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Studies of d-d Reactions in Deuterated Palladium by Using Low-Energy Deuterium Ion Bombardment

Hiroyuki SHINOJIMA, Takashi NISHIOKA,
Koji SHIKANO, and Hiroshi KANBE

NTT Basic Research Laboratories
3-1 Morinosato-Wakamiya Atsugi-Shi,
Kanagawa 243-01 Japan

1. Abstract

The cross sections and branching ratios of d+d reactions were measured as a function of deuteron energy by using low-energy deuterium ion bombardment. The branching ratio of d(d,^{3}He)n to d(d,p)t were found to be one to one at energies from 2.5 keV to 20 keV in the CM frame. The reation rate of d(d,p)t at 2.5 keV was four orders of magunitude less than that at 20 keV. These energy dependences were good agreement with those extrapolated from measurements of the d+d reaction which was derived by the high-enegy (mega-electron-volts) deuterium ion bombardments.

2. Introduction

E. Yamaguchi and T. Nishioka detected ^{4}He from deuterated palladium metals by using an "in vacuo" method,[1] thus indicating the possibility of nuclear fusion reactions occurring in condensed matter. However, the mechanism of the ^{4}He production from palladium metals has not yet been clarified, because it is confirmed in the high-energy region of deuterons that two reactions, d(d,p)t and d(d,^{3}He)n, are dominant in d+d reactions, and that the branching ratio (ρ) of d(d,p)t to d(d,^{3}He)n was one to one. Futhermore, the reaction cross section of producing ^{4}He is theoretically (and has been experimentally confirmed to be) less than 10^{-7} of those for d(d, p)t and d(d,^{3}He)n in the energy range above a few tens of kilo-electron-volts. It is very important to study d+d reactios in the low-energy region less than a few tens of kilo-electron-volts to clarify the possibility of ^{4}He production from palladium metals. The energy dependences of ρ and the cross sections in the low-energy region have not been examined experimentally.

We therefore measured the deuteron energy dependence of the branching ratios (ρ) and of the reaction rates by bombarding deuterated palladium metals with deutrons.

3. Experiment

The target sample was prepared by using the same procedures used in the ^{4}He-detection experiments.[1] One side of the deuterated palladium plate was coated with a 10-nm-thick MnO_x film and the other side was coated with a 100-nm-thick Au film in order to reduce D_2-release from the sample in vacuum. The loading ratio (D/P_d) was about 0.65. The experimental setup is shown in Figure 1. We bombarded deuterated palladium plates with deuterium ions (D^+,D_2^+) accelerated by 5 to 40 kV. The beam currents of D^+ and D_2^+ were about 10 μA and 17 μA, respectively. The deuterium beam was bombarded on the MnO_x side, and the beam diameter at the sample position was 3 mm. Si-SSDs (solid states devices) and TPS-451S (Aloka Ltd.) were used for measuring charged particles and neutrons, respectively. The active thicknesses of the two SSDs were 300 μm and 100 μm, and the active area of each SSDs was 300 mm^2. The active area of the neutron detector was 20 cm^2. The conversion rate of the neutron detector was 5400 counts/μSV. The branching ratio (ρ), and the rates of d(d,p)t and d(d,^{3}He)n reactions were measured, as a function of the deuteron energy (E_d) in the CM frame, from 2.5 keV to 20 keV.

4. Results and Discussion

The energy spectrum of the charged particles detected during the deuteron bombardments at E_d=10 keV is shown in Fig. 2, and Figs. 3 and 4 show the energy dependence of the branching ratio obtained by comparing the proton and triton counts and by comparing the ^{3}He and netron counts, respectively. Each branching ratio was one to one throughout the deuteron energy range from 2.5 keV to 20 keV.

Figure 5 shows the energy dependence of the reaction rate (Γ_p (E_d)), which corresponds to the cross section ($\sigma_p(E_d)$) of d(d, p)t. This reaction rate Γ_p is propotional to the number of protons produced by d(d, p)t reaction at the incident deuteron flux of 1.0x10^7 counts/s, and at E_d=2.5 keV is four orders of magunitude less than that at E_d=20 keV. Note that this energy dependence can be achieved by the extrapolation of d+d reactions in the high-enegy region[2].

