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THE INFLUENCE OF RADIATION ON THE LATTICE DEFECTS IN p-type GaAs

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The radiation defects in p-type GaAs single crystals, Cd-doped, with the free curier concentrations, 10^{16} cm^{-3}, were studied. The defects were induced by x-rays, 4 MeV maximum energy, and by Co^{60} gamma rays. The radiation of 10^{21}photon/cm^2 induces defects which behave as acceptors in 10^{16} cm^{-3} concentration. These defects anneal out via the two stages in temperature regions (300-400)°C and (460-520)°C, with the activation energies of 1 eV and 1.5 eV, respectively, determinated by "variable temperature" method.

1. INTRODUCTION

The prospective application of GaAs as a semicontudctor is still chaleng-ing the attention of many scientists. The crysatl lattice defects affects very much its physical and chemical properties, as they are present in a smaller or larger number in GaAs crystals obtained by the growth from the liquid phase. The most pure single crystals contain about 10^{16} cm^{-3} "impurities" or defects i.e. the irregularities in crystal lattice. The impurities of the VI groupe of Periodic system (S, Se and Te) behave as donors substituting the arsenic in its sublattice, while the impurities of the II group (Zn, Cd) behave as acceptors substituting the Ga atoms.

The self defects or impurity defects, behave as acceptors or electrically neutral. It is very difficult to predict the electrical behaviour of defects and impurities, therefore, their electrical activity is usually determined experimentally. The most frequent defects in GaAs are the Ga-vacancies, Ga-devacancies and As-vacancies established experimentally[1,2]. These defects can interact with impurity atoms[3] making the neutral complex (donor + defect or acceptor + defect), or associate in cluster defecets.

Some of authors[4] presume that arsenic vacincies are single charged acceptors. Pons, Mircea et al[5] noticed that different GaAs single crystals behave differently after irradiated by the fast energy particles or by photons, so, it was not quite clear whether the changes occur because of impurities or lattice defects. In fact, a real nature of these changes is still unknown. Thus, the perplexity concerning the nature of lattice defects in GaAs in stimulates further investigations.

2. EXPERIMENTAL

In this work, the rectangular secimens, $18x2x1\ mm^3$, of p-type GaAs, Cd doped with the concentration of free carriers $p_o = 1.1x1016\ cm^{-3}$, have been used. The specimens were cutted from the ingot plates in (111) plane, then mechanically polished and further etched in $H_2O{:}H_2O_2{:}H_2SO_4$ = 1: 2: 3 solution. The electric conductivity and Hall coefficients of samples before and after defects induction were measured. The defects were induced by x-ray and Co^{60} gamma rays irradiation. The roentgen apparatus, 4 MeV maximum energy, was used for induction of defects. Before irradiation, the specimens prepared were sealed in the high purity quartz ampoules under the vacum of 10^{-4} Pa. The fluence of Co^{60} gamma radiation was 10^{18} to 10^{21} photon/cm^2. The concentration of induced defects pa was determined by Hall coefficient measurements, i.e. on the ground of the established differnce between the majority carrier concentration, before irradiation, po, and after irradiation pr.

To determin the number of annealing stages and the activation energy for defect migartion, the irradiated specimens were isochronically annealed. The annealing was performed in the high vacuum in time intervals of 10 minutes, increasing temperature gradually for 10°C. After each cycle of annealing, the equilibrium concentration of defects was measured in the range from 180 to 250°C. The remaining fraction of defects after annealing cycle was defined as

$$f = \frac{po-pt}{po-pr}$$

where po denotes the initial concentration of majority carriers; pt- the concentration after annealing cycle and pr- the concentration of carrier immediately after defect induction by irradiation.

3. RESULTS AND DISCUSSION

In the specimens exposed to x-rays, maximum energy 4 MeV, a large increase of currier concentration was established, pr-po = 2.02×10^{16} cm^{-3}, thus indicating that the induced defects are of the acceptor type.

The isochronic annealing curve (Fig. 1) of these samples consists of two annealing stages, the first one is in the range from 290 to 400°C and the second is in the range 440-480°C. The majority defects anneal out via the first stage.

