Synchronized Magnetic Field and X-ray Pulses to Study Quantum Matter in Extreme Conditions

X-ray scattering technique is a powerful tool to study symmetry breaking phenomena in quantum materials. The recent development of brilliant x-ray free-electron laser (FEL) sources is now pushing the limit of photonic scattering techniques to new levels. Here, we aim at exploring uncharted territory of quantum matter physics by the synchronization of x-ray FEL pulses and magnetic field pulses under extreme sample environment.

The experimental platform for single-shot x-ray scattering experiment is being developed at SwissFEL free-electron laser through a collaboration of Tohoku University (Prof. Nojiri), University of Zurich (Prof. Chang) and Paul Scherrer Institut (Dr. Gerber). The intense femtosecond x-ray pulses from the SwissFEL will be synchronized with millisecond high magnetic field pulses of up to 35 Tesla at a minimum temperature below 2 Kelvin. The scientific potential of this scheme was demonstrated at the LCLS x-ray FEL in 2015, where Prof. Nojiri and Dr. Gerber were key actors [1, 2].

Two young researchers, Dr. Choi (postdoc) and Rechsteiner (scientific engineer), visited Prof. Nojiri's group through the ICC-IMR single visit program. We had technical discussions and achieved considerable progress in the collaboration project.

First of all, we finalized a prototype design of dual-cryostat experimental platform (Fig. 1). Fruitful feedbacks and advices were provided by Prof. Nojiri's team, based on rich experience in similar developments. We gained knowledge in designing kapton windows, magnet holders/leads, and cryogenic wiring (Fig. 2). The transferred knowledge is being essentially used for realization of our experimental setup.

To reach temperature below 2 Kelvin, minimization of thermal loss is of utmost importance. We discussed how to improve thermal contact and cooling efficiency of both sample and pulsed magnet assembly, based on finite-element method (FEM) heat transfer modeling. As a result, we reached a conclusion that installation of radiation shields enables us to achieve a minimum sample temperature below 2 Kelvin. Proper design of heat sinks and cold fingers is also important to reduce temperature on magnet assembly and its duty cycle. The thermal conductivity of magnet assembly might be improved by use of sapphire core.

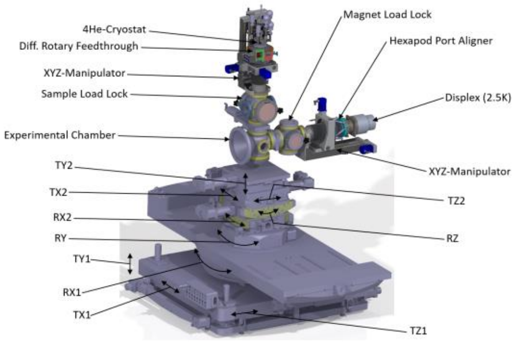

Fig. 1. Dual-cryostat platform containing pulsed magnet coils for the x-ray scattering experiment at SwissFEL

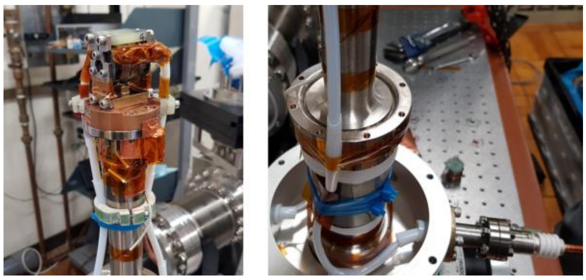

Fig. 2. (Left) Photo of pulsed magnet assembly mounted on a pulse-tube-type cryostat. (Right) Photo of magnet leads and feedthroughs. Both photos were taken at Prof. Nojiri's research group.

To sum up, the IMR-ICC single visit program was an excellent starting point in establishing a long-term collaboration between IMR, PSI and UZH for the single-shot x-ray scattering experiment at SwissFEL under pulsed magnetic field. Time and work plan for future cooperation to test the instrument and to conduct experiment is being organized for achieving successful collaboration.

References

[1] S. Gerber *et al.*, *Science* **350**, 949 (2015).
[2] H. Jang *et al.*, *Proc. Natl. Acad. Sci. USA* **113**, 14645 (2017).

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