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SEARCH FOR COHERENT DEUTERON FUSION BY BEAM AND ELECTROLYSIS EXPERIMENTS

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[Abstract] Procedures and results of three kinds of experiments i.e., closed type D_2O/Pd electrolysis, electron beam irradiation and ion-beam bombardment on titanium-deuteride (TiDx) have been introduced in this paper. In the electrolysis experiment, upper gas of the electrolysis cell was analyzed using a Quadrupole Mass Analysis System (Q-MAS). Significant amount of helium-4 was detected without neutron emission in several experiments and in one of these experiments, the amount of helium-4 atom in the released gas from the palladium cathode was $8.1\text{x}10^{16}$ atoms. Under electron beam irradiation to highly D-loaded palladium, anomalous spectra were taken in X-ray measurement. In the experiments using deuteron beam and TiDx, responses which suggested 3D multi-body fusion were taken and the reaction rate of which was increased compared to the D(d,p)T reaction rate, below 100 keV. This result may reflect the coherent effect of the solid state in the reactions. From the results of the experiments using proton beam and TiDx, peaks which suggested 3D multi-body reaction were detected with high reproducibility. Moreover, high energetic protons having 17-20 MeV emitted kinetic energy which suggested H-D-D three-body coherent fusion were also detected.

1. Introduction

In lattice dynamic conditions, where plasma oscillation and/or vibrations of deuterium atoms trapped in metal lattice are excited coherently, there is possibility that anomalous nuclear reactions are enhanced drastically compared with random processes, with consideration of the following points:

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

Some kinds of researches have been performed in our group to induce these reactions and to detect the phenomena. [3-5] In this paper, three kinds of experimental researches, namely closed type D_2O/Pd electrolysis, electron beam irradiations to metal-deuteride and ion-beam bombardment on titanium-deuteride (TiDx) are presented. Detection of ^{4}He atoms accumulated during electrolysis and on-line detection of neutron emission in correlation with heat generation have been tried in the closed type electrolysis experiments. Under electron irradiation on highly D-loaded metals, measurements of charged particles and X-rays associated with coherently induced deuteron fusion have been tried. In ion beam experiments, peaks that might suggest the occurrence of coherently induced multi-body deuteron fusion have been detected with high reproducibility.

Existence of non D-D type nuclear reactions i.e., coherently induced deuteron fusion in lattice dynamics condition, will be recognized by the results of present three kinds of experiments, as explained in the following.

2. Closed Type D_2O/Pd Electrolysis Experiment

On-line measurements of correlation between time-variation of D/Pd ratios, excess power (by mass flow calorimetry) and neutrons (measured by NE213 scintillation counter) and off-line quantitative measurements of ^{4}He atoms accumulated in the cell and the cathodes during electrolysis (by Q-MAS; Quadrupole Mass Analysis System) have been performed using a closed type D_2O/Pd electrolysis system.[4] The upper-cell gas was sent to the Q-MAS after the electrolysis. In addition, the electrolyzed palladium cathode was heated up and released gas from the cathode was also analyzed because it was considerable that ^{4}He generated during electrolysis was trapped in the cathode palladium. By using an improved Q-MAS with a sorption pump for collection of deuterium and hydrogen, quantitative analysis was possible. Results are summarized in Table 1. In three out of seven data, meaningful increase of ^{4}He was recognized. The increased number of ^{4}He atom in the upper-cell gas during electrolysis in exp. 4-7 is summarized in Table 2. In exp. 4, significant increase of ^{4}He was detected (40 times). This result cannot be explained by contamination of air, because much (about 10 Torr of) air-leakage during electrolysis was necessary if the result is assumed to be contamination of air. In this run, ^{4}He atom was detected clearly also in the released gas analysis: 8.1×10^{16} atoms. Considering no ^{4}He atom was detected before the heating up of the cathode and the heating up analysis was completed in few minutes, detected ^{4}He atoms must be released from the cathode. Slight amount of ^{4}He atom (10^{14}-10^{15} atoms) was detected in exp. 2 and exp. 3 in the released gas analysis. No meaningful amount of neutron exceeding the confidence level ($+3\sigma \sim 19.5$ counts per hour) was detected through this series of experiments. Unfortunately neutron measurement was not performed in exp. 4, but by the results of the other runs, it seems that there is no clear correlation between the ^{4}He generation and the neutron emission. In exp. 3, slight amount of heat generation was detected according with increase of D-loading ratio. The excess power was about 2 W for 60 W input and continued for 130 hours. In the other runs, clear heat generation was not detected.

