Dairaku, T., et al. *Studies of nuclear-reactions-in-solid in titanium deuteride under ion implantation.* in *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science*. 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press.

STUDIES OF NUCLEAR-REACTIONS-IN-SOLID IN TITUNIUM DEUTERIDE UNDER ION BEAM IMPLANTATION

T.Dairaku, Y.Katayama, T.Hayashi, Y.isobe, A.Takahashi

Department of Nuclear Engineering, Osaka-University, 2-1, yamadaoka Suita, Osaka, Japan

ABSTRACT

In order to find the signature of multi-body fusion, experiments of ion-beam implantation were carried out using titanium deuteride target made by the gas-loading method. Up to now, charged particles that are not known in the ordinary beam-target interaction have been observed in the experiment.[1,2,7]

1. INTRODUCTION

A multi-body fusion model in metal deuteride (especially PdD_x and TiD_x) has been proposed to explain anomalous results that have been reported in cold fusion studies. The model assumes that in lattice dynamic conditions, where plasma oscillation and vibrations of deuterium atoms trapped in metal lattice are excited coherently, there is possibility that multi-body fusion rates are enhanced drastically compared with random processes. In this model there are two important points as follows:

1. Deuterium atoms trapped in metal lattice make well-regulated array symmetrically in metal solid.
2. Free electrons, which screen the Coulomb potential wall in nuclear fusion process, can exist.[3,4]

Under these conditions, by ion-beam implantation to metal deuteride, coherent motion of deuterons in metal is thought to be induced at the end of the beam scanning range or deeper and multi-body fusion is taken place.[5] The possible channels of the three-body fusion are assumed as follows:

$$D+D+D \rightarrow {}^{6}Li^*(25.32MeV) \rightarrow d(15.9MeV) + {}^{4}He(7.90MeV) \text{------(a)}$$
$$\rightarrow t(4.75MeV) + {}^{3}He(4.75MeV) \text{------(b)}$$
$$\rightarrow n + p + {}^{4}He + 20.1MeV \text{------(c)}$$

$$H+D+D \rightarrow {}^{5}Li^*(21.88MeV) \rightarrow p(19.1MeV) + {}^{4}He(4.77MeV) \text{------(d)}$$
$$\rightarrow d(3.30MeV) + {}^{3}He(2.20MeV) \text{------(e)}$$

We have tried to detect charged particles emitted form these channels using silicon surface barrier detectors (SSBD) and titanium deuteride target (TiD_x). To inspect a reaction channel (b), two kinds of experiments were carried out under deuteron beam bombardment to TiD_x. The one is experiment using a ΔE-E counter telescope, the other is measurement with reducing pileup signals of D-D reactions. Before these two experiments, we could not search the unique charged particle spectrum exactly because of pileup signals of D-D reactions. In proton beam experiment, high energetic protons having 17-20MeV emitted kinetic energy that might suggest channel (d) have been detected with high reproducibility. To investigate whether multi-body fusion includes incident particles (direct multi-body fusion) or not (indirect multi-body fusion), we tried an experiment to irradiate TiD_x target with Si-beam. We observed an isolated peak at about 3.6MeV, which was supposed to be response of triton by channel (b).

2. DEUTERON BEAM EXPERIMENT

Fig. 1 shows the charged particle spectrum emitted from TiD_x irradiated by 300keV-deuteron. Two unique charged particles were observed. They are supposed to be ^3He (4.75MeV) and t (4.75MeV) emitted by 3D fusion. However, the yield of them couldn't be evaluated precisely because the responses of ^3He (4.75MeV) were on the shoulder of D-D protons and the responses of t (4.75MeV) were on the pileup signals of D-D protons. To inspect ^3He (4.75MeV), experiment using a ΔE-E counter telescope was performed. Helium-3 by 3D fusion stops in the ΔE detector and doesn't reach to E detector. Fig.2 shows the charged particle spectra of ΔE (upper Fig.) and E (lower Fig.) respectively. The peak measured at about 3.5MeV in spectrum of the ΔE detector was assigned to be ^3He counts by 3D fusion. The ratio of the yield of ^3He to that of D-D proton was about $2.2*10^{-4}$.