Figure 6 shows the deuteron energy dependence of d(d,^{3}He)n-reaction cross section. The cross section was estimated in the assumptions that the distribution and concentration of deuterons in the palladium metal were uniform and that all incident deuterons reacted in the region from the surface of the palldium to the deuteron penetration-depth at the energy. The cross section at E_d=5 keV is two orders of magunitude less than that at E_d=20 keV. This energy dependence of d(d,^{3}He)n cross section corresponded to the energy dependence of Γ_p .

Open circles and open triangles shows the experimental results obtained by using D^+ and D_2^+ beam, respectively in Fig. 3, 4, 5, 6. There was no difference between the experimental results for D^+ and D_2^+ bombardment if the incident deuteron energy was identical. The cluster effect,[3] so-called "cluster impact fusion," related to the bombardment of D_2^+ was not observed in the present work.

In conclusion, we investigated the d+d reaction driven by the deuteron bombardments with ion currents of a few tens of microamperes in the deuteron energy range above 2.5 keV. The cross sections and branching ratios of the fusion reaction did not differ from the values extrapolated from higher-energy bombardments. The new nuclear phenomena observed in condensed matter, however, remain to be studied.[4,5] We have to continue investigating d+d reactions in dense matter in the low-energy region (E_d < 2.5 keV). Accompanying high-resolution/high-sensitivity detection of ^{4}He/neutrons will give futher information on these reactions.

References

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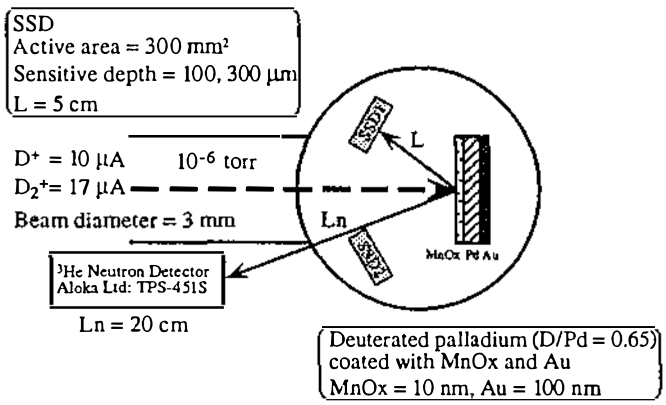

Figure 1. Experimental setup.

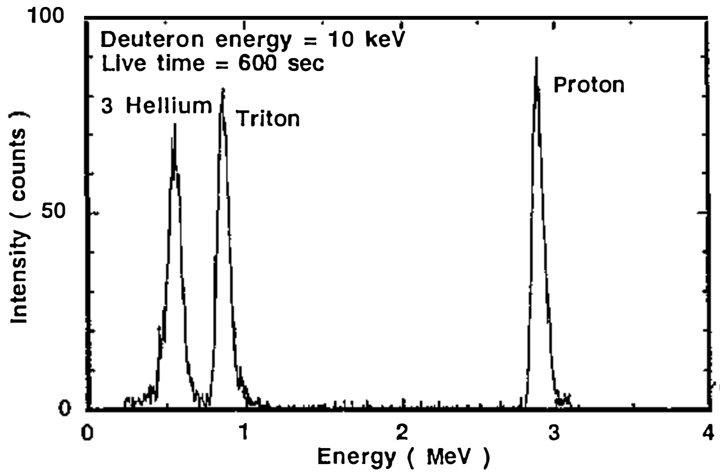

Figure 2. Energy spectrum in d+d reactions.

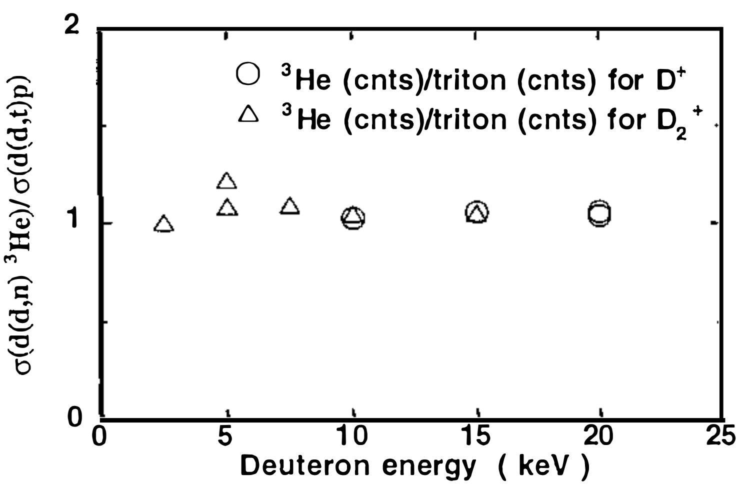

Figure 3. Energy dependence of the branching ratio obtained from proton and tritoncounts.

