Towards 1.3 GHz NMR: A Persistent 400 MHz NMR with Superconducting Joints for High-Temperature Superconductors

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Introduction: Superconducting joints of high-temperature superconductor (HTS) are a key technology to develop an NMR magnet that operates at ^{1}H NMR frequency higher than 1 GHz in a persistent mode (i.e. without a power supply). In 2015, we developed a 1.02 GHz NMR using HTS innermost coil, which was the world's first high-resolution GHz NMR system(1). However, the magnet operated in the power-supply-driven mode because a practical technology to implement superconducting joint between HTSs or that between HTS and low-temperature superconductor (LTS) was not developed. In the end of 2017, we started a 10-year new project to develop a 1.3 GHz NMR operated in the persistent mode, as presented at the Ultra-high-field NMR Workshop at the last ENC(2). To make the magnet reasonably compact, we have employed a design concept to generate major part of the magnetic field by HTS inner coils in combination with LTS outer coils. The biggest technical challenge is to operate the magnet in the persistent mode. Such a magnet requires several tens of *superconducting* joints between HTSs. Here, we demonstrate the first NMR equipped with superconducting joints between REBCO-type HTSs.

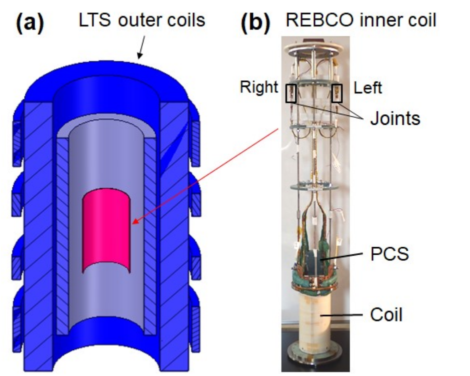

Fig. 1. Conceptual diagram of the persistent 400 MHz LTS/REBCO NMR

Experimental Procedure: We fabricated a REBCO inner coil and a persistent current switch (PCS), and connected them with intermediate grown superconducting (iGS) joints(3). The joint, 1 cm in length, provided an outstanding high-current-transport property in magnetic fields, achieving a low joint resistance of < 10^{-12} Ω. We installed the HTS inner coil in a LTS outer coil (**Fig. 1**) that operated individually in the persistent mode in a liquid He bath.

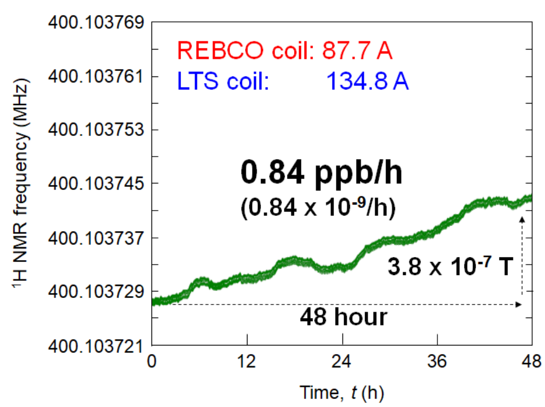

Fig. 2. A drift of the magnetic field at 400 MHz.

Results and Discussion: A drift of the magnetic field showed excellent stability 1 month after the charge to 400 MHz (**Fig. 2**). The field did not "decay" and slightly increased with a drift rate of 0.84 ppb/h over 48 h. This positive drift was due to the relaxation of screening currents in the wide REBCO tape(4). The field homogeneity after RT-shimming provided linewidth of < 0.5 Hz for chloroform sample (no sample spinning). With regular shim-tracking, the field was stably uniform for > 1 week. The 3D (H)CCH-TOCSY spectrum on GB1 (**Fig. 3**) was essentially perfect and no field distortions or instability was observed. These results show that the superconducting joints for HTSs fully functioned in a real high-resolution NMR system, which gives a promising prospect of a persistent 1.3 GHz NMR. Other interesting findings will be discussed.

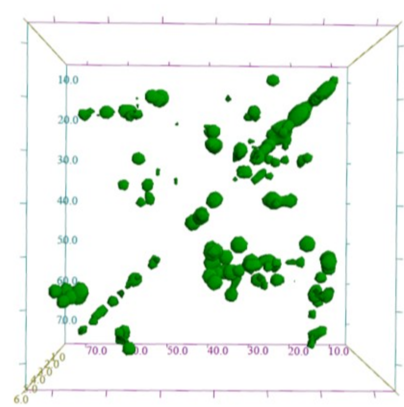

Fig. 3. 3D (H)CCH-TOCSY spectrum of ^{15}N,^{13}C-labeled 0.1 mM GB1 (protein G - B1 domain, 58 amino-acid residues) in D_2O PO_4 buffer. The in-plane axes are ^{13}C chemical shifts and the depth direction is ^{1}H chemical shifts.

References: (1) Hashi et al., *J. Mag. Res.* **256**, 30-33, 2015. (2) Maeda et al., presented in ENC2018. (3) Ohki et al, *Super. Sci. Tech.* **30**, 115017, 2017. (4) Maeda et al., *eMagRes* **5**, 1109-1120, 2016.

Acknowledgements: The present project is supported by the JST Mirai-Program Grant Number JPMJMI17A2.