Table 1: Results of the closed type electrolysis experiments

			^{4}He detection		
Exp. No.	Pd-cathode treatment	Current mode 1)	Upper-cell gas	Released gas 2)	Neutron
1	Annealed	S.U, L.H	No	No	No
2	Anneal + Ti coating	S.U, L.H	Yes (?)	Yes	No
3	Annealed	S.U, L.H	Yes (?)	Yes	No
4	Anneal + Au coating	S.U, L.H, S.T, Co.	Yes	Yes	--
5	Anneal + Au coating	S.U, L.H, Co.	Yes (?)	No	--
6	Anneal + Au coating	S.U, L.H, S.T	No	No	--
7	Anneal + Au coating	S.U, L.H	Yes (?)	No	No

1) S.U: Step up mode
L.H: Low high mode
S.T: Saw teeth mode
Co.: Constant current mode
2) Analysis of released gas by heating up electrolyzed cathode Pd.

Table 2: The number of 4He atoms detected in the upper-cell gas

	Exp. No.			
	4	5	6	7
No. of ^{4}He before electrolysis	1.1×10^{15}	1.1×10^{15}	1.1×10^{15}	1.1×10^{15}
No. of ^{4}He after electrolysis	4.7×10^{16}	4.4×10^{15}	1.7×10^{15}	3.3×10^{15}
Difference	4.6×10^{16}	3.3×10^{14}	6.3×10^{14}	2.2×10^{15}

3. Electron Beam Stimulation Experiments

Figure 1 shows the experimental setup. Two SSBDs for charged particle and two CdTe detectors for X-rays were attached to a vacuum chamber keeping about 10^6 Pa. By using two detectors having the same ability and shape, detected signals could be crosschecked. Electron beam was produced by an electron gun, of which energy could be changed continuously from 100 eV to 3 keV, beam current was about 3.5 µA, and beam diameter was about 1mm on target. Pre-D-loaded Ti (TiDx: x~1.5, by gas loading method) or Pd (PdDx: x~0.7, by electrolysis method) was used as a target. Surface of PdDx was coated with cupper layer (~ 0.05 µm) by electroplating method after D-loading by electrolysis method (150 mA/cm^2, 8 hour) for making blocking-layer to prevent loaded deuterium releasing out. Figure 2 shows energy spectra measured with twin CdTe detectors under electron beam irradiation to PdDx. Bumps from 10 keV to 20 keV are recognized in the both of spectra and counts above 20 keV very increased comparing with background (see Table 3). Since electron beam energy was 3 keV, energy of X-rays by slowing down of the electron beam must not exceed 3 keV. These spectra were not detected in other runs, using Ti or TiDx as a target. Considering that similar spectra were detected by both detectors, these spectra cannot be explained by detectors' malfunction. If these phenomena are due to electromagnetic noise, increase of counts would be detected also in energy spectra by SSBDs, however, no such signals were detected in this run. Therefore, there is every possibility that these spectra are due to a tail of a Compton continuum or a continuous X-rays by slowing down of high energetic charged particles. After this run, a lithium drifted silicon detector Si (Li) and a HP-Ge detector were set up for low energy X-ray analysis and for γ-rays, respectively. Further experiments are necessary to investigate the origin of these responses.

Table 3: Comparison of foreground count ratio (cps) with background

	CdTe_1		CdTe_2	
	10keV- 20keV	20 keV- 60 keV	10 keV- 20 keV	20 keV- 60 keV
Background	6.6E-3*)	2.5E-2	5.4E-3	2.8E-2
Foreground	1.7E-1	1.3E-1	1.2E-1	1.4E-1
Ratio (fore/back)	26	5.2	22	5.0

*) counts per second (cps)