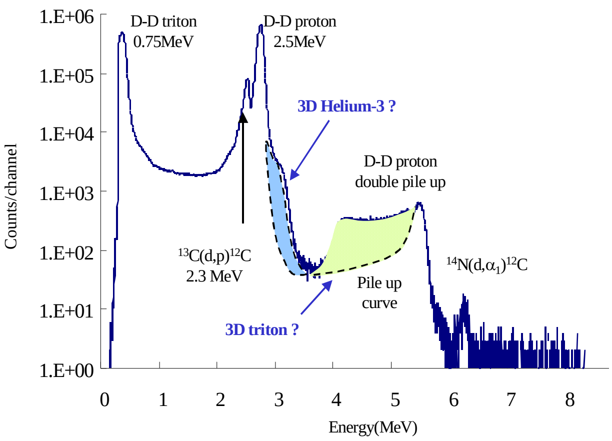

Fig.1 Charged particle spectrum measured with Ek-detector under 300keV deuteron beam irradiation to TiDx

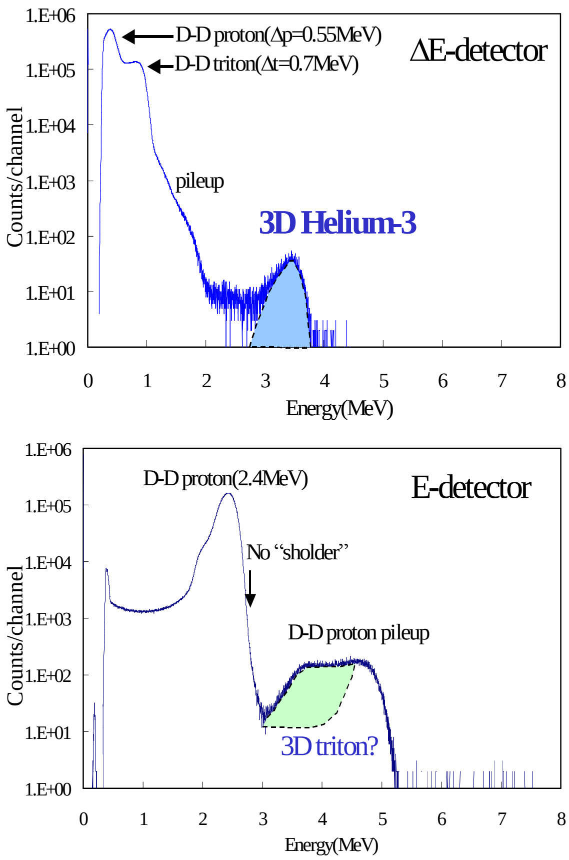

Fig. 2 charged particle spectra observed by ΔE and E detector emitted from TiD_x implanted 300keV deuteron beam

In order to estimate the triton by 3D fusion, a reduction technique of pileup signals of D-D reactions was applied to experiments of deuteron beam implantation. The rise time of pileup signals is longer than single event signal. Then, we can discriminate between pileup signals and normal signal by difference of rise times. The spectra shown in Fig. 3 were obtained under the implantation of 300keV deuteron beam to TiD_x sample. Charged particle spectra with pileup reduction and without pileup reduction are compared. The spectra were greatly improved by the reduction technique for pileup signals. Pileup signals of D-D reactions were fully decreased in the range above 3.5MeV. Especially the peak of alpha-particle by $^{14}N(d, \alpha)^{12}C$ reaction could be confirmed clearly at about 6MeV. The signals in the range of 4-5MeV are supposed to be the responses of triton (4.75MeV) by 3D reactions. The ratio of the yield of triton by 3D fusion to that of D-D proton was about $2.1*10^{-4}$, which agreed with the yield of ^{3}He estimated with ΔE-E counter telescope. It was reported that the reaction rate ratio (R_{3D}/R_{2D}) between two-deuterons (D+D) and three-deuteron (D+D+D) fusions was about 10^{-30} [6], which was a typical value for cascade reactions in random theory.[6,7] Therefore, these two experiments suggest that 3D multi-body fusion rate (R_{3D}/R_{2D}~$2*10^{-4}$) would be greatly enhanced by 10^{26} times referred to the random theory rate 10^{-30}.

