°K, it was true that $\sigma_p = 4 \cdot 10^{-14}$ cm^2, $\sigma_n = 1 \cdot 10^{-15}$ cm^2. Fig. 5 shows the temperature dependence of n/n_o (ratio of the electron concentration in the irradiated

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Volume Recombination of Current Carriers in n-Type Silicon Containing Radiative Structural Defects

sample to the electron concentration n_o in the non-irradiated sample). Within the temperature range investigated, n_o was constant and equal to $1.1 \cdot 10^{15}$ cm^{-3}. Contrary to Wertheim's data, the trapping cross sections were thus different. $E_c - 0.16$ ev is an acceptor level which can be due neither to an insulated vacancy, an interstitial atom, nor due to a "near" pair, but to the presence of oxygen. The authors thank V. M. Malovetskaya and N. A. Penin for critique and advice, and Ye. M. Divil'kovskaya, S. P. Zharov, and E. L. Nolle for their collaboration. There are 5 figures and 11 references: 3 Soviet and 9 US.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva AN SSSR, Moskva (Institute of Physics imeni P. N. Lebedev of the AS USSR, Moscow)

SUBMITTED: February 10, 1960

Card 3/3

80557 S/051/60/008/06/018/024
E201/E691

24.7700

AUTHORS: Britsyn, K.I. and Vavilov, V.S.

TITLE: On the Process of Photoionization in Silicon

PERIODICAL: Optika i spektroskopiya, 1960, Vol 8, Nr 6, pp 861-867 (USSR)

ABSTRACT: The paper reports data on the wavelength and temperature dependences of the quantum yield (number of electron hole pairs generated by one photon) of absorption of photons with energies up to 4.9 eV in silicon. By the use of p-type Si with pn junctions produced by thermal diffusion of phosphorus (Fig 1) the effect of capture (trapping) centres was avoided. The short-circuit current I in the external circuit (Fig 1) between the n-type and p-type regions (which is produced by weak excitation in the fundamental absorption-band region) is proportional to the number, n, of generated electron-hole pairs: $I = \alpha qN$, where q is the electronic charge. The coefficient α is smaller than unity and is a function of the geometry of the crystal, the diffusion lengths of the charge carriers, the rate of surface recombination, the carrier mobilities and the absorption coefficient of light (Ref 9). The quantum yield, Q, can be found from:

$$Q = \frac{I}{qeN_{ph}(1 - R_{\nu})},$$

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On the Process of Photoionization in Silicon

where R_γ is the reflectivity of silicon (shown in Fig 2) and $N_{h\gamma}$ is the number of photons per second which is measured by means of a calibrated thermal pile (the apparatus is shown in Fig 3). It was found that the quantum yield, Q, depends on temperature only in the region where collision ionization is produced by carriers liberated on absorption of photons (Figs 8 and 9). On increase of temperature the collision-ionization region is shifted towards the lower photon energies which is partly due to reduction of the forbidden band in silicon. Acknowledgments are made to B.M. Vul, S.G. Kalashnikov, M.N. Alentsev and V.A. Chuyenkov for their advice. There are 9 figures and 14 references, 5 of which are Soviet, 3 English, 3 Czechoslovak, 1 German and 2 translations into Russian.

SUBMITTED: October 19, 1959

VAVILOV, Viktor S. and PLOTNIKOV, A. F.

"Spectra and Kinetics of Photoconductivity in P-type Silicon Irradiated by Neutrons."

report to be submitted for the Intl. Conference on Photoconductivity, IUPAP, Cornell University, Ithaca, N. Y., 21-24 Aug 1961.

Physics Inst. im. P. N. Lebedev.

MOSS, T.S., fizik; GORSHKOV, M.M. [translator]; VAVILOV, V.S., red.; NAKHIMSON, I.G., red.; DZHATIYEVA, F.Kh., tekhn. red.

[Optical properties of semiconductors] Opticheskie svoistva poluprovodnikov. Moskva, Izd-vo inostr. lit-ry, 1961. 304 p. (MIRA 14:10)
(Semiconductors—Optical properties)

CHUKICHEV, M.V.; VAVILOV, V.S.

Mean energy of the formation of pairs of nonequilibrium carriers in germanium irradiated by gamma rays from Co^{60}. Fiz. tver. tela 3 no. 3:935-942 Mr '61. (MIRA 14:5)

1. Fizicheskiy institut imeni P.N. Lebedeva AN SSSR, Moskva.
(Germanium) (Gamma rays)

23120
S/181/61/003/005/025/042
B108/B209

9.4300 (1136, 1043, 1144)

AUTHORS: Chukichev, M. V. and Vavilov, V. S.