Almost the same effect was observed in the samples irradiated by Co^{60} gamma-rays of the total fluence 3×10^{21}photon/cm^2 (Fig. 1).

The free carrier concentration in this case was pr-po = 3.83×10^{16} cm^{-3}, indicating also the acceptor behaviour of defects. The major fraction of defects anneal out in the region of 300 to 400°C, and the remaining faraction in the region 460 to 520°C.

The annealing stage appearing at temperature of 240 to 400°C, were discovered also by Brailovskii and Brudnyi[6)]. The assumed that this stage corresponds to the complex of point defects. Accordingly, this stage should be strongly pronounced in the intensively irradiated specimens (ϕ = 10^{17} photon/cm^2, 1 MeV, or irradiated by the high energy electrons (5 MeV).

Here, it was established that irradiation of p-type GaAs single crystals by x-ray (4 MeV) and Co^{60} (10^{21} photon/cm^2), the former stage becomes strongly pronounced and shifted towards low temperatures in respect to the results of Brailovskii and Brudnyi (380-400°C)[6)]. The activation energy of this stage was 1 eV and the annealing obeys the first order kinetics. It is assumed that radiation induced defects could be either mobile or immobile. The mobile defects, at irradiation temperature interact with each other forming defect clusters and/or the "defect impurity" complexes.

In p-type GaAs, Cd-doped, it is possible that mobile defects, such as Cd-vacancies, associate with Cd, forming electrically neutral complex:

$$Cd^- + V^+_{Ga} = (Cd^- V^+_{Ga})^o.$$

The charge state of defects is not yet precisely defined. Therefore, some authors believe that Ge-vacancies behave as acceptors[7)], while the others[8)] that As vacancies behave as acceptors. However, according to the results of earlier investigations on gamma ray induced defects (ϕ = 10^{18}photon/cm^2), (which indicate the donor properties of defects) as well as the results of this work, (where the induced defects are considered as acceptors), it can be concluded that vacancies charge state can be either positive or negative in the p-type GaAs, depending on the Fermi level position.

The annealing stage observed in the temperature range (460-520)°C for the samples irradiated by x-ray (4 MeV) and (460-520)°C, for gamma rays irradiated samples seems to correspond to the clusters of defects. The same stage was found10) for thermally induced defects as well as for radiation induced defects in n-type GaAs. The activation energy for this stage Ea = 1.5 MeV, considerably higher value indicates a strong bibning of defects in the clusters.

4. CONCLUSION

On the basis of experimental data on the radiation induced crysta lattice defects of p-type GaAs, the following conclisions can be derived:

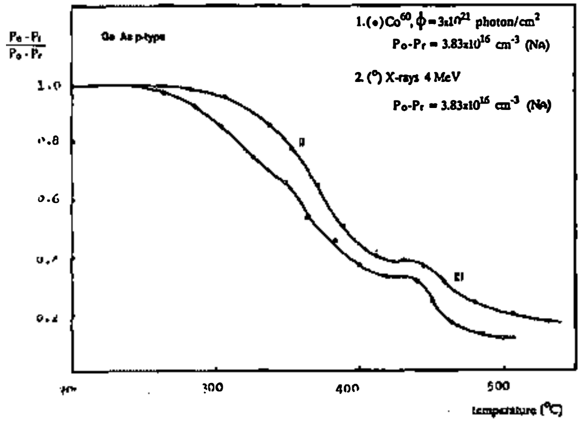
- By x-ray irradiation (4 MeV) p-type GaAs, the acceptors resembling the lattice defects are induced;

- These defects anneal out via two stages in the temperature range from 290 to 400°C and 440 to 480°C, respectively;

- By Co^{6O} gamma irradiation, $\phi = 3x10^{21}$ photon/cm^2, the induced defects in 10^{16} cm^{-3} concentration, are acceptor like also;

These defects anneal out via the two stage in the temperature range from 300 to 400°C and 460 to 520°C, respectively.

The activation energies for this two annealing stages determined by the "variation temperature" method, are 1.0 eV and 1.5 eV, respectively.



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