THE SECOND ACCEPTOR LEVEL OF ARGENTUM IN SOLID SOLUTIONS Ge-Si

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The investigation results of second acceptor level of argentum in solid solution Ge-Si, containing 18 at.%Si are given in the paper. The monocrystals are obtained by the withdrawal from the melt with the application of feeding ingot. The second acceptor level of argentum is in the upper half of forbidden band. That's why for its revealing it is necessary to doubly dope crystals by Ag and Sb impurities with such calculation, that the first acceptor level of argentum can be doped totally, and the second one can be doped partly. Sb is introduced in crystals in the monocrystal growth process through gas phase, and Ag is introduced by diffusion method.

The argentum depth of occurrence is defined by the investigation of temperature dependence of Hall coefficient and by the comparison of experimental data with results of equation solution of electrical neutrality crystal. The depth of occurrence of argentum second level, counted from depth of conduction band, is equal to 0,41 eV.

The revealing of the second acceptor level of argentum in solid solution Ge-Si, containing 18at% Si and definition of its activation energy is the aim of the present paper. At the given composition of Ge-Si system the argentum in it acts as amphoteric impurity and reveals the multiplet character. In Ge the argentum creates three acceptor and one donor levels, and in Si creates probably one acceptor and one donor levels.

The second level of argentum is in upper half of forbidden band in the composition considered by us. For its revealing it is also necessary the presence of small donor acceptors in crystal. The stibium (Sb) is used in one's capacity of donor impurity. The monocrystals of Ge-Si alloys are obtained by the withdrawal from the melt with the application of feeding ingot. The stibium is introduced into melt from its gas state through small vent, made on crucible bottom. The argentum is introduced into crystals by the diffusion method.

It is necessary to chose by such way for revealing and investigation of second acceptor level of argentum in Ge-Si crystals of Ag(N_{Ag}) and Sb(N_{Sb}) concentrations, that the following relation should be filfilled:

$$\left(N_{Ag}+N_a\right)< N_{Sb} \le 2N_{Ag}+N_a \tag{1}$$

Here the concentration of having small acceptors in crystal is designated through N_a and it is accepted, that concentrations of all levels of argentum are equal each other. At carrying out of the condition (1) Sb donor centers, being near the bottom of conduction band in forbidden band, send their fifth valency electrons and totally fill the small acceptor states and first acceptor centers of argentum, and second acceptor state fills either totally, or partly. At that both small acceptor state and first acceptor state of argentum are in passive state and practically don't give the contribution in crystal conductivity (donor state of argentum also doesn't reveal itself as below it there aren't empty acceptor centers). The centers of the second acceptor state of argentum at $N_{Sb} = 2N_{Ag}+ N_a$ are filled by electrons totally, and at $N_{Ag}+N_a< N_{Sb}< 2N_{Ag}+N_a$ are filled partly.

In both cases electrons from the second state with temperature increase transit into conduction band, i.e. it acts as donor state ("pseudo-donor state"). The temperature dependence of Hall coefficient (R) of the one of the samples of n-type, in which impurity concentrations satisfy the relation (1) is given on the fig.1. As it is seen from the figure, R practically linearly depends on the temperature in low-temperature region in semi-logarithmic scale. The slow dependence of R on T in high-temperature region connects with the fact that second acceptor state of argentum gradually fails, wasting its electrons with the temperature increase.

The saturation absence in low-temperature region shows, that there aren't residual (non-compensated) stibium centers after the compensation of acceptor centers. Besides, the change of R on T more, than on two orders allows one to define the depths of occurrence of the second acceptor sate of argentum ε^{II}_{Ag} to enough high accuracy.