TITLE: Formation of lattice defects in silicon single crystals by irradiation with thermal neutrons in a nuclear reactor

PERIODICAL: Fizika tverdogo tela, v. 3, no. 5, 1961, 1522-1527

TEXT: The authors calculated and estimated the number of lattice defects formed in silicon by irradiation with thermal neutrons from the heavy-water reactor of the AS USSR. The mean number of dislocated atoms per captured thermal neutron is calculated from the mean energy of the recoil nucleus obtained by radiative capture. The recoil energy (in ev) transferred to the nucleus by gamma quanta is given by the formula

$E_{rec} = \frac{537}{A}(h\nu)^2$ (1), where A is the atomic weight of the recoil nucleus, and $h\nu$ the energy of the gamma quanta (in Mev). The mean recoil energy averaged over all gamma transitions is found to be 780 ev. At such energies (elastic scattering), the mean number of dislocated atoms is given by

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Formation of lattice defects in ...

$\bar{\nu} = \frac{\bar{E}_{rec}}{2E_d}$ (2), where E_d is the threshold energy of displacement of Si atoms from lattice nodes into the interstice. On the basis of data from the exposure of Si to fast electrons, E_d may be assumed to have a value of 13 ev (Ref. 4: J. J. Loferski and P. Rappaport. Journ. of Appl. Phys., 30, 8, 1296, 1959). In this way, the authors calculated $\bar{\nu} = 29$ and found that about 20 displaced atoms are formed per 100 thermal neutrons inciding upon 1 cm^3 of silicon. The n-type samples were ultrasonically cut to small oblong plates. All the measurements were made at room temperature in a magnetic field of 4000 gauss. The thermal neutron flux was $8.7 \cdot 10^{12}$ neutrons/cm^2.sec. The integral radiation dose was $1 \cdot 10^{16}$ and $6.3 \cdot 10^{17}$ neutrons/cm^2, respectively, for the two sets of irradiated samples. In order to make a distinction between the action of thermal and that of fast neutrons, part of the samples were irradiated through an 0.5 mm thick cadmium screen. The experiments showed that approximately 4.5 conduction electrons are displaced per 100 neutrons impinging upon 1 cm^3

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Formation of lattice defects in ...

of silicon. This number is about four times less than the number of displaced atoms as calculated by the formula $\bar{n}_d = (nvt)N\sigma\nu$ (3), where (nvt) is the integral radiation dose (neutrons per cm^2), N the number of silicon atoms per cm^3, and σ the total cross section of radiative capture of thermal neutrons in Si. The authors thank B. M. Vul', Corresponding Member AS USSR, for a discussion of the results. There are 4 figures, 1 table, and 5 references: 2 Soviet-bloc and 3 non-Soviet-bloc.

ASSOCIATION: Moskovskiy khimiko-tekhnologicheskiy institut imeni D. I. Mendeleyeva (Moscow Institute of Chemical Technology imeni D. I. Mendeleyev). Fizicheskiy institut im. P. N. Lebedeva AN SSSR (Institute of Physics imeni P. N. Lebedev, AS USSR)

SUBMITTED: November 19, 1960

Card 3/3

27288

S/181/61/003/008/018/034
B102/B202

24.7700

AUTHORS: Galkin, G. N., Nolle, E. L., and Vavilov, V. S.

TITLE: Recombination levels in p-type silicon occurring at high-temperature treatment

PERIODICAL: Fizika tverdogo tela, v. 3, no. 8, 1961, 2355-2361

TEXT: Heat treatment of silicon at temperatures above 1200°C leads to a strong increase of the suface recombination rate. The lifetime of the non-equilibrium carriers decreases to values of the order of 1 μsec and less. The nature of the recombination centers occurring in this connection has hitherto not been explained. In a previous paper (Galkin, FTT, II, 1, 8, 1960) it was demonstrated that in p-type silicon the dependence of the carrier lifetime on the injection level (with injection levels of 0.005-0.05 ev) corresponds to the Shockley-Read law. The recombination level is at a distance of 0.13 ev from the valence band. At higher injection levels, however, no linear dependence could be observed. Hence the authors assumed that another level participates in recombination. This problem is studied in the present paper. The authors study the dependence

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Recombination levels in p-type ...