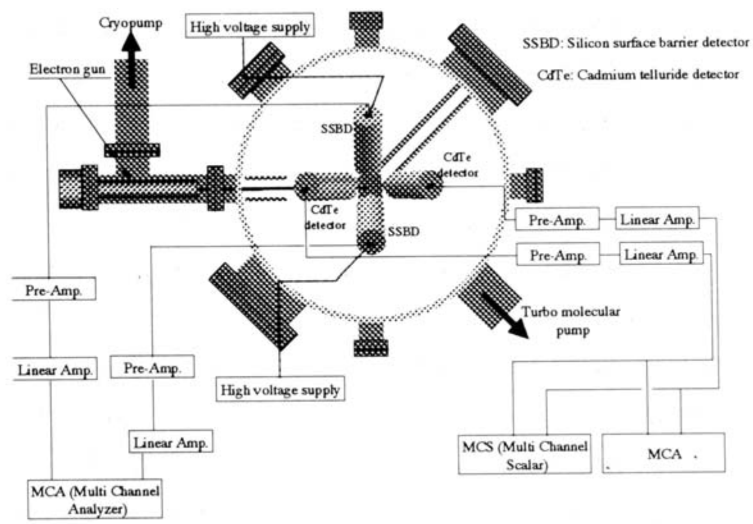

Fig. 1: Schematic view of the experimental setup

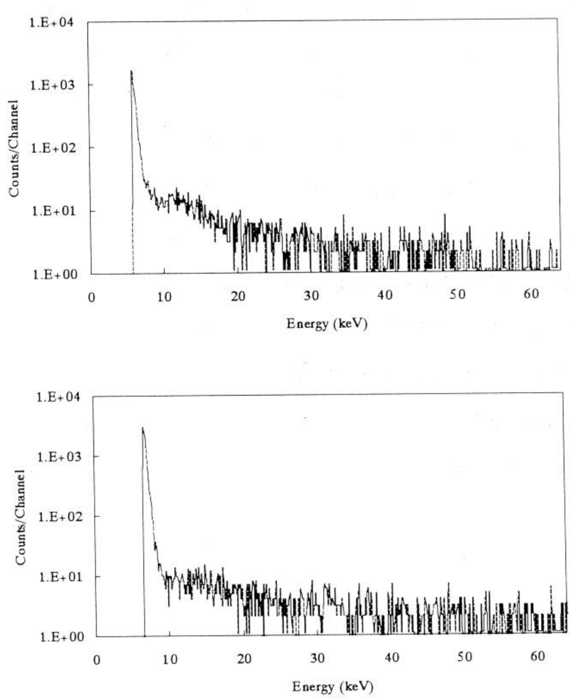

Fig. 2: Energy spectrum measured with CdTe detectors under electron beam irradiation Beam current, energy: 0.5 μA, 3 keV Measurement time: 5000 sec.

4. Ion Beam Experiment

4-1. Deuteron Beam Experiment

Charged particles emitted from the TiDx were measured with silicon surface barrier detectors (SSBDs) under deuteron beam bombardment. For identification of the detected charged particles, ΔE&E-counter-telescope which consisted of a thin transmission type detector (ΔE-detector) and a conventional SSBD (E-detector) was used. For the measurement of the total energy of each particle, one more conventional SSBD (Ek-detector) was also set up. Figure 3 shows energy spectra measured with Ek-detector under deuteron beam irradiation to TiDx. Two strange shoulders which obviously differ from the double pile-up responses are recognized between the peak of the D(d,p)T reaction and the double pile-up 5T peak of the D(d,p)T. Looking over the energy spectra •§ measured with ΔE&E-counter-telescope and/or results of JT experiments with changing the thickness of Al screen foil set in front of the detectors, it was concluded that lower energy shoulder (at 3.4 MeV) is a responses of ^{3}He and the other shoulder is of triton (at 4.3 MeV). These particle conceived to be produced by the 3D multi-body fusion; 3D → t (4.75 MeV) + ^{3}He (4.75 MeV), at deeper place in the target. Considering the energy loss value of each particle (1.4 MeV for ^{3}He and 0.5 MeV for t), the depth where the 3D reaction was induced was estimated to be 3μm-5μm. Scanning range of deuteron beam in Tt is about 2μm, so the reaction was occurred at the end of the beam scanning range or deeper. [6-8] In addition, the yield ratio; [Yield of the ^{3}He]/[Yield of the proton by D(d,p)T reaction], showed a tendency to increase at lower beam energy (see Fig. 4). In general beam/target interaction at low energy, reaction cross-section decreases more than D-D reaction as incident beam energy decreases. Therefore, the detected 3D fusion is not direct interaction with the incident deuteron but may be indirect reactions under coherent effect in the far less energy than the beam. Namely we imagine warm or "cold" fusion.

