# Development of Thin Solid HD Target for Polarized Nuclear Laser Fusion Study: III

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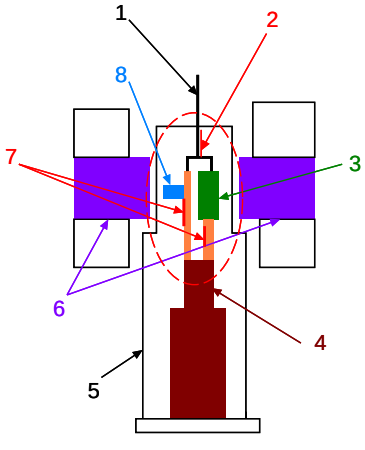
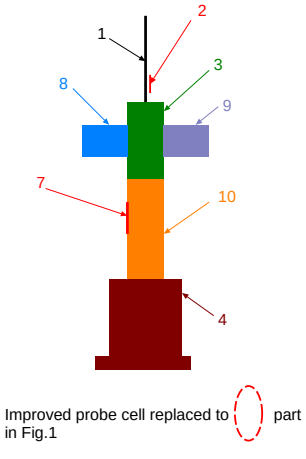
Among possible spin alignments in the collision of D and T nuclei, the process for anti-parallel spin combination of T to D is forbidden to form a spin 3/2 compound nucleus $^5$He$^*$. Therefore, if D and T could be polarized in parallel, all interactions will contribute to the reaction rate [1,2]. In advance to such experimental studies on polarized DT fusion concept, polarized DD experiments will be instructive since DD laser fusion experiments are in progress [3]. Based on the technical achievement of the polarized proton target project in our laboratory [4], we started the experimental studies on a polarized HD target development for the laser fusion experiment, because of the possibility of the polarization transfer from H to D with the application of the RF method [5].

As the polarization scheme applicable to the DT fusion experiment, a new polarization approach different from the method described in [4] should be employed since the decay beta heating in a DT target induces serious difficulty to cool down to the temperature around 10 mK. Our original idea of employing ferromagnetic complex for the polarization was described in our first report, RCNP Ann. Rep 2013.




1:Gas feed capillary, 2:Antiblockade heater, 3:Ferromagnetic complex cell, 4:Refrigerator, 5:Vacuum container, 6:A pair of electromagnet poles, 7:Temperature control heater, 8:NMR measurement cell, 9:NMR reference cell, 10:Connecting copper rod

Fig.1: Initial planned arrangement (*Left*). Fig.2: Improved multilocular cell (*Right*).

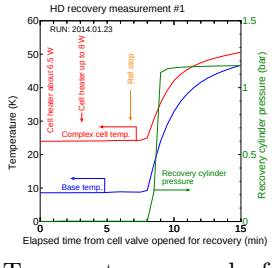



Fig.3: Temperature record of ferromagnetic complex HD desorption.

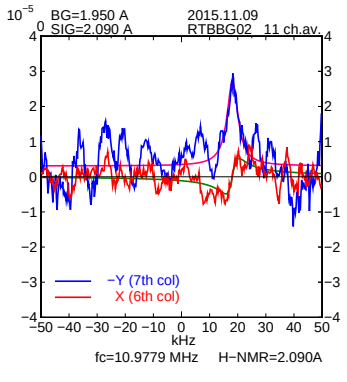



Fig.4: NMR absorption and dispersion fitting on a room temperature probe ($R$=-Y, $\varphi'$=X, $X = 1 \sim 400$).

Our initial plan of the experimental arrangement consists as shown in Fig.1, of a 3 K refrigerator, a 0.6 Tesla ordinary electromagnet, and a pair of 150 ml gas cylinders. Due to the complicated structure and technical difficulty of exchanging the gas line, we later simplified the cell configuration to employ a multilocular cell as shown in Figure 2.

We use Prussian blue analogue as the ferromagnetic complex as described in our first report. An important performance on the temperature response of the complex for the heating-up desorption, shown in Fig.3 indicates that HD desorption was only initiated by stopping the refrigerator, then the desorption process almost completed at the temperature of about 50 K.

Our first step for the NMR measurements on a dummy sample of white rubber with the diameter 4.1 mm, was started with a PC-based portable NMR system [6], as described in our second report, RCNP Ann. Rep 2015. Figure 4 shows one of the results at room temperature on the white rubber contained in a KelF cell. These data are fitted by a set of the theoretical equations, Eq. (1), for NMR absorption and dispersion [6],

$$R = R_{\mathrm{BG}} + \frac{A_R}{1 + \{(X - X_{R0})/\Delta_R\}^2}, \qquad \varphi' = \varphi'_{\mathrm{BG}} + \frac{A_\varphi \cdot \{(X - X_{\varphi 0})/\Delta_\varphi\}}{1 + \{(X - X_{\varphi 0})/\Delta_\varphi\}^2}. \tag{1}$$

The results of these fittings are listed in Table 1 with $X$ and $X_{R0}$ being channel numbers. The last column $m$ in the Table indicates the ratio of the magnetic current to the frequency at the center of NMR pattern.

