EFFECT OF NEUTRON TRANSMUTATION DOPING ON THE ELECTROPHYSICAL PROPERTIES OF Si-Ge ALLOYS

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We have developed a method of neutron transmutation doping (NTD) of the single crystal solid solutions $Si_{1-x}Ge_x$ (x=0.8—19 at.%) [1,2]. It has been established that one can use NTD of Si—Ge alloys to produce materials with a controlled conductivity type, smoothly variable compensation and photosensitivity, and homogeneity higher than that obtained by metallurgical methods of compensation.

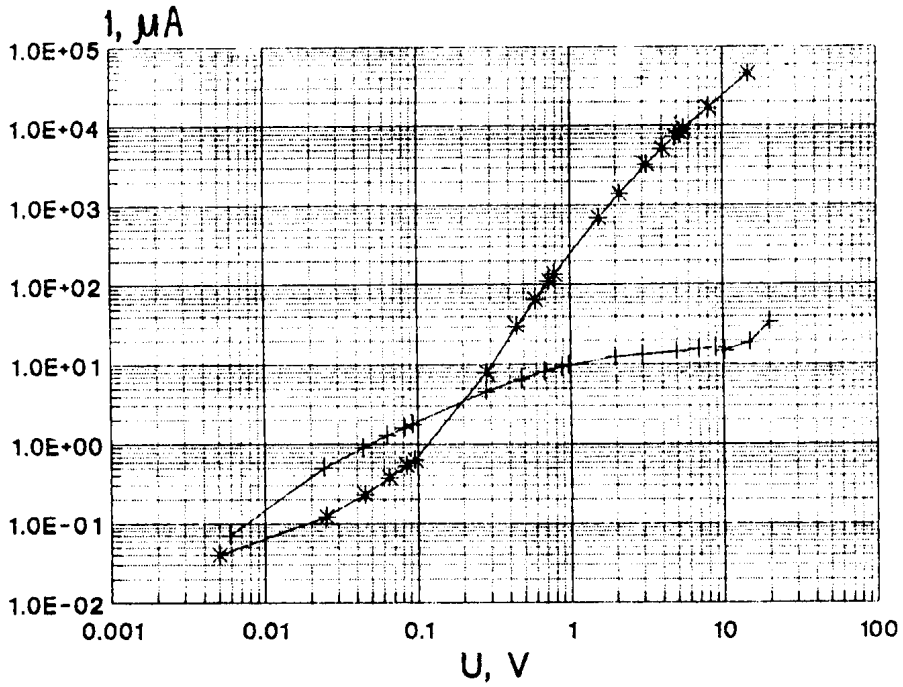

Fig.1. I—V characteristics of a P—I—N diode prepared from NT-doped, variable composition $Si_{1-x}Ge_x$ alloy (x = 0—2 at.%) * — forward bias, + — reverse bias

