INTERACTIONS BETWEEN ENERGETIC ION BEAMS AND SOLIDS AND THEIR APPLICATIONS

Kunio Ozawa

Physics Division, Japan Atomic Energy Research Institute
Tokai-mura, Ibaraki

A review on the recent studies and future program based on ion-solid interactions in JAERI is given. (1) Ion beam mixing in layered specimen (2) Ion irradiation effect on depth profile in metals. (3) Profiling and location of implanted atoms and (4) Hydrogen profiling using nuclear reactions are discussed.

Energetic ions can penetrate solid substance depositing their energy and especially in a crystalline solid, the incident ions can pass through along crystallographic planes and/or directions with less energy loss (channeling). These ions suffer from inelastic interaction with electrons and/or collide with atoms in the solid. In atomic collision, various processes are involved; (A) Incident ions are scattered with the characteristic energy and angle of Rutherford scattering. (B) Nuclear reactions can be caused for particular combination between incident ions and targets. (C) Many lattice atoms are displaced dynamically from their original sites, which causes mass transport of constituent atoms, and (D) ultimately the ions come to rest with leaving the significant damage in the crystal lattice.

Process (A) has been applied to analyze the structural change associated with the processes (C) and (D). The energetic ions with the energy of a few MeV range are reasonably assumed to make a single collision with atoms of substrate and to lose their energy through electronic process. Process (B) is also effective for detecting light elements in heavy matrix elements. Process (C) and (D) are expected to be dominant for heavy ions with rather lower energy of a few hundreds keV and play influential role on the property change by ion irradiation.

1. Ion beam mixing in layered specimen.

Study about the fundamental mechanism of metastable material formation by ion irradiation has been done using the process (C) [1]. The layered specimen were prepared by successive evaporation of metallic elements in vacuum. Mass transport associated with Ar^+ ion irradiation was studied in the Al base system. The mixing behaviour of element distribution was compared between miscible system (Ag in Al) and immiscible system (Sn in Al). The He^+ ion backscattering analysis employing the process (A) showed the existence of ion induced mass transport (ion beam mixing) by collisional cascades below some critical dose of Ar^+ ions in Al-Sn system in Fig. 1. The more effective mixing is expected to operate at the higher dose region. In the miscible Al-Ag system, Ag atoms are easily transported to the surface and sputtered away which causes asymmetrical distribution of Ag atoms with the sharp tail at near surface region. This mixing process was applied to the Cu base multi-layered system. Ion backscattering and electron diffraction analyses on these specimens suggest that the ion beam mixing is accomplished effectively in the miscible system and that the complete formation of solid solution is obtained in the Cu-Au system.

2. Ion irradiation effect on depth profile in metals.

In addition to the fundamental investigation described above, the fusion related studies have attracted our interests. The irradiation effect on hydrogens and/or those isotopes in metals, which is associated with the process (D), is one of our interesting themes. Deuterium atoms were introduced into V, Nb and Ta single crystals to the contents of 1 % thermally. The depth profiles for induced damage and deuterium concentration by He^+ ion irradiation were determined by the backscattering analysis combined with nuclear reactions (process(B)) and channeling phenomena. With increasing irradiation dose, the deuterium concentration near the surface of $VD_{0.01}$, $NbD_{0.01}$ and $TaD_{0.01}$ crystals is found to increase gradually. Both profiles for the induced damage and the increased deuterium concentration exhibit good correspondence, indicating trapping behaviour of deuterium atoms by the radiation induced defects. The deuterium concentration near the surface after irradiation is measured between room temperature and 100°C, and its reversible change was observed on heating and cooling runs. The binding energy is 0.11±0.02 eV, typically for $VD_{0.01}$ specimen [2].

3. Profiling and location of implanted atoms.

The process(D) is accompanied by the implantation effect of incident ions, and the surface erosion by the implanted rare gas ions has been one of the important themes in connection with the plasma-wall interaction in a thermo-nuclear fusion device. Most of the surface erosion studies have been done in the heavy metallic system implanted with light elements. Ne^+ ions were implanted to Nb single crystal, and the depth profiles of Ne atoms and induced damage were determined by the combined structural analysis of processes (A),(B) and channellings phenomena [3]. Implanted Ne atoms were detected using $^{20}Ne(p,\gamma)^{21}Na$ resonant nuclear reaction. In Fig. 2(a), the Ne profile change is observed with increasing Ne^+ ion dose. The rather simple depth profile of Ne atoms is converted to the more complicated one with fine structure with increasing Ne^+ dose to the dose just below the critical value for blistering. Fig. 2(b) shows He^+ ion irradiation effect on the Ne profile. He^+ ion irradiation makes the as-implanted profile (solid line) into broader and deeper one (dotted line) reflecting Ne trapping at lattice defects.