In Fig. 3, there is a peak, called peak A, at lower energy side of d-d proton peak. This peak was recognized to be a response of proton and the energy of this peak agree with proton of the ^{12}C(d,p) ^{13}C reaction. However, by the fact of that if the peak is produced by the ^{12}C(d,p)^{13}C reaction, peak yield for 150 keV should be less than 1/10 of the observed yield considering the reaction cross-section and peak shape should be of sharp spike. The observed peak-A may include proton responses of anomalously enhanced "cold" D-D reaction process at deeper place in the target.

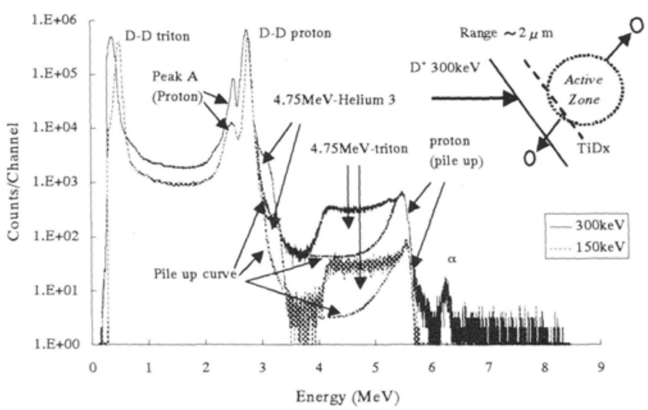

Fig. 3: Charged particle spectra measured with Ek-detector under deuteron beam irradiation to TiDx

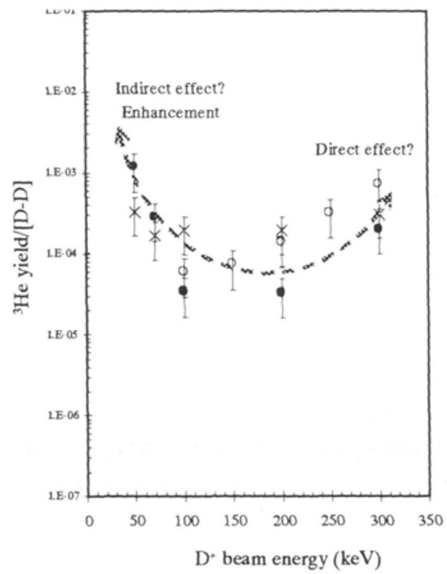

Fig. 4: Variation of the yield ratio, [^{3}He yield]/[D-D], by deuteron beam energy

4-2. Proton Beam Experiment

To investigate whether the indirect coherent deuteron fusion is induced by ion beam stimulation, measurements of charged particles were performed during the proton beam irradiation to TiDx. Figure 5 shows a charged particle spectrum which was taken during proton beam irradiation to TiDx. The peaks at 2.5 MeV and 2.8 MeV were recognized to be a-particles of the ^{15}N(p,α)^{12}C reaction and protons of the D-D reaction induced by recoil deuterons by incident proton beam, respectively. Peak around 4.3 MeV was a response of charged particle which was detected with high reproducibility. However, no reactions explaining this peak were found by looking into interactions with impurities. If multi-body deuteron fusion (3 D → t + ^{3}He + 9.5 MeV) was induced in the target at 3 μm - 5 μm depth, emitted triton may have about 4.5 MeV kinetic energy at the front of the detector, by the calculation. Since the partner particle, ^{3}He, should have about 3.3 MeV kinetic energy, the response might be covered by the continuum from 2.0 MeV to 3.5 MeV in Fig. 5. This explanation is consistent with the discussion for the results of the deuteron beam experiments. This result suggests that the incident beam played a role only for generating the condition in which the multi-body reactions were induced; multi-body D-reactions are not a direct beam/target interaction. Figure 6 shows a high energetic charged particle spectrum measured in the run using proton beam and TiDx. These signals were supposed to be responses of protons by the HDD reaction, i.e. H + D + D → p (19.1 MeV) + ^{4}He(4.77 MeV), because any other considerable emitted charged particles cannot penetrate through the thick screen foil (Ni: 600 μm thickness) set in front of the detector because of their large stopping power. Although these signals spread from 17.5 MeV to 18.2 MeV, protons having 19.1 MeV kinetic energy should have energetic deviation width of about 1.2 MeV after penetrating through a 600 μm thickness Ni sheet as a result of the struggling in materials. In the runs using pure Ti instead of TiDx as a target, these signals were not detected. A possible mechanism to explain the production of the HDD reaction is as follows: under the stimulation by ion beam irradiation, two deuterons approach each other closely in transient coherence and D-D pairs are produced transitionally, then, incident proton hits to induce H + D + D reaction.