Table 1: NMR data fitting parameters.

| Date&RUN | Probe temp. | $R_{\rm BG}$ $\times 10^{-5}$ | $A_R$ $\times 10^{-5}$ | $\Delta_R$ | $X_{R0}$ | $A_\varphi$ (degree) | $\Delta_\varphi$ | $m=(I/F)_{\rm NMR}$ [A/MHz] |
|---|---|---|---|---|---|---|---|---|
| 2015.11.09 BBG02 | RT | 0.309 | 2.40 | 9.49 | 272.5 | 24.0 | 9.49 | 0.19007 |
| 2017.01.07 RUN21 | RTVac | 1.40 | 0.968 | 7.07 | 170.5 | -13.7 | 2.0 | 0.19021 |
| 2017.06.18 RUN10 | LT | 2.30 | 3.42 | 14.14 | 185.5 | 24.3 | 14.14 | 0.18979 |
| 2018.03.11 RUN03 | RTVac | 4.17 | 1.73 | 4.47 | 100.5 | -44.8 | 2.24 | 0.18952 |
| 2018.03.10 RUN14 | LT | 6.40 | 7.62 | 4.47 | 100.5 | 32.9 | 4.47 | 0.18962 |

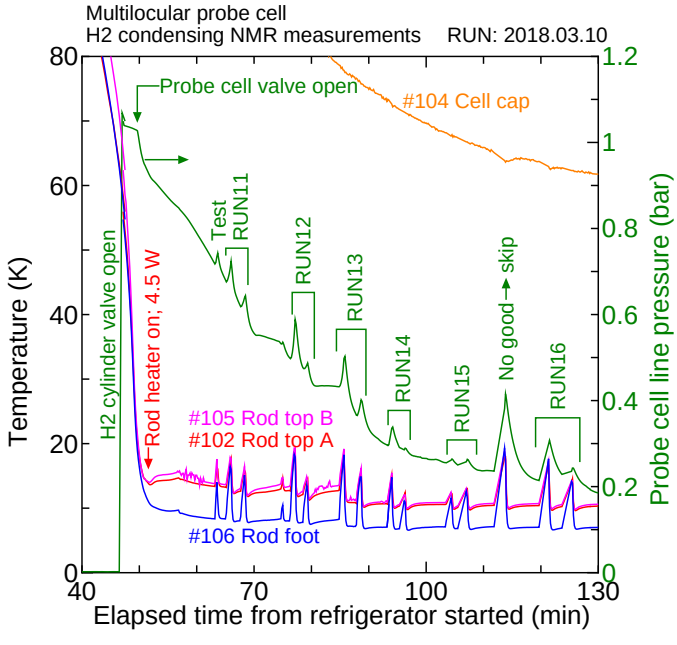



Fig.5:NMR measurements on the reference probe of white rubber at the $H_2$ condensation temperature.

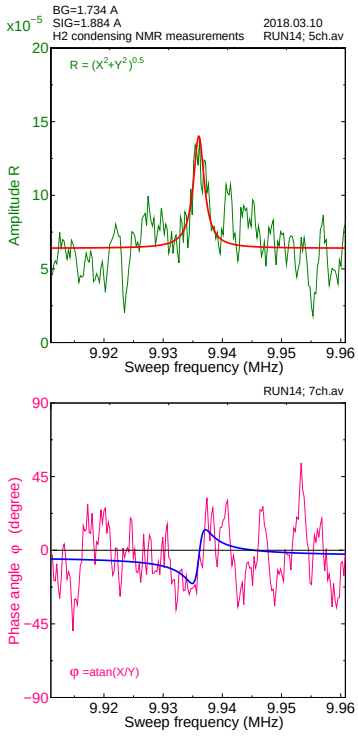



Fig.6: NMR absorption and dispersion fitting on a $H_2$ condensed low temperature probe.

Next step was the NMR measurements at low temperature carried out in 2017, the results of which are also given as the second group in Table 1. They indicate the temperature effect as the amplitude increase as well as the background increase induced by the thermal shielding and the vacuum container.

The third step for NMR measurement with the sufficient amount of HD condensed in the cell induced a serious hydrogen evaporation during the refrigerator short stop for the NMR measurement, as shown in our second report. Therefore, we improved at the end of 2017 the cell structure as shown in Fig. 2, containing a few number of activated carbon pellets with the diameter 4 mm inside the NMR probe for maintaining HD adsorbed. The present geometry successfully worked and the observed temperatures and hydrogen pressure with the ferromagnetic complex 0.3g in the cell are given in Fig. 5. One of the measured results with a twice faster NMR control unit PXIe-8840 on the dummy probe at the $H_2$ condensation is shown in Fig. 6 for central 200 channels and further listed as the third group in Table 1. Now, we proceed to the NMR measurements on HD adsorbed in the activated carbon, which should include the effect of the ferromagnetic complex.

## References


[1] P.C. Souers and P.A. Fedders, Phys. Rev. B41 (1990) 8643. [2] H. Paets gen Schieck, Eur. Phys. J. 44 (2010) 321. [3] T. Nagai, Master Thesis (2012), Inst. Laser Eng., Osaka Univ. [4] H. Kohri *et al.*, Proc. 10th Int. Workshop on the Physics of Excited Nucleons (NSTAR2015). JPS Conf. Proc. 10, 010008 (2016). [5] C.M. Bade, Ph. D. Thesis, College of Arts&Sci., Ohio Univ., March 2006. [6] T. Ohta *et al.*, Nucl. Instrum. Meth. A633 (2011) 46.