Neutron emission in the D+D fusion in cooled Palladium at 100 keV bombarding energy

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Introduction

D+D and D+T reactions are among the nuclear processes responsible for the production of light elements in nucleosynthesis [1,2]. Understanding of nuclear fusion reaction rates of these reactions are essential for the development of neutron sources, fusion-fission hybrid systems and for the advancement of nuclear technologies for controlled fusion [2]. Though bare D+D reaction is very well studied and established, large enhancement of the reaction yields observed for this nuclear reaction proceeding in a number of metallic targets in several recent experiments have evoked considerable attention worldwide [3]. Though the Coulomb barrier for pure D + D fusion is ∼200 keV, detectable reaction rate may occur even at much lower kinetic energies ∼10 − 15 keV if there is enhancement of fusion due to Coulomb screening. Further, the host material temperature dependence of the enhancement factor for the D + D reaction is also an important topic being investigated recently [4].

Experimental setup

Experiments were performed using the 100 keV D^+ -ions provided by the ECR source at the Bhabha Atomic Research Centre, Mumbai. The target assembly (Fig. 1) consisted of a solid copper rod (cold finger) of ∼25 cm length and a diameter of ∼2 cm with one end connected to a LN_2 cryocan. The other end of the cold finger was attached to a very thin copper disc through a thermo-conducting electrically insulating paste. The Palladium foil, which has a surface area ∼1 cm^2 (1 cm × 1 cm) and thickness of 2.5 μm was pasted onto the copper disc using conducting silver paste. A resistance temperature detector (PT-100) was mounted on the copper disc to measure the temperature of the target region online. Provision was also made on the target to read the beam current.

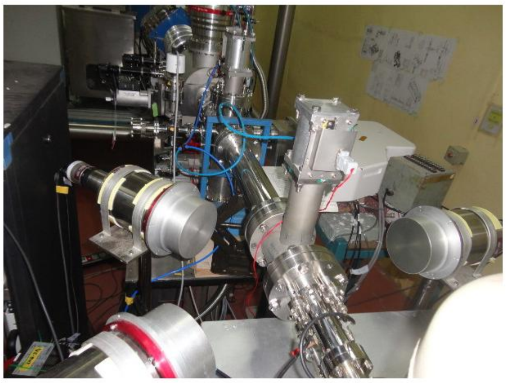

Fig. 1. Photograph of the experimental setup.

The entire target assembly was attached to the beam tube and was operated under high vacuum better than 1 × 10^{-6} mbar. The neutron detector setup consisted of 3 liquid scintillator detectors (each 5” × 2”) mounted at a distance of ∼ 30 cm from the target (Fig.1). Each of the neutron detectors, was calibrated using the standard gamma sources ^{137}Cs and ^{22}Na. The threshold for all the three detectors were kept around 52.6 keVee (D1), 72.7 keVee (D2) and 70.6 keVee (D3), respectively. The intrinsic efficiency of the detectors were found to be around 42%, 40% and 40%, respectively, for the three detectors for 2.45 MeV neutrons.

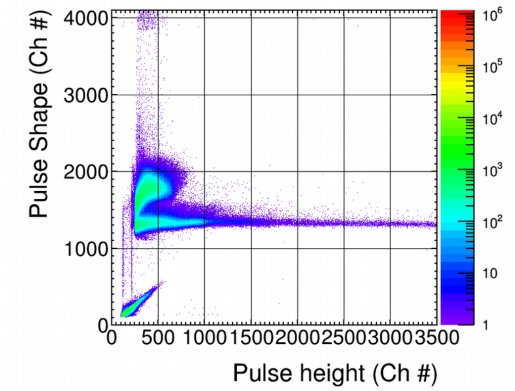

Fig. 2. The 2D plots of Pulse Shape vs Pulse Height for for the D + D reaction.

Deuterium ions accelerated to 100 keV by the ECR source were made to fall on the target. The beam current was kept around 5 μA and average temperature of the target was ∼−76° C during the experiment. The neutron rates along with the beam current were monitored on-line as well as recorded in list mode using a VME based DAQ system. All three neutron detector signals and the current integrator signal were OR − ed to provide the master trigger for acquisition system. The data were collected till the total number of implanted ions exceeded 3.5×10^{18}. A typical 2D graph of Pulse Shape vs Pulse Height for D+D reaction at 100 keV is shown in Fig. 2 .

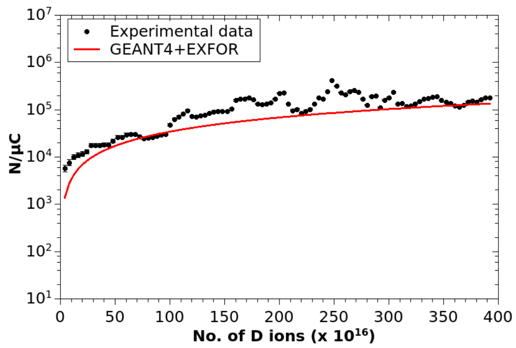

Fig 3. N/μC as a function of total implanted D^+ ions along with simulated results.

Figure 3 shows the experimental data of N/μC as a function of total implanted ions. The total number of neutrons emitted were obtained after correcting for the efficiency and the solid angle of the corresponding detectors. As can be seen from the figure, the N/μC shows a smooth rise in the initial stages of the implantation up to $\sim 20 \times 10^{16}$ D^+ ions, but large deviations and oscillations start occurring as the implanted ion number increases further. It should also be noted that the deviation observed are way beyond the statistical fluctuations. Preliminary simulations based on GEANT4 incorporating EXFOR cross section for bare D+D reaction are also shown in Fig. 3.

In summary, 2.45 MeV neutrons emitted in D+D fusion reaction occuring in a cooled Palladium foil were measured as a function of implanted D^+ ions. The N/μC as a function of total implanted D^+ ions showed distinct oscillatory behaviour as opposed to the smooth trend seen in the calculations. This may be attributed to the microscopic effects due to screening in metal lattice at high d/Pd ratios. We are planning more measurements in order to generalize the present observations for a detail understanding of the role of Pd matrix for the observed oscillatory neutron emission pattern.

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References

[1] R.G.Pizzone et al.,Astrophys. J., 786 (2014), p. 112

[2] P. R. Goncharov, Atomic Data and Nuclear Data Tables, 120 (2017) 121-151.

[3] F. M. Prados-Estevez et al., Nucl. Inst. and Meths. in Phys. Res. B, 407 (2017) 67-72.

[4] V. M. Bystritsky et al., Physics of Atomic Nuclei, 75 (2012) No. 8, 913-922.