of the lifetime on the injection level in a wide range of the injection levels, the position of the recombination levels (generated by heat treatment) in the forbidden band and also their nature. First, they theoretically study recombination by local levels which lie in the forbidden band. They experimentally study the dependence of the lifetime of the non-equilibrium carriers on temperature and injection level in p-type single crystals with p-n junction by the "frequency" method of S. G. Kalashnikov and N. A. Penin (ZhTF, XXV, 1111, 1955). The p-n junction was produced by diffusing phosphor into p-type Si (20 min, 1230°C). This was made in quartz ampuls. Under the same conditions part of the specimens had been previously subjected to heat treatment (30 min - 2hr) in order to increase the concentration of the recombination levels. Ohmic contacts were obtained by melting Ag onto the n-type side and Al onto the p-type side. In order to keep the current which is due to surface generation and which passes through the p-n junction low, the junction area was chosen sufficiently large (0.12 cm^2) and etched prior to the measurement. The lifetime was determined between -70 and +185°C and the injection levels between 0.01 and 0.6 ev. The initial carrier lifetime was at 50 μsec, resistivity was

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Recombination levels in p-type ...

~10 ohm·cm. The ratio between diffusion current and generation current component was determined from the volt-ampere characteristics of the current in forward direction. The characteristics ($v = f(\log I)$) have two linear sections of different slope. The first one (0.26 ev) corresponds to the current due to generation in the space-charge region, at higher voltages, current occurs due to diffusion. The majority carrier concentration p_o was determined from the Hall-emf. It was constantly equal to $7.5 \cdot 10^{14}$ cm^{-3} in the entire temperature range. It became constant after a 2.5 hour heat treatment (within the limits of measurement accuracy) which indicates a low concentration of the introduced centers. The curves $\tau(1+\Delta n/p_o) = f(\Delta n/p_o)$ of specimens with annealing times of less than 1.5 hr were not liner. They corresponded approximately to formula

$$\tau\left(1+\frac{\Delta n}{p_0}\right)=\left\{\frac{1}{\tau_{01}+\tau_{\infty 1}\frac{\Delta n}{p_0}}+\frac{1}{\tau_{02}+\tau_{\infty 2}\frac{\Delta n}{p_0}}\right\}^{-1}. \qquad (5)$$

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Recombination levels in p-type ...

Δn is the concentration of the electrons (minority carriers), p_o that of the holes (majority carriers), τ the lifetime of the latter; the subscripts o and ∞ refer to an infinitely small or infinitely large injection level, 1 and 2 number the two existing recombination levels. Only with specimens that had been subjected to heat treatment for more than two hours these curves were linear. Heat treatment at temperatures exceeding 1200°C also leads to the generation of two donor-type recombination levels at distances of 0.1-0.2 and 0.35 ± 0.02 ev from the valence band. The concentration of the centers with the level E_{t2} = 0.35 ev increases with increasing time of heat treatment so that - in the case of long-lasting heat treatment - recombination by the first level can be neglected. The level E_{t2} = 0.35 ev may be explained by the presence of gold atoms in the crystal which, according to Collins et al., form donor levels in p-type Si which are at a distance of 0.35 ± 0.02 ev from the valence band. According to Bemski the gold concentration in Si subjected to heat treatment for 2.5 hours, should amount to 10^{13} cm^{-3}. The reason of this gold impurity might be the quartz ampul which contained the Si during the heat treatment. The authors thank

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Recombination levels in p-type ...

B. M. Vul, Corresponding Member AS USSR, and E. I. Adirovich for advice, B. Ya. Yurkov for help. There are 7 figures and 11 references: 4 Soviet and 7 non-Soviet. The three most important references to English-language publications read as follows: M. Lax. Phys. Rev., 119, 1502, 1960; C. B. Collins et al. Phys. Rev., 105, 1168, 1957; G. Bemski. Phys. Rev., 111, 6, 1515, 1958.

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva AN SSSR Moskva (Physics Institute imeni P. N. Lebedev AS USSR, Moscow)

SUBMITTED: March 10, 1961

X

27297

S/181/61/003/008/027/034
B109/B202

9,4177
26.2420

AUTHORS: Vavilov, V. S., Plotnikov, A. F.

TITLE: Photoconductivity of neutron-irradiated p-type silicon

PERIODICAL: Fizika tverdogo tela, v. 3, no. 8, 1961, 2455-2457

TEXT: The authors discuss the spectral dependence of photoconductivity and the energy band scheme of p-type silicon with radiation defects. The measurements were made in boron-doped silicon with $5 \cdot 10^{15}$ cm^{-3} oxygen atoms at most and a resistivity of approximately 100 ohm·cm. The fast-neutron flux was approximately 10^{13} n/cm^3. According to the theory of Kinchin - Piz the concentration of displaced atoms was assumed to be 10^{14} cm^{-3}. The hole concentration in the valence band which was determined by electric measurements was found to be $8 \cdot 10^{13}$ cm^{-3} at a temperature of approximately 300°K. The results of the measurements are shown in Fig. 1. (σ - conductivity, $\Delta\sigma$ - conductivity change upon action of light) The "edges", which correspond to a wavelength of 4.1, 3.3, and 2.8 μ are directly related to the minimum energies of photoionization, i.e., to the transitions of electrons from the valence band to the incomplete levels $E_v + 0.30$, $E_v + 0.38$ and

