MMC-based Phonon-scintillation Detection for Rare-event Search Experiments

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***Abstract* – Metallic magnetic calorimeters (MMCs) are highly sensitive temperature sensors that use the paramagnetic nature of erbium ions and superconducting electronics composed of a superconducting quantum interference device (SQUID) with superconducting input coil. In rare-event search experiments such as search for neutrino-less double beta decay (0νββ), MMCs provide high precision tool for simultaneous measurement of phonon-scintillation signals from a target crystal. The MMC-based phonon-photon simultaneous measurement technology has been adapted in the Advanced Molybdenum-based Rare process Experiment (AMoRE), an international project searching for 0νββ of ^{100}Mo, which aims to realize zero background measurement condition for the Majorana neutrino mass sensitivity of 12-22 meV.**

***Keywords* – Metallic magnetic calorimeter, SQUID, low-temperature detector, scintillating crystal**

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Metallic magnetic calorimeters (MMCs) are highly sensitive temperature sensors that operate at millikelvin temperatures [1]. They employ the paramagnetic properties of erbium ions in a metallic host and superconducting electronics usually composed of a superconducting niobium coil and a current sensing superconducting quantum interference device (SQUID) to accurately read the temperature change of the sensor due to particle absorption.
A cryogenic particle detector based on MMC technology is typically composed of three main parts; an absorber that absorbs the energy of the incident particle, a sensor pad that is made of a dilute alloy of paramagnetic erbium ions in a metallic host such as gold or silver, and a superconducting niobium input coil which is connected to the SQUID.

The MMC sensors used in the present experiment have been fabricated at Korea Research Institute of Standards and Science (KRISS) [2]. The Au:Er layer was sputtered on a meander-shaped pickup coil that is connected to an input coil of a current-sensing SQUID. In the MMC operation, a persistent current up to 100 mA is injected in the meander-shaped niobium coil to magnetize the paramagnetic ions. The temperature rise reduces the magnetization of the sensor [3] (poster, Metallic Magnetic Calorimeter panel). Then, it results in a current change inside the superconducting coil, which is then read by the current sensing SQUID [4].
The high-energy resolution of MMC-based particle detectors arise from extremely suppressed heat capacity of the sensor material at low temperature and supreme sensitivity of SQUID sensors. A recent alpha spectroscopy measurement with a thin gold foil absorber and an

optimized MMC sensor showed the full width at half maximum resolution to be as good as 0.86 ± 0.05 keV [5]. MMCs' high energy resolution makes the calorimeter a suitable sensor for rare-event search experiment such as direct detection of dark matter [6] and search for neutrino-less double beta decay [7, 8, 9]. One of the possible experimental setup is the phonon-scintillation simultaneous detection using a scintillating crystal [7, 8]. In this setup, a thin gold film is evaporated on a polished surface of a scintillation crystal (poster, Phonon-Scintillation Detection panel). The absorber is thermally connected to an MMC sensor, which is weakly coupled to the copper holder which serves as a thermal reservoir (poster, Phonon-Scintillation Detection panel, right). When a particle is absorbed by the crystal, the incident energy is transferred to a lattice vibration of the crystal and phonons are generated [9]. The phonons are then collected by the gold film and are thermalized to give their energy to the electronic system of the absorber, raising its temperature. The change in temperature read by the MMC sensor is a direct measure of the energy of the incident particle. The amount of scintillation light is also measured with an additional MMC, using crystalline semiconductor wafer of germanium or silicon as a light absorber. An MMC sensor is employed to read out the temperature increase of the wafer when absorbing the scintillation light. Using both the heat energy readout and the scintillation light data with the knowledge of the difference in scintillation light emission of alpha- and gamma-originated events, we achieve not only a very accurate particle energy measurement but also a very precise particle identification that can be used as a background rejection tool [6, 10, 11, 12].
One of the experiments that utilizes such phonon-scintillation simultaneous measurement detectors is the Advanced Molybdenum based Rare process Experiment (AMoRE) [8, 13, 14]. The AMoRE is an international project searching for the neutrinoless double beta decay ($0\nu\beta\beta$) (poster, Advanced Mo-based Rare Process Experiment (AMoRE) panel, Middle) of ^{100}Mo. It will utilize up to 200 kg of $^{40}Ca^{100}MoO_4$ crystals by the end of planned three phases: AMoRE-pilot, AMoRE-I and AMoRE-II. Located at an underground laboratory in South Korea, AMoRE-II will fulfill 1×10^{-4} counts/keV/kg/year background rate. The extreme precision of MMC detector with the background rejection technique available from the phonon-scintillation measurement will allow the $0\nu\beta\beta$ search with 1.1×10^{27} year half-life sensitivity that corresponds to 12-22 meV Majorana neutrino mass (poster, Advanced Mo-based Rare Process Experiment (AMoRE) panel). The commissioning run of the AMoRE-pilot was performed successfully during the past two years, and many improvements have been made to lower the background rate and to reduce the baseline fluctuation by the operation of the pulse tube refrigerator used in the cryogen-free dilution refrigerator (poster, Experiment and results panel, Waveform plot). The final run of the pilot phase is now in progress.

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