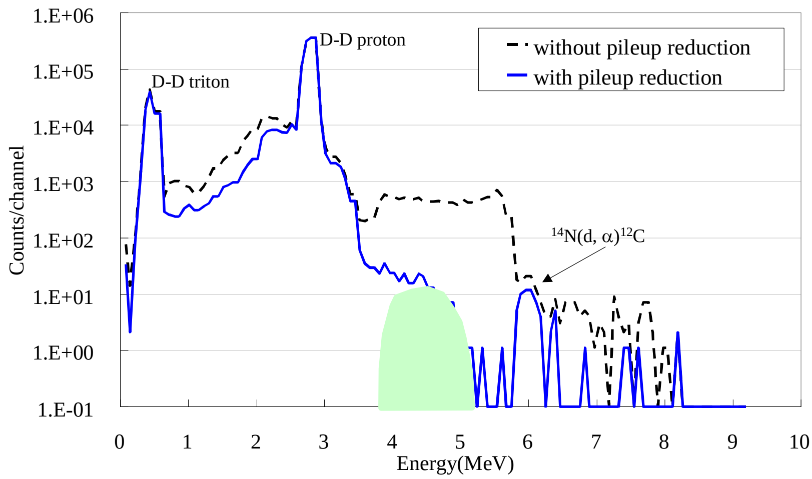

Fig. 3 Charged particle spectra emitted from TiD_x implanted with 300keV-deuteron beam

3. PROTON BEAM EXPERIMENT

We have measured anomalous high energetic charged particles with SSBD set up at the back side of the target during proton beam irradiation to TiD_x. Since the thickness of the target was 1mm, no charged particles emitted by impurity reactions and normal D-D reaction could reach to the detector. However, protons emitted by multi-body fusion have enough energy to reach to the detector after penetrating through the target and the absorbing foil set up to reject the scattering particles in front of the SSBD. In order to identify these high energetic charged particles, we changed the thickness of absorbing foils (Al-410μm, Al-450μm). Fig.4 shows energy spectra obtained under 300keV proton beam implantation to TiD_x with two different absorbing foils (upper fig aluminum-410μm), (lower fig aluminium-450μm). The difference between these two spectra indicates that high energetic charged particle on

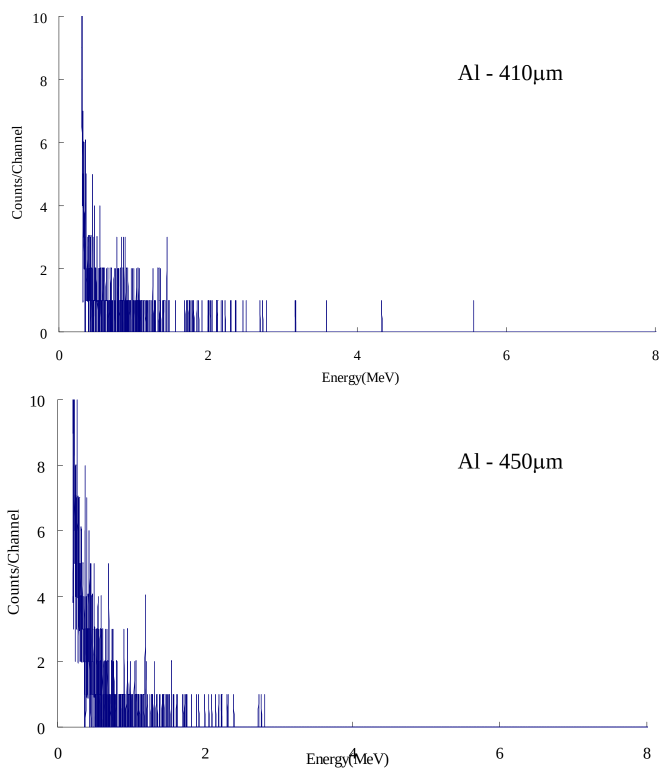

Fig.4 Charged-particle spectrum emitted from TiDx sample impinged by 300keV-proton

