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Phase Transition of Ni_3Ta Intermetallic Compound Induced by Energetic Ion Beam

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1 Introduction

Energetic ion irradiation locally gives high density energy deposition into a target, and it can induce non-thermal equilibrium phases. In ordered alloys (intermetallic compounds), such as AB or A_3B, each of the A and B atoms occupies specific sub-lattice sites, and their atomic ordering is described by the long-range order parameter. For these alloys, an irradiation-induced rearrangement of A and B atoms can give rise to a change in long-range parameter. A great deal of experimental data has demonstrated that ordered alloys such as Ni_3Al, Zr_3Al, CuTi, $NiZr_2$ show the transition to a disordered structure or an amorphous state by ion or electron irradiations. Such lattice structure transformations were mainly investigated by using the transmission electron microscopy, but, changes in physical properties which are accompanied by the irradiation-induced lattice structure transformations have little been discussed so far. In our previous results, we showed the energetic ion irradiation induced lattice structure transformation and the change in Vickers hardness for Ni_3Al [1)], Ni_3V [2)] and dual-phase Ni_3Al-Ni_3V [3)] intermetallic compounds. In the present study, we have chosen Ni_3Ta intermetallic compound as targets for the irradiation study. The intermetallic compound Ni_3Ta, which shows a limited ductility, has been considered as a reinforced phase in directionally solidified Ni based eutectic alloys. In this report, we will show the effect of energetic ion irradiation on the lattice structures and hardness for Ni_3Ta intermetallic compounds.

2 Experiment

A Ni_3Ta alloy was prepared by using 99.99 wt. % Ni and 99.99 wt. % Ta. These alloy ingots were made by arc melting under an argon gas atmosphere. The ingot of Ni_3Ta alloy was thermally annealed at 1273 K for 144 h under vacuum followed by the furnace cooling at a cooling rate of 10 K/min. After the thermal annealing, this ingot was cut into some sheets with the dimension of 1 × 1 × 0.1 cm^3. The surfaces of sheets were polished with #80, 180, 400, 800, 1200 and 1500 emery-papers. Finally, they were polished by using #3000 Al_2O_3 buff. They were irradiated at room temperature with 16 MeV Au^{5+} ions by using the 3 MV tandem accelerator at Takasaki Advanced Radiation Research Institute, Japan Atomic Energy Agency. The ion fluences were 1×10^{13}, 5×10^{13} and 5×10^{14} cm^{-2} for Ni_3Ta alloy. The effect of the ion irradiation is restricted only at the surface region, depth of which is about 2μm. If we carried out a conventional XRD measurement, we would observe not only this surface region but also a deeper region which is not affected by the irradiation. Therefore, we performed the grazing incidence X-ray diffraction (GIXD) as an evaluation method of the lattice structure only near the surface of the samples. Its incident angle was kept at 0.5 degree, and the Cu Kα (λ=0.154nm) X-ray was used for the diffraction.
We also performed the extended X-ray absorption fine structure (EXAFS) measurement. It is a useful tool for the observation of local atomic arrangements around selected atoms. Furthermore, this measurement is nondestructive testing, which is different from TEM observations. To observe the local structures around Ni and Ta atoms in the lattice structure of the unirradiated Ni_3Ta sample and those irradiated with the fluences of 5×10^{13}/cm^2 and 5×10^{14}/cm^2, we performed the EXAFS measurements around the Ta L3 absorption edge (9.88 keV) at the 27B beamline of the synchrotron radiation facility of High Energy Accelerator Research Organization (KEK-PF). The EXAFS spectra were obtained by using the fluorescence method with a 7 element germanium x-ray detector at room temperature. We used the computer software, WinXas, for analyzing the obtained EXAFS spectra. In the analyses, all EXAFS spectra were Fourier transformed using k^3 weighting with the k range from 2 - 3 to 10 - 15 $Å^{-1}$.

The surface hardness change was estimated by using a Vickers hardness tester at room temperature with a load of 98.07mN (10 gf). The time interval of indentation was kept at 10 seconds.

3 Results and Discussion

Fig. 1 (a) shows the results of X-ray diffraction overall spectra for the unirradiated and irradiated specimens. Fig. 1 (b) shows the spectra magnified at the narrow range from 38° to 48°. All the peaks for the unirradiated sample correspond to the ordered monoclinic lattice structure, which has been reported as a thermal equilibrium structure of Ni_3Ta at room temperature. For the Au ion irradiated Ni_3Ta, the ordered peaks tend to disappear with an increase in ion fluence. The peaks for the ordered structure nearly completely disappear after the irradiation with the fluence of 5×10^{14}/cm^2. Similarly to Ni_3Nb[4)], this result suggests that Ni_3Ta transform from the monoclinic

ordered structure to the amorphous state by the ion irradiation at room temperature.

