MMC-based phonon-scintillation detection for rare-event search experiments

Inwook Kim[1,2,3], Hyon-Suk Jo[1,2], Chan Seok Kang[1,2], Geon-Bo Kim[1,2], Hye Lim Kim[1,2,3], Sora Kim[1,2,3,4,5], Hyejin Lee[1,2,3], Chang Lee[1,2], Seung-Yoon Oh[1,2,3,4,5], Jungho So[1,2], Youngsoo Yoon[1,2,3], and Yong Hamb Kim[1,2,3,4,5]

1Institute for Basic Science, Republic of Korea, 2Seoul National University, Republic of Korea, 3Kyungpook National University, Republic of Korea, 4Korea Research Institute of Standards and Science, Republic of Korea, 5Sejong University, Republic of Korea

:: Metallic Magnetic Calorimeter (MMC) is a highly sensitive temperature sensor that uses the paramagnetic nature of erbium in gold host and superconducting electronics composed of a planar niobium coil and a current sensing Superconducting Quantum Interference Device (SQUID). It operates at cryogenic temperature typically with a scintillating crystal that is a target material for rare-event search experiments. A small increase in temperature change of the crystal induced by particle absorption is measured with an MMC-based phonon sensor which is in strong thermal contact to the crystal. The phonon sensor is also weakly coupled to the copper holder which serves as a thermal reservoir to maintain its low temperature. The amount of scintillation can also be measured with an additional MMC, using crystalline semiconductor wafer such as Germanium or Silicon as light absorber. MMC sensor is employed to read out the temperature increase of the wafer when absorbing the scintillation light. Its high energy resolution obtained by using a low-noise SQUID and low heat capacity of material at cryogenic temperature makes the calorimeter a suitable sensor for rare-event search experiment such as direct detection of dark matter and search for neutrino-less double beta decay. We present the measurement principle of the simultaneous detection of phonon and scintillation signals together with astroparticle physics applications.

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### Cryogenic Detectors

Heat capacity of metal, given as a function of temperature $C = g/VT + AT^2$, decreases radically at cryogenic temperature. This means a small energy input to a metallic absorber results in a great temperature change of the absorber. The metallic absorber at cryogenic temperature can then be used as a highly precise energy sensor which can be applied to measuring the energy of radiation-induced events with extremely high resolution.

### Metallic Magnetic Calorimeter

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### Phonon-Scintillation detection

**Detector concept**

- Paramagnetic material in metallic host
- Cryogenic temperature, e.g., $5\text{K}$

**Photons (Scintillation)**

- Single gold absorber film covering large area
- Cu support
- Gold film

** MMC sensor**

- Au film
- SQUID
- Heat bath

**Phonons**

- Annealed gold wires for thermal link to the bath.
- Single gold absorber film covering large area
- Heat bath

**Light detector**

- Cu support
- Gold film

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### Advanced Mo-based Rare Process Experiment (AMoRE)

AMoRE (Advanced Mo-based Rare process Experiment) is an international project searching for the $0^+\gamma$ decay of $^{100}\text{Mo}$. It utilizes up to 200 kg of $^{100}\text{Mo}$ in the form of $^{100}\text{MoO}_2$ crystals. The project is divided into three phases: AMoRE-Pilot, AMoRE-I and AMoRE-II. Located at underground laboratory in South Korea, AMoRE-II will fulfill $10^{10}$ counts/keV/kg/year background rate. The extreme precision of MMC detector in this zero-background condition will allow the search for the $0^+\gamma$ decay mode of $^{100}\text{Mo}$ with $\sigma(1.1\times10^{-27} \text{pot})$ sensitivity for half-life that corresponds to $12-22\text{ meV}$ Majorana neutrino mass.

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### Experiment and results

**Use of Mass-filling scanning system in vacuum and vibrational noise cancellation**

- Use of Mass-filling scanning system in vacuum and vibrational noise cancellation

**Pulse shape discrimination enables further separation between alpha and gamma events**

- Use of Mass-filling scanning system in vacuum and vibrational noise cancellation

**Experiment in the underground laboratory to achieve extremely low background rate**

- Use of Mass-filling scanning system in vacuum and vibrational noise cancellation

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**Table: AMoRE**:%e

<table>
<thead>
<tr>
<th>Isotopic events</th>
<th>Detection Eff.</th>
<th>Resolution (FWHM)</th>
<th>$\delta\Delta E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{100}\text{Mo}$</td>
<td>$1.2\text{keV}$</td>
<td>$1.6\text{eV}$ FWHM Gaussian width</td>
<td>$10\text{keV}$</td>
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**Graphs and Figures**

- Graphs illustrating the energy resolution, efficiency, and background rate for various isotopes.
- Figures showing the phonon and scintillation detection signals together with astroparticle physics applications.

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**References**


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