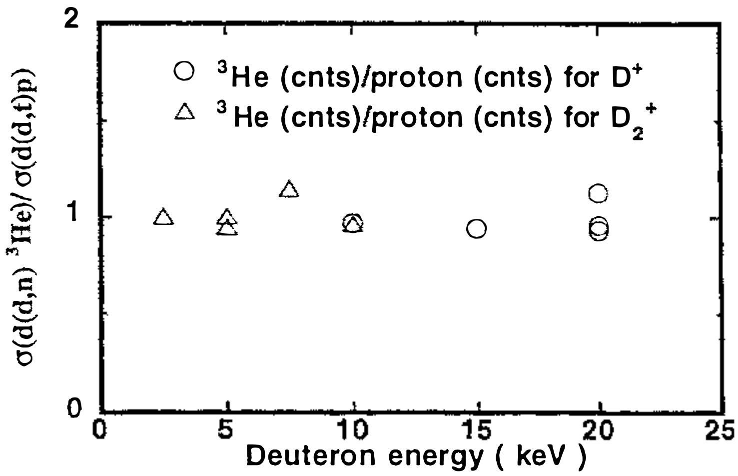

Figure 4. Energy dependence of the branching ratio obtained from ^{3}He and neutron counts.

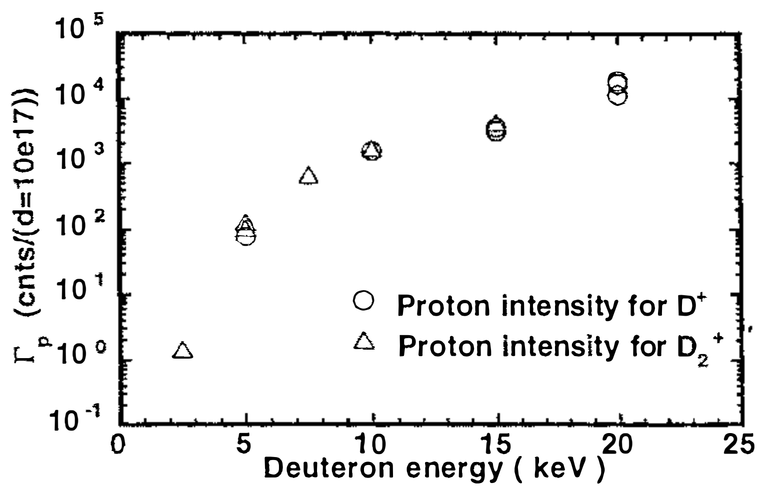

Figure 5. Energy dependence of the reaction rate Γ_p.

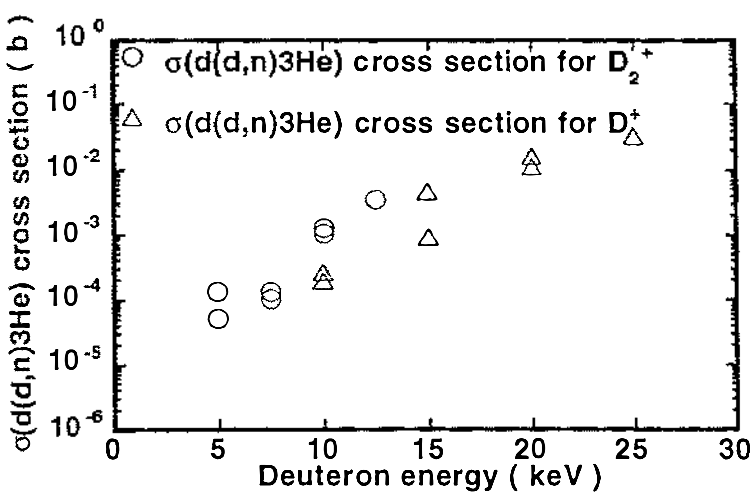

Figure 6. Energy dependence of the cross section.