I. Introduction

In previous papers, results of the time differential perturbed angular correlation (TDPAC) measurements using $^{111}\text{In}$ probe nuclei on several Cd-In alloys are reported. Since the probe atom $^{111}\text{In}$ behaves as exactly the same manner as the alloyed In atoms, one can study the metallurgical state of the In atoms by measuring the TDPAC spectrum by $^{111}\text{In}$ nuclei. From the results of the annealing study above the room temperature, several phase changes were found to take place above the room temperature and the phase diagram constructed from the TDPAC measurements show a good agreement with that determined by conventional methods. In the course of the research, however, it was noticed that the TDPAC spectrum at the first measurement after $^{111}\text{In}$ production irradiation by 25 MeV protons is that of the high concentration phase. This shows that In atoms precipitates to form In cluster at a some temperature between 77 K and the room temperature. Since the proton beam current was as high as 400 nA to shorten the irradiation time, the specimen temperature during irradiation may reach to the room temperature where In precipitation may take place.

In the present experiment, therefore, the temperature of the specimen during the irradiation is carefully controlled with using low proton beam current and a controlled annealing study is performed between 77 K and the room temperature. The purpose of the experiment is to find the temperature where the In precipitation takes place and also to examine the possible participation of irradiation induced lattice defects in the In precipitation process.

II. Experimentals

Cd-In alloys were prepared by melting 4-9% Cd and In metal in an Ar atmosphere. After rolling to .2 mm thickness sheet, they were annealed at 483 K for 1 day followed by a quench into water. In concentration was .58 at. %. It was irradiated by 25 MeV proton beam from the cyclotron to introduce $^{111}\text{In}$ by $^{112}\text{Cd}(p,2n)^{111}\text{In}$ reaction. The specimen was clamped to a cold finger cooled at 77 K. The proton beam current was kept below 20 nA to keep to specimen temperature below 90 K during the irradiation. After several days of cooling off the residual radioactivity other than $^{111}\text{In}$ activity at 77 K, TDPAC spectrum was measured by 3-detectors system. The measurements were performed in the as irradiated state and also after pulse annealing at a
temperature between 77 K and the room temperature. Measurements were performed at 77 K when the annealing temperature is below RT and were performed at RT when the annealing temperature is above RT.

III. Results

Figure 1 shows results of the experiments for the .58 at. % alloy. Here the spectra after the annealing above 180 K are shown. Between 180 and 240 K, the spectra with the 50 nsec period precession signal are nothing but that of $^{111}$In at the substitutional site of polycrystalline Cd. In these temperatures, therefore, $^{111}$In atoms are isolated from other In atoms and form a solid solution. However after the annealing at 295 K (RT) for 30 min, the 50 nsec signal shows the trend of reduction. After the annealing at RT for 5 hrs, the signal completely disappears and a long period component take place, which has been known to correspond to a high In concentration phase. Therefore the result clearly shows that $^{111}$In atoms migrate at RT to form a cluster. Upon annealing the specimen above RT, at 426 K, the 50 nsec signal again takes place to show that In clusters disappear and In atoms are in $\alpha$-phase. These phase changes of the Cd-In (.58) alloy are in accord with the phase diagram since a solid solubility of In is less than .01 at % at RT and more than 1 at % at 426 K. Therefore the results in Fig. 1 are reasonable thermodynamically. However In atoms have to migrate to form In clusters and the temperature where the migration takes place is considerably lower than that expected from the thermal diffusion of In atoms via a vacancy mechanism, of which causes will be discussed in the next section.

IV. Discussions

Several alloys of different composition from the present have been studied after quenching from temperatures above 483 K (the quenching temperature employed in the present) and TDPAC spectra measured at RT. Even for the alloy where a phase is unstable at RT, the spectrum is that of $^{111}$In atoms in a phase even after 1 day duration of the measurement. This shows that the thermal vacancy quenched in at the time of the solution treatment is not responsible for the In migration at RT in the present. On the other hand, vacancies in Cd have been known to migrate near 120 K and trapped to $^{111}$In atoms and detrapped near 150 K from TDPAC studies of irradiated or quenched Cd.$^{2, 3}$ Therefore, there should be left no single vacancies at RT to participate in the present In clustering at RT. Because of the merit of the hyperfine technique, one can be sure that $^{111}$In atoms never keep trapping vacancy near RT, since the spectrum is that of $^{111}$In atoms without any defects nearby. Therefore one can discard the argument that In-vacancy complex is stable upto RT and starts to migrate near RT.
These considerations may suggest that the In migration in Cd is not caused by a vacancy mechanism. Also the rearrangement of vacancy cluster at RT, which are formed during the annealing between 77 K and RT, may be responsible for the In clustering in the present. Further works are now in progress.

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References

![Diagram](image-url)

Fig. 1. TDPAC spectra of CD-In (0.58 at %) alloy after isochronal annealing. 77 KM: 77 K measurements. RTM: RT measurements.