Abstract. An international collaboration has grown around the project of Microcalorimeter Arrays for a Rhenium Experiment (MARE) for a direct and calorimetric measurement of the electron antineutrino mass with sub-electronvolt sensitivity.

MARE is divided into two phases. The first phase (MARE-1) consists of two independent experiments using the presently available detector technology to reach a sensitivity of $m_\nu \leq 2$ eV/c$^2$. The goal of the second phase (MARE-2) is to achieve a sub-electronvolt sensitivity on the neutrino mass.

The Milan MARE-1 experiment is based on arrays of silicon implanted microcalorimeters, produced by NASA/GSFC, with dielectric silver perrhenate absorbers, AgReO$_4$. We present here the status of MARE-1 in Milan which is starting data taking with 2 arrays (72 detectors). In this configuration a sensitivity of about 5 eV can be achieved in two years. We describe in details the experimental setup which is designed to host up to 8 arrays (288 detectors). With 8 arrays, two years of measurement would improve the sensitivity to about 3 eV. This talk reports on the activity of the group for the MARE project in Milan.

Keywords: Cryogenics detector, Neutrino mass

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1. INTRODUCTION

Neutrino oscillation experiments have shown that neutrinos are not massless particles, but they are not able to determine the absolute neutrino mass scale. Therefore, the absolute value of neutrino mass is still an open question in elementary particle physics.

The experiments dedicated to effective electron-neutrino mass determination are the ones based on kinematic analyses of electrons emitted in single $\beta$-decay. The most stringent results come from electrostatic spectrometers on tritium decay ($E_0 = 18.6$ keV). The Mainz collaboration has reached $m_\nu \leq 2.3$ eV/c$^2$ [1]. With the Troitsk neutrino mass experiment, an upper limit on electron-antineutrino mass of 2.5 eV/c$^2$ has been obtained [2]. The next generation experiment KATRIN is designed to reach a sensitivity of 0.2 eV/c$^2$ in five years.

To scrutinize the current results of Mainz, Troitsk and future results KATRIN, an entirely different method to determine the neutrino mass from single $\beta$-decay has been investigated. This complementary approach is the calorimetric one. With this technique, the beta source is embedded in the detector so that all the energy emitted in beta decay is measured, except for the one taken away by the neutrino. The study of the $\beta$-decay spectrum of $^{187}$Re provides a suitable method to determine the mass of the anti-neutrino. The method consists in searching for the deformation caused by a non-zero neutrino mass to the spectrum near its end point. Previously, a sensitivity of $m_\nu \leq 15$ eV/c$^2$ was achieved with the experiments MIBETA in Milan and MANU in Genoa [3]. In these experiments, the systematic uncertainties are still small compared to the statistical errors. The main sources of systematics are the background, the pile-up, the theoretical shape of the $^{187}$Re $\beta$ spectrum, the detector response function and the Beta Environmental Fine Structure (BEFS) [4], [5]. The MANU and MIBETA results together with the constant advance in the performance of low-temperature detectors open the door to a new large scale experiment able to explore the sub-eV neutrino mass range.

2. THE MARE PROJECT

MARE is a new large scale experiment to measure directly the neutrino mass from the end-point of the $^{187}$Re beta decay ($E_0 = 2.47$ keV). The final aim of this project is to explore the sub-eV neutrino mass range. To achieve this goal, a statistic up to $10^{14}$ $^{187}$Re beta decays and detectors with excellent energy and time resolutions (i.e. about 1 eV and 1 µs) are required. These requirements have been studied in details both with Monte Carlo simulations and with a numerical statistical analysis. This latter analysis, limited to the first order expansions and in absence of background, gives the following expression for the statistical sensitivity on $m_\nu$ at 90% C.L.
The Milan MARE-1 arrays are based on semiconductor thermistors, provided by the NASA/Goddard group. These arrays, developed as detectors for the XRS2 experiment on the ASTRO-EII mission, consist of 6 x 6 implanted Si:P thermistors with a size of 300 x 300 x 1.5 μm³. An energy resolution of 3.2 eV FWHM at 5.9 keV has been obtained with these thermistors and HgTe absorbers [6].

Adapting these thermistors, optimized for X-ray spectroscopy, to the measurement of the beta spectrum of the $^{187}$Re, single crystals of AgReO$_4$ replace the HgTe absorbers and act as absorber. An R&D work has been dedicated to determine the best crystal geometry and the optimal thermal coupling between Si thermistors and AgReO$_4$ absorbers.

Our studies have shown that with crystals cut in regular shape of 600 x 600 x 250 μm³ (approximatively 500 μg, giving 0.27 decays/sec) and gluing silicon pieces of 300 x 300 x 10 μm³ between the thermistor and the rather large absorber, it is possible to achieve an energy and time resolution of 25 eV and 250 μs respectively. The AgReO$_4$ are grown by Mateck GmbH (Germany). Mateck has developed a procedure to grow large single crystals with high purity and to cut them in regular shape as precisely as possible. A spectrum of one test detector can be seen in Fig. 2. The thermal coupling of this detector is made of Araldite Rapid between the thermistor and the silicon spacer and made of ST2850 epoxy between silicon spacer and AgReO$_4$ absorber. Fig. 1 shows a sketch of our microcalorimeters.