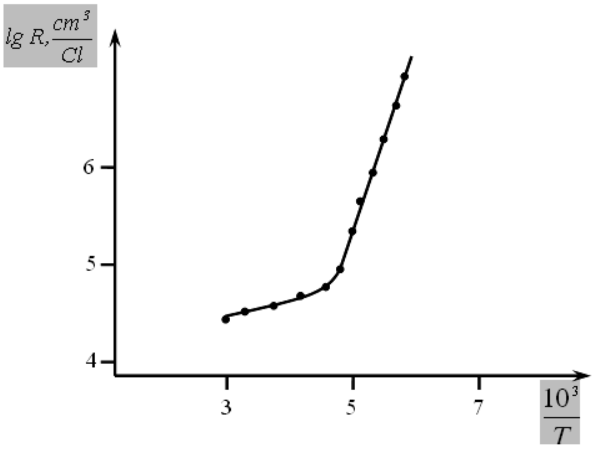

Fig.1.

In the given case the equation of crystal electrical neutrality has the following form:

$$n+N_a+N^I_{Ag}+\left(N^{II}_{Ag}-n_2\right)=N_{Sb}\ . \tag{2}$$

Here n is concentration of free electrons and first acceptor state of argentum correspondingly, n_2 is concentration of the centers of second acceptor state of argentum, captured by electrons. n and n_2 are expressed by the following known formulae:

$$n=N_C\exp\left(\frac{F}{kT}\right), \tag{3}$$

$$N_c=2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{\frac{3}{2}} \tag{4}$$

$$n_2 = \frac{N^{II}_{Ag}}{\frac{1}{\gamma_2}\exp\left(\frac{-\varepsilon^{II}_{Ag} - F}{kT}\right) + 1}\,. \qquad (5)$$

where F is Fermi level, ε^{II}_{Ag} is depth of occurrence of the second acceptor state of argentum, counted out the bottom of conduction band. N^{II}_{Ag} is concentration of compensated part of the centers of second acceptor state of argentum, k is Boltzmann constant, h is Planck's constant, T is Kelvin temperature, γ_2 is statistical weight of the second acceptor state of argentum, m_n^* is effective mass of electron state density. Let's designate the required unknown by the following method:

$$y = \exp\left(\frac{F}{kT}\right). \qquad (6)$$

Substituting (3), (5), (6) into (2), we obtain after vanilla calculations:

$$y^2 + \frac{1}{\gamma_2}\exp\left(-\frac{\varepsilon^{II}_{Ag}}{kT}\right)\cdot y - \frac{1}{\gamma_2}\cdot\frac{N^{II}_{Ag}}{N_C}\cdot\exp\left(-\frac{\varepsilon^{II}_{Ag}}{kT}\right) = 0\,. \qquad (7)$$

Let's write the solution of equation (7):

$$y = \frac{1}{2\gamma_2}\exp\left(-\frac{\varepsilon^{II}_{Ag}}{kT}\right)\left[-1 + \sqrt{1 + 4\gamma_2\frac{N^{II}_{Ag}}{N_C}\cdot\exp\left(\frac{\varepsilon^{II}_{Ag}}{kT}\right)}\right]. \qquad (8)$$

Here we eliminate the negative root as it hasn't the physical meaning. In the temperature interval, when the condition is:

$$4\gamma_2\frac{N^{II}_{Ag}}{N_C}\exp\left(\frac{\varepsilon^{II}_{Ag}}{kT}\right) >> 1 \qquad (9)$$

the solution (8) is simplified and has the following form:

$$y = \left(\frac{N^{II}_{Ag}}{\gamma_2 N_C}\right)^{\frac{1}{2}}\exp\left(-\frac{\varepsilon^{II}_{Ag}}{2kT}\right). \qquad (10)$$

The relations (10) and (2) allow one to find the temperature dependence of the concentration of free electrons:

$$n = \left(\frac{N_C N^{II}_{Ag}}{N_C}\right)^{\frac{1}{2}}\exp\left(-\frac{\varepsilon^{II}_{Ag}}{2kT}\right) \qquad (11)$$

or

$$n = C\cdot T^{3/4}\exp\left(-\frac{\varepsilon^{II}_{Ag}}{2kT}\right) \qquad (12)$$

here:

$$C = \left[\frac{N^{II}_{Ag}}{\gamma_2}\cdot 2\left(\frac{2\pi k m_n^*}{h^2}\right)^{3/2}\right]^{1/2} \qquad (13)$$

is constant value.

