Development of high-resolution hard X-ray detector system by using transition-edge sensor for accelator-based experiments

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A transition-edge sensor (TES) is a type of low-temperature microcalorimeter that provides a much better energy resolution than semiconductor detectors by using a superconducting material as the temperature sensor at the superconducting-to-normal transition-edge. Recently, a detector system with TES was employed for accelator-based experiments.[1)] For instance, a high-resolution X-ray measurement of a Kaonic atom was succesfully performed at J-PARC in spring 2018.[2)] An energy resolution of 5.7 eV in FWHM was shown for the Co Kα X-ray line (6.9257 keV) during the beam time, while a resolution of 5 eV in FWHM can be achieved for the same line with the beam off. As the next step of high-resolution X-ray spectroscopy with a TES detector system for accelator-based science, we are constructing a new system by indroducing a modern cryogenic system (HPD Co. Ltd. model 107 adiabatic demagnetization refrigerator, ADR, cryostat) and novel microwave readout system for TES. The model 107 cryostat has a helium-3-backed, single-stage ADR with an ADR base temperature of 30 mK and a 300-h no-load regulation at 100 mK. Figure 1(a) shows the inside of the new cryogenic system.

The sensitivity of the TES is expressed as $\Delta T = E/C$, where ΔT is the temperature change, E the energy of X-rays, and C the heat capacity of the TES. Thus, the size of the TES, which determines C, is limited for a target performance. Typically, the size of one pixel is 100×100 μm^2. In order to enlarge the acceptance of the detector, it is necessary to increase the number of TES pixels (readout channel). However, the number of electric connections to the cryostat is limited to less than ~100 due to the limitation in cooling power of the cryogenic system. Recently, a novel readout technique using a microwave resonator was developed.[3)] By introducing such microwave readout, the number of readout channels is expected to be increased up to ~1000 per readout connection. Figures 1(b) and (c) show the transmitted power of the prototype resonator, which gives 64 tones, where one tone is used for one TES pixel readout.

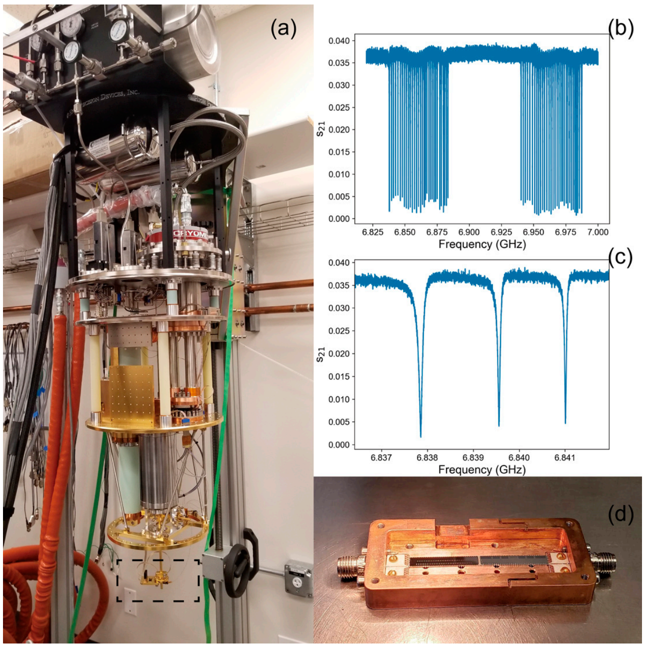

Fig. 1. (a) New cryogenic system to introduce the novel TES detector. The top plate is used for vacuum sealing. The other plates are used for shielding thermal radiation of 300 K, 3 K, and 300 mK from top to bottom. The TES detector is supposed to be mounted on the bottom part indicated by dashed square. (b) Transmitted power of the prototype resonator. Each tone corresponds to one channel (TES pixel). (c) Enlarged view of the X-axis of (b). (d) Prototype resonator mounted in model 107.

After finishing the construction of the new detector system, we plan to execute online experimental projects for the precise measurement of hard X-ray lines from atomic/nuclear excited states. For example, X-rays from a muonic atom will be measured for the validation of quantum electromagnetics. Furthermore, X-rays from the excited isomeric state of Th-229 are proposed to be measured. Currently, a molybdenum-gold bilayer TES microcalorimeter for X-rays in the range of 20 keV to 45 keV X-rays has been designed, and its prototype has been tested.

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