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LATTICE DEFECTS IN NEUTRON IRRADIATED GERMANIUM

V. Spirić, M. Stojić and D. Kostoski
"Boris Kidrič" Institute of Nuclear Sciences, Beograd

Abstract: Lattice defects in n- and p-type germanium irradiated in the nuclear reactor at 60°C have been investigated. The carrier concentration has been determined by the Hall coefficient measurement at room temperature. It was found that neutron irradiation produces acceptor-like defects.

Isochronal annealing revealed three broad annealing stages. Comparing the magnitudes of these stages in n- and p-type Ge it was concluded that in p-type Ge intrinsic defects such as divacancies and small vacancy clusters are predominantly produced. Additionally in n-type Ge the complexes of primary defects with donor impurity are observed.

1. Introduction

The defects in germanium produced by fast neutron irradiation are expected to be very complex defect clusters involving of the order of 10^3 displaced atoms in each cluster[1)]. The annealing of germanium containing such large disordered regions below room temperature is explained by the dissociation of large clusters into smaller clusters or even single vacancies and interstitials[2-4)]. Because of the complexity of neutron-induced damage, detailed features of the defects are not well established.

In our previous papers we investigated separately lattice defects in neutron irradiated n- and p-type Ge[5,6)]. In both cases three broad and poorly resolved annealing stages above 100°C have been observed. They were assigned to the complexes of primary defects with donor impurity atoms in n-type Ge and to the intrinsic defects such as divacancy and vacancy clusters in p-type Ge.

For the further study we compare the results of isochronal annealing in specimens of p- and n-type Ge which were neutron irradiated under the same conditions.

2. Experimental procedure

Germanium single crystals gallium doped ($8x10^{13}cm^{-3}$) and antimony doped ($1.6x10^{14}$ and $1.06x10^{15}cm^{-3}$) have been simultaneously irradiated at $60^{o}C$ in the Vinča nuclear reactor. The time of irradiation was 10 minutes, which corresponds to the thermal neutron dose of $2.2x10^{16}n/sm^{2}$. The equivalent fast neutron dose was estimated to be one order of magnitude smaller.

After irradiation the specimens were held at room temperatur one month, the period of time which is sufficient for decaying of radioactive Ge^{71} into the stable Ga^{71} [7].

Twenty minutes isochronal annealing in helium atmosphere up to $450^{o}C$ has been performed. After each annealing temperature the carrier concentration was determined by the Hall coefficient measurement at room temperature.

3. Results and discussion

Figure 1 shows the results of irradiation and isochronal annealing for specimens A, B and C with different initial characteristics. The hole concentration in p-type Ge (specimen A) was increased and two n-type specimens (B and C) were even converted to p-type due to irradiation. The concentration of induced acceptor-like defects is higher in n-type specimens exceeding the corresponding concentration in p-type specimen for an amount which is almost proportional to the concentration of donor impurity. This indicates that in n-type Ge a portion of induced defects involves donor impurity atoms.

In Figure 1 three broad annealing stages occuring in the temperature ranges $80^{o}-180^{o}C$, $200^{o}-300^{o}C$ and $280^{o}-400^{o}C$ can be observed in all specimens. These stages are not well resolved and for instance the second and the third stage are partly overlapped. The carrier concentration after irradiation and annealing is higher than before irradiation. This effect can be attributed to the creation of gallium atoms by the decay of radioactive Ge^{71} [7].

In our previous work we investigated the dose dependence of annealing stages in p-type Ge and concluded that stage I and stage III may be related to intrinsic defects such as divacancy and vacancy clusters, but stage II is probably a complex of an impurity with either a vacancy or an interstitial[6]. On the basis of this explanation and because

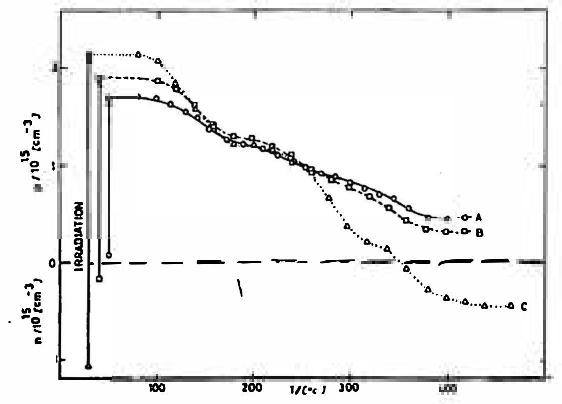

Fig. 1. Results of isochronal annealing in three different Ge specimens irradiated in the nuclear reactor to the total thermal neutron dose of $2.2\times10^{16}n/cm^2$.

the intrinsic defects are supposed to be formed by the dissociation of large defect clusters produced in a displacement cascade, the same damage can be expected in p-type and n-type Ge. However, if we compare the magnitudes of the stage I in three specimens, it comes out that the stage I is more pronounced in n- than in p-type Ge. We investigated the stage I more carefully by measuring after each annealing temperature the hole concentration at room temperature and at liquid nitrogen temperature and observed the beginning of the annealing at 80°C and 140°C respectively. This means that the stage I in n-type Ge is complex stage consisting of two close stages. In the stage beginning at 80°C a defect with a deep laying acceptor level disappears and in the stage beginning at 140°C a defect with a low laying acceptor level disappears or a defect with donor level restores. A possible explanation for the stage I is that in p-type Ge divacancy anneals and in n-type Ge additionally the annealing of a defect which contains donor atom such as VD and VVD complexes takes place.

The exact quantitative comparison of the stage II and the stage III is difficult because these stages partly overlap. It is however evident that the stage II is more pronounced in n-type Ge and even moved to higher temperature in specimen C. This stage can also be considered as a composite stage involving at least two bad resolved stages, and a precise identification is not possible. It can only be concluded that in n-type Ge in one of the stages of the stage II a defect including donor atoms disappears.

Stage III is almost equally pronounced in all specimens and it can be assigned to an intrinsic defect, probably to a small vacancy cluster which appeared after the dissociation of large defect clusters produced in a displacement cascade.

In summary, the results of the present investigation confirm that the large disordered regions created by fast neutron bombardment break up above room temperature into single vacancies and single interstitials and more complicate intrinsic defects such as divacancies and small vacancy clusters. Furthermore, for the p-type Ge it can be concluded that divacancies and small vacancy clusters are the predominant defects but in n-type Ge single vacancies and interstitials form with donor impurity atoms additional complexes whose annealing interfere with annealing of intrinsic defects.

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