With 288 detectors and such performances, a sensitivity of 3.3 eV at 90 % CL on the neutrino mass can be reached within 3 years. This corresponds to a statistics of about $7 \times 10^9$ decays [7].

The performance of such bolometers, which are characterized by high impedance at low temperature (around 4 MΩ at 85 mK), depends not only on the thermistors and the quality of the crystals but also on the read-out electronics and the wiring of the apparatus. A cold unity gain buffer stage, based on JFETs working at 135 K, is installed to shift down the impedance of the thermistors.

![FIGURE 1. Structure of AgReO$_4$ microcalorimeter.](image)
amplifier stage at room temperature. This amplifier stage makes the difference between the signal presents at the cold buffer output and the reference ground signal. The presence of only one reference ground signal for all the channels cancels the ground loop interference. The output signal is filtered with an active Bessel low pass antialiasing filter, placed close to the acquisition system.

The wiring has been optimized to reduce the parasitic capacitance and the microphonic noise. To electrically connect the cold electronics (135 K) to the detectors at 85 mK with low thermal conductance wires, microbridges are produced by the Memrsad/FBK in Trento, Italy. The microbridges are thin wires (thickness around 200 nm) made of Ti or Al deposited onto polyamid. The silicon wafer below these wires is completely etched away. To manipulate them, the chip presents two wings which connect the two ends of the wires. After mounting, the wings must be carefully cleaved along the furrows, made during the microbridges fabrication. Ti or Al microbridges are glued on the dedicated PCB with epoxy resin. The microbridges provide thermal decoupling between detectors and JFETs, but they do not guarantee mechanical stability. Therefore, materials with very low thermal conductivity are used as a mechanical support, namely Kevlar and Vespel.

A first microbridge stage provides a thermal decoupling between the detectors and the JFET holder (4 K). These microbridges are made of titanium and the typical resistance is 3 kΩ. The 4 K parts are suspended by three Kevlar crosses. This structure can be seen in Fig. 3.

A second step of thermal decoupling is made in the JFET box. The microbridges connecting the JFETs to their holder are made of aluminium and the resistance of one wire is 10 Ω at 77 K. The dedicated PCB is suspended by two thin Vespel rods. Thanks to the thermal resistance of microbridges and Vespel rods, the JFET bias is almost sufficient to warm up the preamplifier temperature to its optimal working temperature of 135 K. The assembled JFET box can be seen in Fig. 4.

The cryostat wiring is thermalized through pieces of copper with three slits produced using an electroerosion machine. Taking a serpentine path, the manganin wires are glued with epoxy resin inside the copper pieces.

We tested the cold buffer stage: the thermal bath was at the nitrogen temperature and the JFETs at 130 K. All the channels are good and in this condition the white noise measured is of 2.1 nV/Hz$^{1/2}$. This Johnson noise is primarily due to the wiring between the cold electronic and the amplifier stage. At 1 Hz the noise is about 5 nV/Hz$^{1/2}$.
FIGURE 5. The cryogenic setup of MARE-1 in Milan for two arrays. The final assembly is 300 mm high.

A calibration source completes the set-up. The energy calibration system, located between the detector holder and the JFETs boxes, consists of fluorescence sources with 10 mCi of $^{55}$Fe as a primary source movable in and out of a Roman lead shield [8]. The fluorescence targets, made of Al, Si, NaCl, CaCO$_3$ and Ti, allow a precise energy calibration around the end-point of $^{187}$Re with the $K_{\alpha}$ and $K_{\beta}$ X-rays.

The cryogenic setup of MARE-1 in Milan is shown in Fig. 5. Mounted in a Kelvinox KX400 dilution refrigerator, it can host up to eight arrays (288 detectors), although only two of them with electronics have been funded so far. For that reason, read-out cryogenic wiring, preamplifiers, anti-aliasing filters, triggers and DAQ system have been installed only for 80 channels.

A first test run with two arrays but only 11 AgReO$_4$ crystals attached is planned to start shortly. The goals of this run are to check the functionality of all the channels and a final test for the thermal coupling between thermistors and silicon spacers. Therefore two different kinds of epoxy resins are tested: five silicon spacers are attached with Araldite Normal and the other six with ST1266 epoxy. ST2850 epoxy is used to glue all the AgReO$_4$ absorbers on the silicon spacers. The 11 crystals on the array can be seen in Fig. 6.

After this test, the remaining AgReO$_4$ crystals will be attached to the thermistors and the complete measurement of 72 channels will start. With two arrays equipped with AgReO$_4$ absorbers, a sensitivity of 4.5 eV at 90% C.L. is expected in three years. Based on the results obtained from the two arrays, a decision concerning funding of the deployment of the remaining six arrays can be made.

4. CONCLUSIONS

The first phase of MARE-1 in Milan is getting ready to start using silicon implanted thermistors array equipped with AgReO$_4$ single crystals absorbers. The experiment, which starts with 72 channels, is designed to be expended to 288 channels to increase the sensitivity on the neutrino mass.

REFERENCES