the fig. 4 were of protons emitted with initial kinetic energy of 17~19MeV, considering stopping powers in the material for different particles. It has been reported that a possible branch of the multi-body fusion; H+D+D→ p+α+23.8MeV, can emit protons with 19.1MeV. Therefore, this result suggests that multi-body reactions were taken place in TiD_x under bombardment with protons.

4. SOLICONE BEAM EXPERIMENT

It is difficult to know whether multi-body fusion includes an incident particle (direct multi-body fusion). Therefore, in order to search the possibility of indirect multi-body fusion, emitted charged particles were measured during 4MeV-Si^{3+} beam implantation to TiD_x (fig.5). We observed small isolated counts around 3.5MeV. In this experimental system, the response beyond the energy of the cascade D-D proton could not be explained with conventional two-body nuclear reactions under the beam-target interactions. Considering the energy losses of charged particles within the thickness of screening foil (Al-5μm), it was possible to say that the responses around 3.5MeV were of charged particles emitted by multi-body reaction; D+D+D→ t(4.75MeV) + ^{3}He(4.75MeV). Although the perfect identification of the responses was not possible because of the statistical problem, the possibility of indirect multi-body fusion was shown in this result.

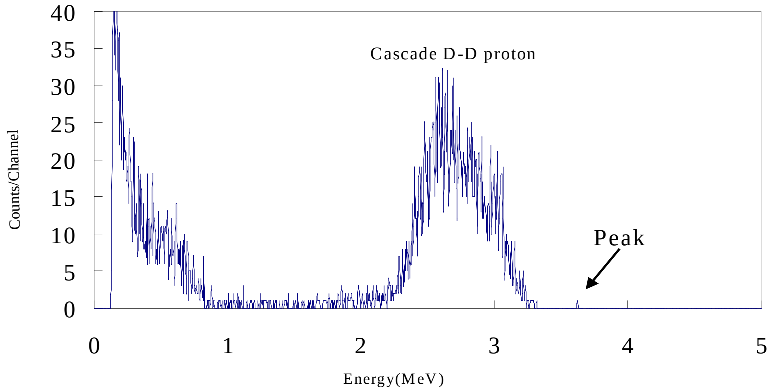

Fig.5 Charged-particle spectrum emitted from TiDx sample bombarded with 4MeV-Si^{3+}

5. DISCUSSIONS AND CONCLUSIONS

We have found that the 3D multi-body fusion rate has been greatly enhanced in highly deuterated titanium, by stimulating it with deuteron beam. In the proton beam experiment, we have succeeded in obtaining high energetic protons with high reproducibility, which were thought to suggest the multi-body fusion. Some unknown responses were measured around 3.5MeV during Si^{3+} beam implantation to TiD_x. The investigation of the measurement may be needed to identify these responses, for example, by applying the ΔE-E counter telescope with extremely thin ΔE (~10μm).

Three experimentally obtained results discussed in this paper can be explained with multi-body fusion induced with stimulating highly deuteron-preloaded titanium target.

REFERENCES

[1] A. Takahashi et al.: Fusion Technology, 34(1998)
[2] A. Takahashi et al.: Physics Letters A225(1999) pp.89-97
[3] A. Takahashi et al.: Fusion Technology, 19(1991) pp.380-390
[4] A. Takahashi et al.: Fusion Technology, 27(1995) pp.71-85
[5] K. Ochiai et al.: Fusion Technology, 36(1999) pp.315-323
[6] A. Takahashi et al.: Anomalous Enhancement of Three-Body Deuteron Fusion in Titanium-Deuteride with Low-Energy D^+ Beam Implantation, Fusion Technology, 34(1998) pp.256-272
[7] Y.Isobe et al.: Jpn.J.Appl.phys.Vol.41 (2002) pp.1546-1556