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Effect of Energetic Ion Irradiation on Lattice Structure and Mechanical Properties of Ni_3Nb Intermetallic compound

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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 our previous results, we showed the ion irradiation induced phase transition for Ni_3V and Ni_3Al intermetallic compounds[1), 2)]. Ni_3V shows the tetragonal ordered structure (D022 structure) at room temperature before the irradiation. After the ion irradiation, it transforms to the cubic disordered structure which is usually found in the thermal equilibrium phase diagram at high temperatures. On the other hand, the unirradiated Ni_3Al shows the cubic ordered structure (L12 structure) and this structure is retained up to the melting point. After the ion irradiation, it transforms to the cubic disordered structure which does not exist in the phase diagram. For Ni_3V and Ni_3Al intermetallic compounds, Vickers hardness decreased with increasing ion fluence. In the present study, we choose Ni_3Nb intermetallic compound as irradiation targets. Figure 1 shows the phase diagram and crystal structure of Ni_3Nb alloys. As can be seen in Fig. 1, Ni_3Nb shows the orthorhombic ordered structure and it is retained up to the melting point, which is similar to Ni_3Al. As compared with Ni_3V and Ni_3Al, however, the lattice structure of Ni_3Nb is very complicated. In this report, we will show the effect of energetic ion irradiation on Ni_3Nb intermetallic compound.

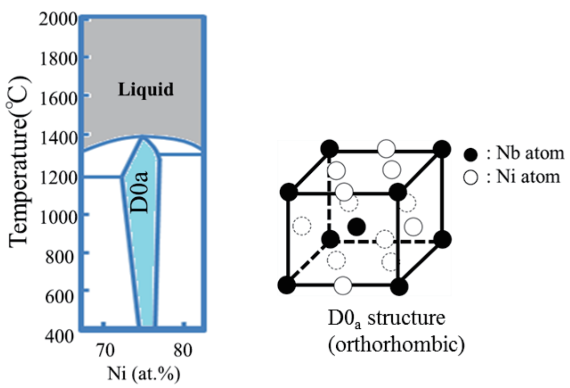

Fig. 1 The partial phase diagram and crystal structure of Ni_3Nb intermetallic compound

2 Experiment

A Ni_3Nb alloy was prepared by using 99.99 wt.% Ni and 99.99 wt.% Nb. An alloy ingot was made by arc melting under an argon gas atmosphere. It was thermally annealed at 1273 K for 96 h under vacuum followed by furnace cooling at a cooling rate of 10 K/min. After the annealing, the ingot was cut into the sheets with the dimension of 1 × 1 × 0.1 cm^3. They were irradiated at room temperature with 16 MeV Au^{5+} ions by using the 3 MV tandem accelerator at Takasaki Ion accelerators for Advanced Radiation Application (TIARA). The ion fluences were from 1×10^{12} to 7×10^{15} cm^{-2}. After the ion irradiation, we performed the surface x-ray diffraction measurement as an evaluation method of lattice structure change.

Also, we performed the extended X-ray absorption fine structure (EXAFS) measurement as a lattice structure analysis. 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 Nb atoms in the lattice structure of the Ni_3Nb specimens, we performed the EXAFS measurements around the Nb K absorption edge (18.9 keV) at the 27B beamline of the synchrotron radiation facility of High Energy Accelerator Research Organization (KEK-PF). The EXAFS spectra were obtained using a 7 element germanium detector by the fluorescence method 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 10 gf. The time interval of each indentation was kept at 10 seconds.

3 Results and Discussion

Fig. 2 (a) shows the results of surface X-ray diffraction overall spectra for the unirradiated and irradiated specimens. Fig. 2 (b) shows the spectra magnified at the narrow range from 38° to 48°. For unirradiated Ni_3Nb, the fundamental 002, 201, 020, 012 and 211 peaks are clearly observed. However, for the Au ion irradiated Ni_3Nb, the fundamental peaks tend to disappear with an increase in ion fluence. Finally, they completely disappear and broad peak appears at around 42° by Au ion irradiation with a fluence of $5\times10^{14}/cm^2$. This result suggests that Ni_3Nb transforms from the orthorhombic ordered structure ($D0_a$ lattice structure) to the amorphous state by ion irradiation at room temperature.