Multiplying both sides of (12) on $T^{-3/4}$ and finding the logarithm, we obtain:

$$\lg\left(nT^{-3/4}\right) = \lg C - \frac{0{,}4343\varepsilon^{II}_{Ag}}{2k}\frac{1}{T}\,. \qquad (14)$$

(14) is the line equation, from the angular coefficient of which it is possible to define ε^{II}_{Ag}. Taking into consideration the relation of the concentrations (n) with Hall coefficient (R), it is possible to define ε^{II}_{Ag} from inclination of R temperature dependence. The dependence of *lg(kT$^{3/4}$)* on $\frac{1000}{T}$, calculated from the curve 1 is presented on fig.2. The calculated value of activation energy of second acceptor state on inclination angle of this *(R)* dependence is equal 0,41eV (the calculation is done from the bottom of conduction band).

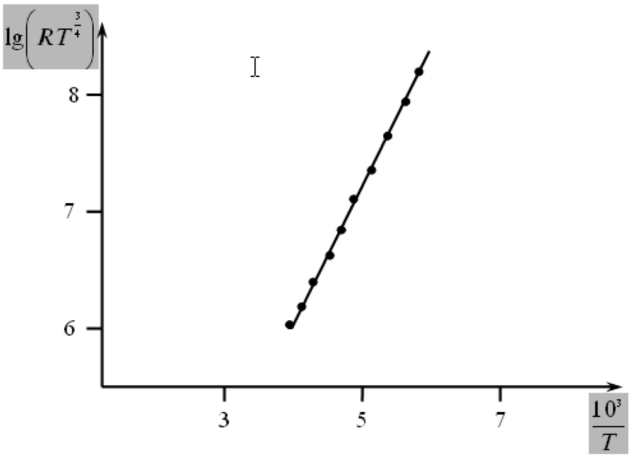

Fig. 2.

The obtained results quit good agree with data of papers [2-4], where the impurity states of argentum for other compositions of Ge-Si solid solutions have been investigated.

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Ge-Si BƏRK MƏHLULLARINDA GÜMÜŞÜN İKİNCİ AKSEPTOR SƏVİYYƏSİ

İşdə gümüşün ikinci akseptor səviyyəsi tərkibində 18 at.% Si olan Ge-Si bərk məhlulunda Holl əmsalının temperatur asılılığına əsasən tədqiq edilmişdir. Bunun üçün monokristallarda mövcud ola bilən dayaz akseptor mərkəzləri və gümüşün birinci akseptor səviyyəsi stibium donor aşqarının köməkliyi ilə konpensasiya edilmişdir. Holl əmsalının təcrübədən alınan temperatur asılılığı kristalın neytrallıq tənliyinin həlli ilə müqayisə edilərək gümüşün ikinci akseptor səviyyəsinin aktivləşmə enerjisi (0,41 eV) tapılmışdır.

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ВТОРОЙ АКЦЕПТОРНЫЙ УРОВЕНЬ СЕРЕБРА В ТВЕРДЫХ РАСТВОРАХ Ge-Si

В статье приведены результаты исследований второго акцепторного уровня серебра в твердом растворе Ge-Si, содержащем 18ат.% Si, Монокристаллы получены вытягиванием из расплава с применением подпитывающего слитка. Второй акцепторный уровень Ag находится в верхней половине запрещенной зоны. Поэтому для его выявления приходилось кристаллы двукратно легировать примесями Ag и Sb с таким расчетом, чтобы первый акцепторный уровень Ag компенсировать полностью, а второй – не полностью. Sb вводилось в кристаллы в процессе роста монокристаллов через газовую фазу, а Ag – методом диффузии.

Глубина залегания Ag определялась исследованием температурной зависимости коэффициента Холла и сравнением экспериментальных данных с результатами решения уравнения электрической нейтральности кристалла. Глубина залегания второго уровня Ag , отсчитываемая от дна зоны проводимости, равна 0,41 эВ.

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