§11. High-precision Temperature Control and Stabilization Using a Cryocooler

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Our group has proposed a new cryocooler system which has two fiber-reinforced-plastic (FRP) dampers installed, on the cryohead of the GM cryocooler and on the sample stage, using a commercial-based two-loop feedback temperature control system.[1] The FRP dampers made it possible to control the temperature precisely at the sample stage, typically at 4.2000 K, with a standard deviation of the temperature fluctuation of 0.21 mK obeying a normal distribution, which is nearly a 1000-fold improvement. In addition, the proposed system can control the temperature correctly from near 3.8000 to 300.000 K.

Figure 1 shows typical time dependence of the temperature fluctuation using the FRP damper with thicknesses of 1.12 mm for the cryohead and 0.76 mm for the sample stage, with the sample stage maintained at 4.2000 K. Detailed monitoring of the time dependence was possible using an oscilloscope for high-frequency sampling (50 Hz). As shown in Figure 1, time dependence of the temperature fluctuation at the sample stage where another FRP G10 damper was installed was measured. The temperature fluctuation was estimated as 3 mK, which was 0.22 times that of the Cu block. The heat flow from the Cu block to the sample stage through this additional FRP damper was more complex because of such structures as an alumina plate and radiation shield. The frequency dependence of the temperature fluctuation as shown by the Fourier transformation was very similar to that of the Cu block in that the main frequency was 1 Hz and only the second harmonic component was clearly observed. The dominant frequency was too low to be cut off by the FRP damper on the cryohead, and the FRP damper on the sample stage only reduced the magnitude of the temperature fluctuation. Figure 2 shows temperature fluctuation on the sample stage controlled at 4.2000 K as a function of the thickness of the corresponding damper using a 1.12-mm-thick FRP damper on the cryohead. Although the temperature fluctuation at the cryohead $\widetilde{T_0}$ was almost fixed, the Cu block $\widetilde{T_1}$ weakly depends on the thickness. The temperature fluctuation at the sample stage was less than 1 mK peak-to-peak for a 3.02-mm-thick FRP damper on the sample stage; using the approximately sinusoidal pattern shown in Fig. 1, the standard deviation was 0.24 mK. An inset of Fig. 2 shows the ratio of decrease between the Cu block and the sample stage. Although thickness dependence was also observed, from 0.21 to 0.08, the dependence was weaker than with respect to the FRP damper on the cryohead; however, what is important is that a temperature fluctuation of less than 1 mK was achieved.

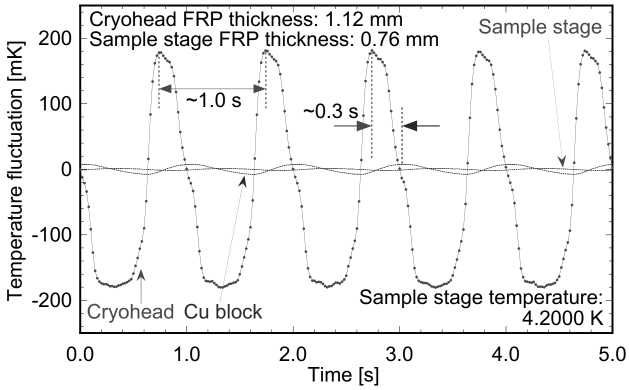

Fig.1 Typical time series of the temperature fluctuation on the cryohead, the Cu block, and the sample stage using a 4.2000 K temperature feedback control with two heaters for a 1.12-mm-thick FRP damper between the cryohead and the Cu block, and a 0.76-mm-thick FRP damper on the sample stage. Acquired sampling frequency is 50 Hz.

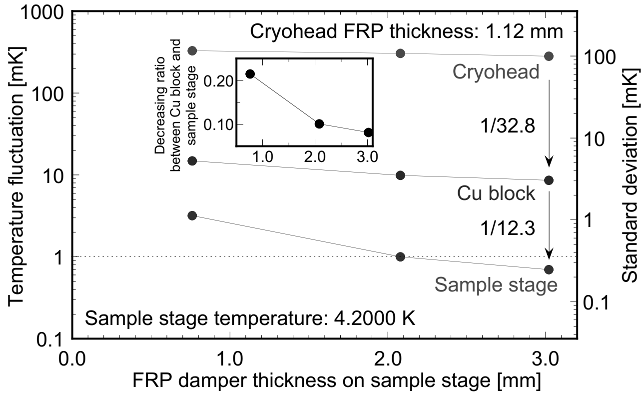

Fig. 2 Temperature fluctuation at the cryohead, the Cu block, and the sample stage as functions of FRP thickness on the sample stage. A 1.12-mm-thick FRP damper and FRP screws between the cryohead and the Cu block were used. Inset shows the decreasing ratio between the sample stage and the Cu block.

1) Hasegawa Y.,Nakamura D., Murata M. , Yamamoto H., and Komine T., *Rev. Sci. Instrum.*, 81, 094901 (2010)