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E_v + 0.45 ev. At 100°K the Fermi level was at a distance of 0.2 to 0.3 ev from the valence band. The sharp decline at 3.8 μ is due to light absorption. The energy band schemes by which Fig. 1 can be explained is shown in Fig. 2. The existence of the level E_v + 0.35 is not proved. The value of the level E_c - 0.16 ev which is an efficient electron trap and whose position was determined from the values of photoionization constants approximately agrees with that which had been obtained by G. N. Galkin, N. S. Rytova, V. S. Vavilov (ZhFTT, II, 9, 1960) by another method. The electrons promoted into the conduction band as a result of illumination do not shorten the relaxation time of conductivity due to the large electron-capture cross section of the centers (approximately 10^{-13} cm^2). The concentration in the electron traps in the crystals investigated does not exceed 10^8 cm^{-3}. Nevertheless, it is possible that the centers to which the levels mentioned belong may be combinations of an oxygen atom and of a radiation defect according to the spin resonance method of Uotkins, Korbett, and Uolker. The authors thank V. Antonov, G. N. Galkin, and L. Smirnov for valuable help. There are 2 figures and 4 references: 1 Soviet and 3 non-Soviet.

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Photoconductivity of neutron- ...

ASSOCIATION: Fizicheskiy institut im. P. N. Lebedeva, AN SSSR, Moskva
(Physics Institute imeni P. N. Lebedev, AS USSR, Moscow)

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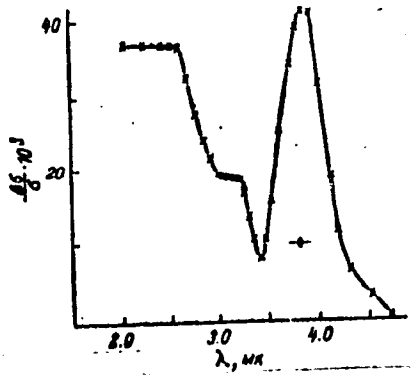
Fig. 1



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AUTHORS: Britsyn, K. I., and Vavilov, V. S.

TITLE: Effect of a high-frequency electric field upon the edge of the fundamental band of optical absorption by silicon

PERIODICAL: Fizika tverdogo tela, v. 3, no. 8, 1961, 2497 - 2499

TEXT: The effect of an outer electric field causes the edge of the fundamental band to be blurred; in the experiment, this appears as a "shift" of the edge. For silicon and in fields of an order of 10^5 v/cm, this shift must have a value of the order of $\Delta\lambda \cong 100$ Å in the region where the absorption coefficient drops sharply. In addition, it exceeds the Stark effect by two orders of magnitude. In theoretical studies, this electro-optical effect is always supposed to be of very low inertia, unlike absorption by non-equilibrium carriers observed in semiconductor crystals. In Ref. 4 (FTT, II, 1937, 1960) the authors had given the results of experiments, in which the electro-optical effect in silicon single crystals was observed in constant fields. The aim of the present work was to study the same effect in h - f electric fields. Measurements were performed at

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about 100°K, with the silicon single crystals being placed in a vacuum of 10^{-6} mm Hg; the resistivity of the crystals was 10^{11} ohm.cm (at 100°K) and the period of h - f oscillations was 10^{-7} sec. Monochromatic light ($\lambda = 0.93\mu$), passed through the crystal and modulated by the variable field, fell upon a photomultiplier. A double-ray pulsed oscilloscope visualized the change in light intensity as a function of E. The oscillograms showed that the pulse-front corresponding to the decrease in transmissivity of the crystal delay did not exceed $2 \cdot 10^{-8}$ sec with respect to the front of the voltage applied. By interpreting the oscillograms, the authors found absorption in silicon to change sharply with changing wavelength in the spectral round 1μ. It is finally observed that, apart from the possibility of h - f light modulation in a semiconductor by a field, this result is significant as it confirms that the shift of the edge is not caused by temperature effects or other effects connected with the carriers. L. V. Keldysh (Ref. 1: ZhETF, 34, 1138, 1958) is mentioned. There are 3 figures and 4 references: 3 Soviet and 1 non-Soviet.

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