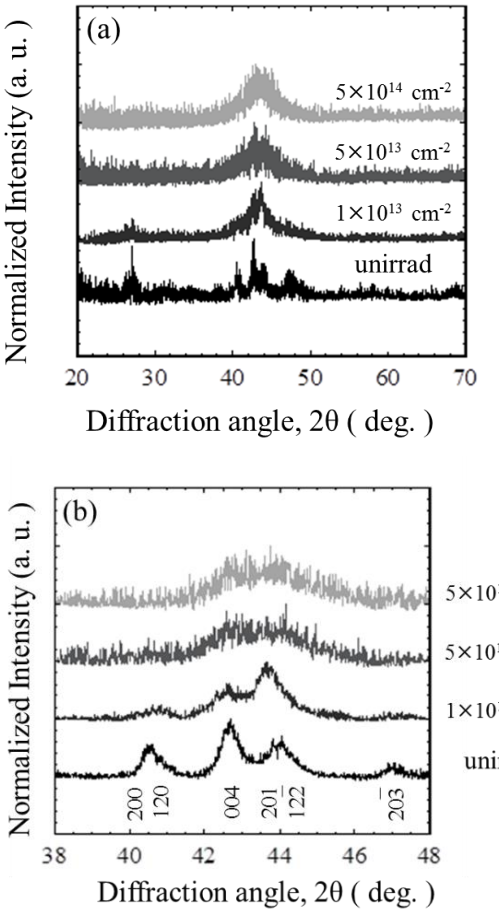

Fig. 1 (a) GIXD spectra of the unirradiated and irradiated Ni_3Ta intermetallic compound
(b) GIXD spectra at the diffraction angles of 38° – 48°

Fig. 2 shows the Fourier Transformed (FT) EXAFS spectra around Ta L3 absorption edge for the unirradiated and irradiated Ni_3Ta. The first peak is, however, still more outstanding than any other peaks even after the irradiation. This result implies that the long range ordering tends to disappear, while the short range ordering still survives the irradiation. The similar change in EXAFS spectrum has been observed for the transition between crystal structures and amorphous in some metal materials. The change in the FT-EXAFS spectrum is, therefore, another evidence for the irradiation-induced amorphization of Ni_3Ta.

Fig. 3 shows the Vickers hardness as a function of ion fluence. The hardness of Ni_3Ta intermetallic compound is increased by the irradiation-induced lattice structure transformation. This change for Ni_3Ta is similar to that for Ni_3Nb [4]. This result can be explained as the conventional fact that the value of hardness for the amorphous state is larger than that for the crystal structure.

Ni_3X intermetallic compounds have been reported to show good mechanical and chemical properties. They have been expected to be used as high temperature structural materials. The result of the present experiment suggests that energetic ion beam can be used to control the surface hardness of the intermetallic compounds.

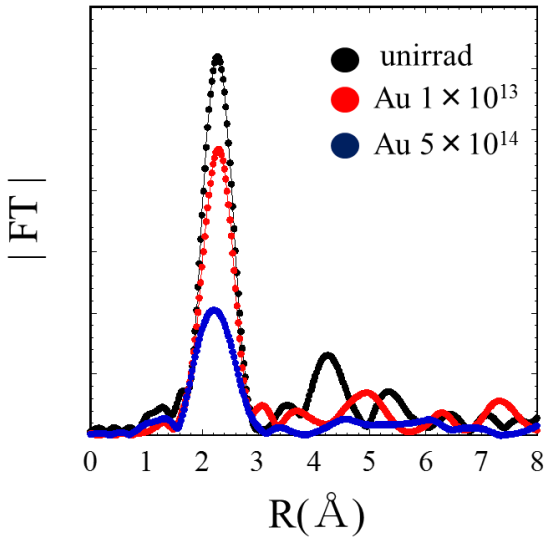

Fig. 2 FT EXAFS spectra around Ta L3 absorption edge for the unirradiated and irradiated specimens by Au ion irradiation

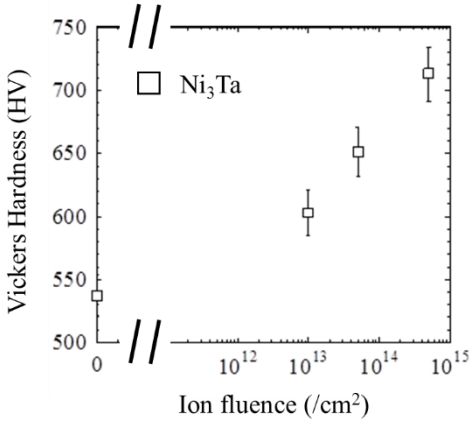

Fig. 3 Vickers hardness as a function of ion fluence

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