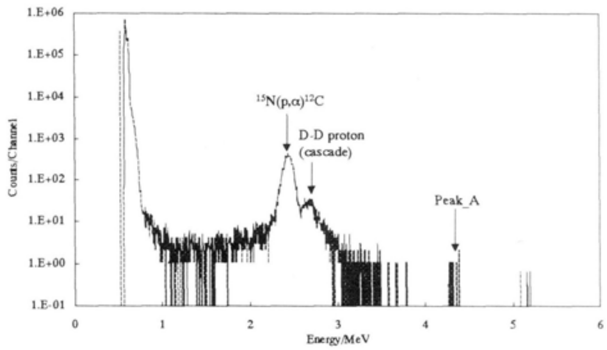

Fig. 5: Energy spectrum measured with Hk-detector under proton beam (300 keV) irradiation

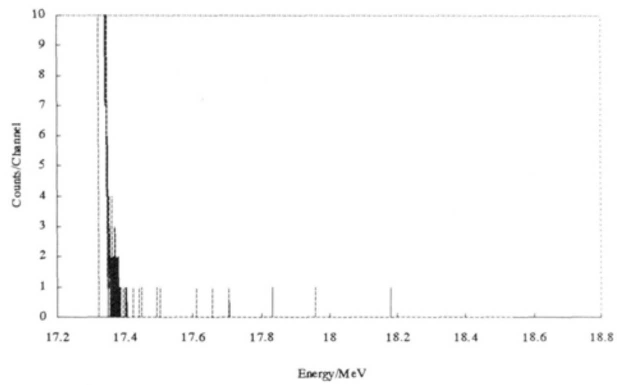

Fig. 6: High-energy charged particle spectrum measured under proton beam irradiation, with 600µm Ni-screen foil

5. Discussions and Conclusions

It seems that multi-body reactions (3D and 4D) are of key importance to explain the experimental results of the both electrolysis and beam experiments consistently. The outgoing channel of 3D and 4D reaction can be drawn as follows:

$3D \rightarrow {}^{6}Li^{*}$ (Ei = 25.3 MeV: 4^{-}) $\rightarrow {}^{6}Li^{*}$ (Ei = 2.18 MeV: 3^{+}) + photon emission (QED-photons)

$\hookrightarrow$ d (0.47 MeV) + ${}^{4}He$ (0.24 MeV) (1)

$\rightarrow$ t (4.75 MeV) + ${}^{3}He$ (4.75 MeV) (2)

$\rightarrow$ d (15.9 MeV) + ${}^{4}He$ (7.9 MeV) (3)

$\rightarrow$ n + p + ${}^{4}He$ + 20.1 MeV, (4)

$4D \rightarrow {}^{8}Be^{*}$ (Ei = 47.7 MeV: 3^{-}) $\rightarrow {}^{8}Be^{*}$ (Ei: I^{π}) + photon emission (QED-photons),

where permitted Ei and I^{π} pairs are (25.5 MeV: 4^{+}), (20.0 MeV: 2^{+}),

(16.6 MeV: 2^{+}) and (3.04 MeV: 2^{+}), and ${}^{8}Be^{*} \rightarrow \alpha + \alpha$ + Ei + 0.0918 MeV (5)

$\hookrightarrow {}^{8}Be^{*}$ (g.s.: 1^{+}) + photon emission (QED-photons), and ${}^{8}Be^{*} \rightarrow \alpha + \alpha$ + 0.0918 MeV . (6)

The detected charged particles in the ion beam experiments may be produced by the reaction (2). But this outgoing channel (2) is supposed to be a minor channel, considering the spin-parity selection rules. The main channels may be (1)(5) and (6). Results of the electrolysis experiments as "He-generation without neutron emissions can be explained by the reaction (1) and/or (6). There is a possibility that the detected signals under electron beam irradiation were bremsstrahlung X-rays by slowing down of those charged particles by the reaction (1), (5) and/or (6), all of which produce ${}^{4}He$ as the effectively same process as d + d $\rightarrow$ ${}^{4}He$ + 23.8 MeV.

These results of the three kinds of experiments can be explained with a common key of multi-body reactions induced with stimulating highly D-loaded metals (TiDx or PdDx). This reaction may be induced under lattice coherent motion in transitional process as suggested in the results of ion beam experiments. It is important task in future to search how these conditions can be realized much more strongly and to work out how 3D or 4D cluster can be made.

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