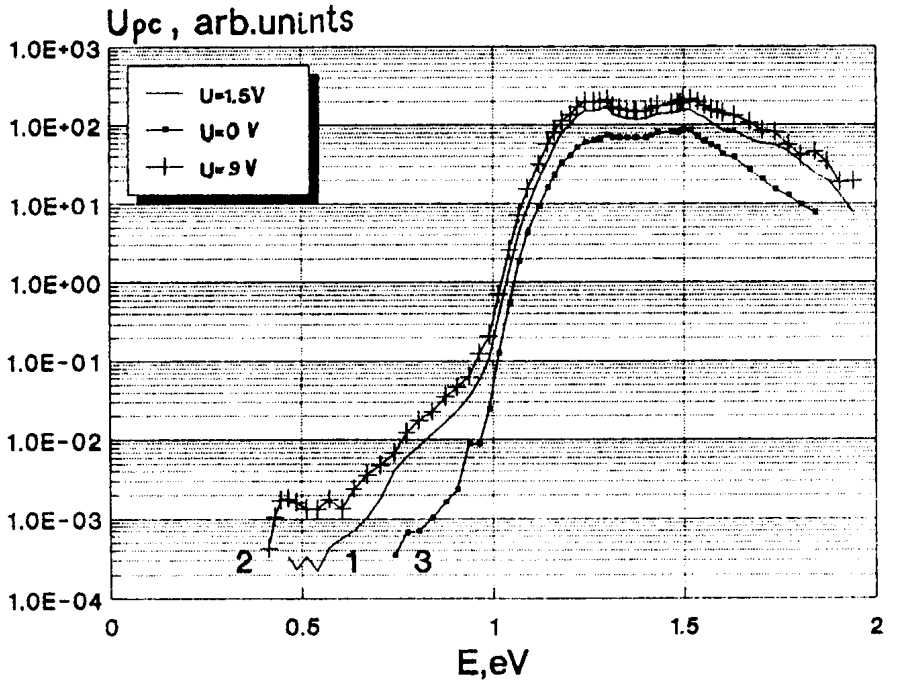

Fig.2. Spectral response of photoconductivity of the P—I—N structures prepared from NT-doped $Si_{1-x}Ge_x$ alloy (x = 0—2 *at.%*) Illumination of the i - region of reverse-biased diode (*1* — 1. 5 *V*; *2* — 9 *V*, *3*—short circuit).

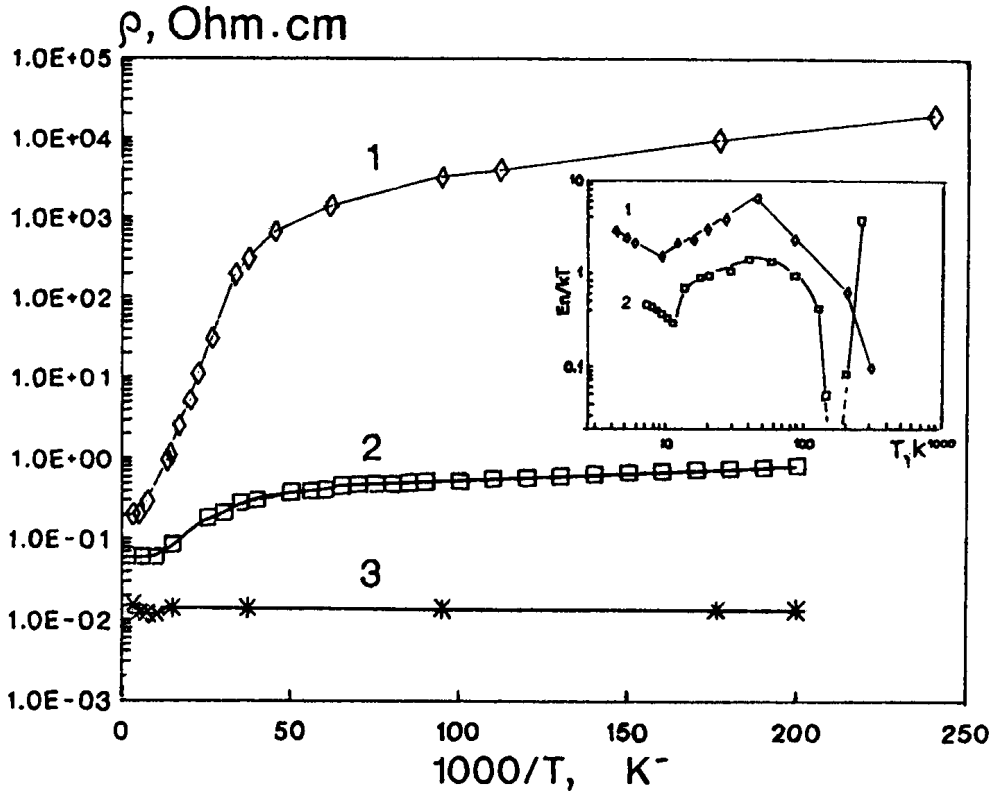

Fig.3. Temperature dependence of resistivity of NT-doped $Si_{1-x}Ge_x$ polycrystals. (Inset: conductivity activation energy vs.T) *1* — $x = 56$ *at.%*; $F = 2 \cdot 10^{19}\ cm^{-2}$; *2* — $x = 93$ *at %*; $F = 1 \cdot 10^{18}\ cm^{-2}$; 3 — $x = 93$ *at.%*; $F = 2 \cdot 10^{19}\ cm^{-2}$

This paper presents the results of an investigation into the electric and photoelectric properties of NT-doped $Si_{1-x}Ge_x$ solid solutions both on silicon-rich side ($x = 0—2$ *at.%*) and a wider composition range corresponding to polycrystallization.