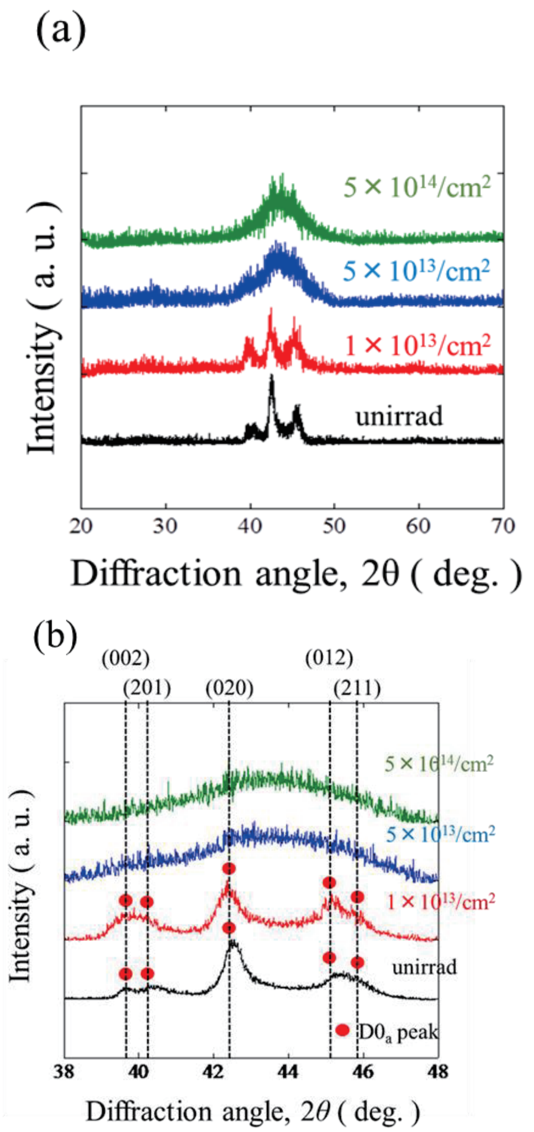

Fig. 2 (a) Surface x-ray diffraction spectra of the unirradiated and irradiated Ni_3Nb intermetallic compound (b) Surface x-ray diffraction spectra at the diffraction angles of 38° – 48°

Fig. 3 shows the Fourier transformed (FT) EXAFS spectra around Nb K absorption edge for the unirradiated and irradiated Ni_3Nb. The intensity of each peak decreases with an increase in ion fluence. This result implies that the atomic arrangement around Nb atoms is disordered by the irradiation.

Fig. 4 shows the Vickers hardness as a function of ion fluence. The hardness of Ni_3Nb intermetallic compound is increased by the irradiation-induced lattice structure transformation. This result corresponds to the conventional fact that the value of hardness for the amorphous state is larger than that for the crystal structure. Fig. 5 shows the Vickers hardness changes for Ni_3V, Ni_3Al and Ni_3Nb. For Ni_3V and Ni_3Al intermetallic compounds, Vickers hardness decreases with increasing ion fluence. The Burger's vector of the dislocation for the ordered tetragonal or $L1_2$ structure is larger than that for the disordered FCC structure. Therefore, the disordered FCC structure is more deformable than the ordered tetragonal or $L1_2$ structure. On the other hand, for Ni_3Nb the Vickers hardness increases with increasing ion fluence. As Ni_3Nb transforms from the ordered structure to the amorphous state, we cannot explain the hardness change by using the dislocation theory.

The present result implies that energetic ion irradiation can be used to control the surface hardness for Ni_3Nb intermetallic compound.

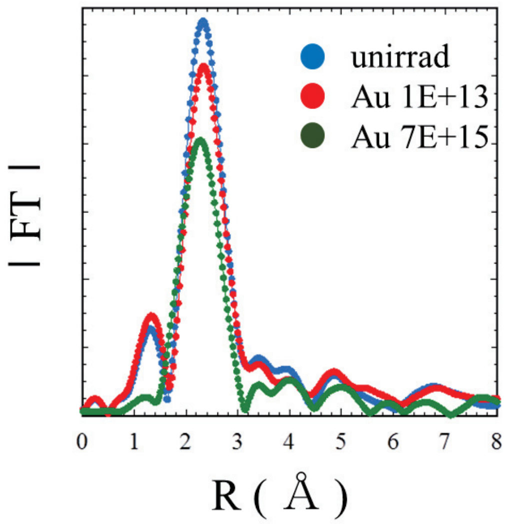

Fig. 3 FT EXAFS spectra around Nb K absorption edge for the unirradiated and irradiated specimens

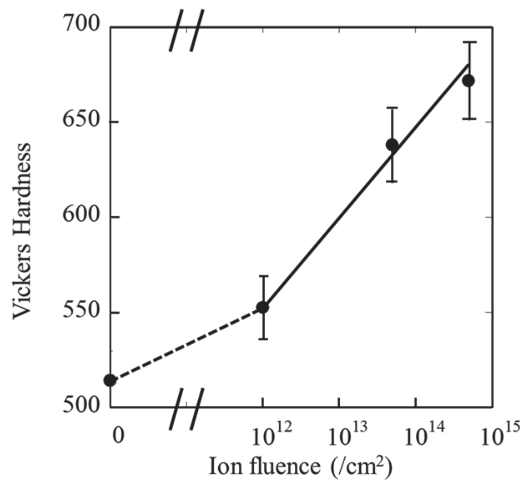

Fig. 4 Vickers hardness as a function of Au ion fluence

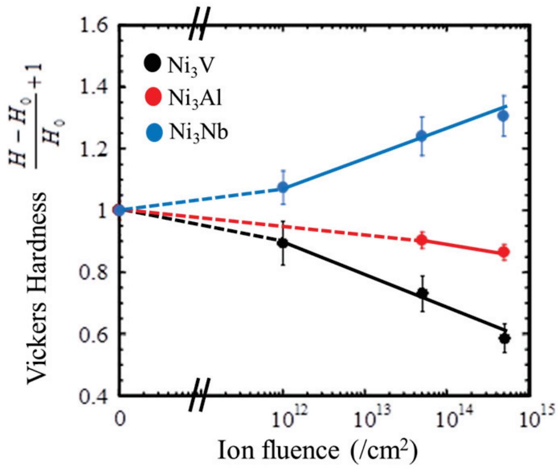

Fig. 5 Relative change in hardness for Ni_3Nb. For comparison, data for Ni_3Al and Ni_3V are also plotted.

To investigate the thermal stability of the amorphous state induced by ion irradiation for Ni_3Nb intermetallic compound, annealing experiments at elevated temperatures for some ion-irradiated Ni_3Nb specimens are now in progress.

References

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