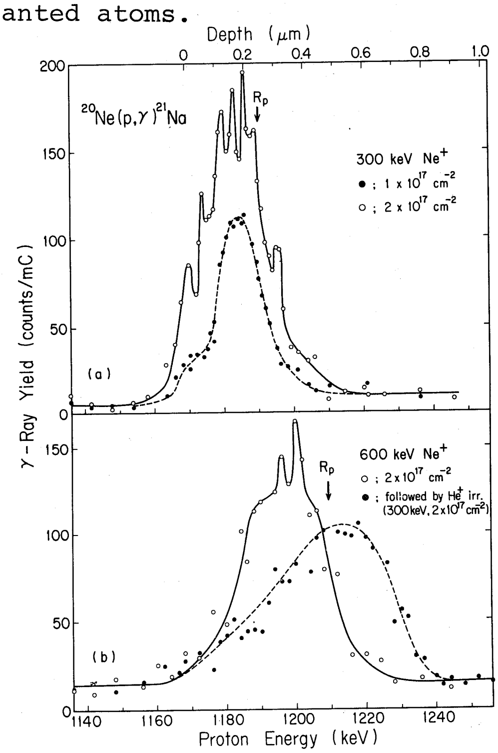

Fig. 2 Excited γ-ray yield as a function of incident proton energy over the 1169 keV resonance for ^{20}Ne nuclei implanted into a niobium single crystal. This γ-ray yield reflects the depth distribution of Ne atoms.

Channelling study showed that implanted Ne atoms occupy octahedral interstices in bcc Nb crystal lattice.

4. Hydrogen profiling using nuclear reactions.

We have studied about the behaviour of deuterium atoms in metals, and it has became possible to investigate the behaviour of hydrogen atoms using 20 MV tandem accelerator in JAERI. Hydrogen atoms react with ^{19}F ion by the nuclear reaction $H(^{19}F, \alpha\gamma)^{16}O$, $E\gamma$=6.1, 6.9, 7.1 MeV, Er=16.4 MeV. This reaction exhibits a strong resonance with a peak cross-section of 0.5 b. The hydrogen profiling is made with increasing the incident energy of ^{19}F ions. The off-resonance contributions to the γ-ray yield makes the hydrogen-profiling complicated, and correction for the off-resonance yield may be necessary. Moreover, for the elements of $z<5$, ^{19}F ion beam of 16 MeV has sufficient energy to overcome the Coulomb barrier, and allows nuclear reactions to occur. It must be necessary to take care in order to ascertain that γ-rays from other possible reactions are not interfering with γ-rays from $H(^{19}F, \alpha\gamma)^{16}O$ reactions.

[1] H. Naramoto, K. Ozawa, H. Yamaguchi, Y. Fujino and S. Yamaguchi, JAERI-memo 57-335 (1982)

[2] S. Yamaguchi, O. Yoshinari, J. Takahashi, Y. Fujino, K. Ozawa, H. Naramoto, M. Koiwa and M. Hirabayashi, Proceeding JIMIS-2, Hydrogen in Metals 249 (1980)

[3] H. Naramoto and K. Ozawa, Phys. Letters 83A 175 (1981)

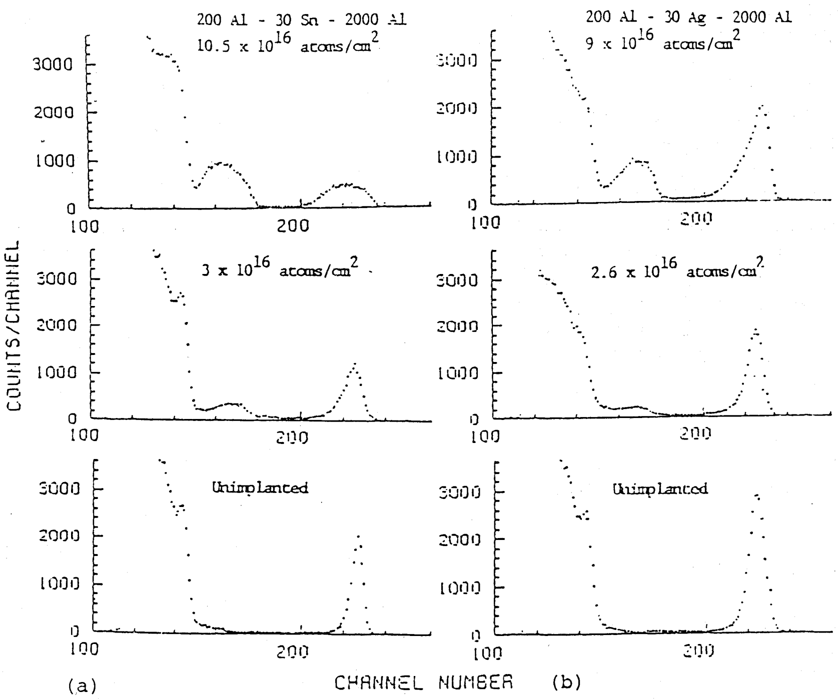

Fig. 1. Change of marker signals associated with 40 keV Ar^+ ion irradiation to Al base immisciable (a) and misciable (b) systems.