1. Thermal neutron irradiation ($F = 2 \cdot 10^{19} - 2 \cdot 10^{20}$ cm^{-2}) of plates of $Si_{1-x}Ge_x$ solid solutions with composition varying along ingot ($x = 0—2$ *at.%*) produced in them P—I—N structures as a result of transmutation of the Ge, Si isotopes and of the formation of an acceptor ($^{70}Ge \rightarrow {}^{71}Ga$) and a donor ($^{30}Si \rightarrow {}^{31}P$) impurities, accordingly, at the ends of ingots with higher and lower values of x. Measurements along the plate of the P—I—N structures of the thermopower, Ge content and inhomogeneity of the resistivity have permitted us to determine the value of the parameter x_0=0.7 *at.%* corresponding to total compensation ($K = N_a/N_d = 1$) of the transmutation-produced impurities in the i-region of the ingot. On these P—I—N structures we measured the I—V characteristics which exibit a typical "diode" shape (fig.*1*) with a rectification factor $K = I_f/I_r = 10^3$ ($V = 10$ *V*, $T = 3000$ *K*) and a reverse current $I_r = 8 \cdot 10^{-5}$ A/cm^2 ($V = 1V$).

Studies of the photoelectric properties of P—I—N structures over the pump photon energy range 0.2—2 *eV* showed the maximum of the diode spectral response to lie within 1.2—1.5 *eV* (fig.*2*). Illumination of the i-region of a reverse-biased diode results in an increase of the photosensitivity in the impurity region of the spectrum with increasing bias voltage, which is due to bordering of the space charge region in the P—I—N structure and, accordingly to increasing carrier collection efficiency. The photosensitivity behaves differently when the N- and P- regions are illuminated. The results of these studies show that NTD of the $Si_{1-x}Ge_x$ solid solutions of variable composition ($x = 0—2$ *at.%*) permits obtaining P—I—N structures which can be used to produce photodiodes with a larger effective area ($S > 1$ cm^2).

2. A study has been carried out of the effect of NTD on the electrophysical properties of $Si_{1-x}Ge_x$ alloys over a broad compositional range $x = 19—93$ *at.%*, corresponding to polycrystallization. Measurements were made of the temperature dependences of conductivity and carrier concentration in the temperature range 300—4.2 *K*, as well as of the longitudinal and transverse magnetoresistivity ($\Delta\rho/\rho_{\parallel}$ and $\Delta\rho/\rho_{\perp}$ at T= 300 *K* and 77 *K*. An analysis of the $\rho(T)$ dependences (fig.3) suggests the existense at the high temperature in NT-doped $Si_{1-x}Ge_x$ polycrystals of band conduction involving thermal ionization of holes from ground state of the transmutation-produced Ga impurity to the percolation level (the so-called "ε_1-conductivity") which crosses over at low temperatures to the hopping conductivity ε_3. An analysis of the conductivity activation energy $\omega = \varepsilon_c/kT$ (see inset in fig.3) showed the activation energies ε_1 and ε_3 to decrease with increasing NT level and increasing x, the conductivity itself being apparently determined by the polycrystalline layers. The magnetoresistivity measurements suggest that the homogeneity of the polycrystalline alloy $Si_{1-x}Ge_x$ increases with increasing NT level.

Thus an investigation of NT-doped polycrystalline solid solutions $Si_{1-x}Ge_x$ showed that the NTD method can be used to advantage to improve the inhomogeneity of the material and to control the temperature dependence of its resistivity (the values of ε_1 and ε_3) by properly varying the composition (x) and neutron fluense. Thus the material obtained in this way can be used in the development of thermoresistors for the low and ultralow temperature ranges which are insensitive to magnetic field.

References

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2.Zabrodskii A.G. et al. // Pros.Conf."Photoelectric Phenomena in Semiconductors", Tashkent, 1989. P.101.