Production and characterization of high-purity natural and enriched ZnMoO₄ crystals to search for neutrinoless double beta decay of ¹⁰⁰Mo

M. Marusych1, D. M. Chernyak1, J. A. Gatovich1, R. Decourt1, A. Giuliani1, I. M. Ivanov3, E. P. Makarov3, P. de Marcillac7, S. Marnieros1, S. G. Nasonov3, C. Nieves1, E. Ovets1, G. Pesina1, D. V. Podin1, V. N. Shigef1, M. Tercero1, V. J. Trettia1, V. V. Vatulev1, W. Velazquez1, V. N. Zharkova1

Abstract

Scintillating bolometers are promising devices for the future experiments on neutrinoless double beta decay (0ν2β). When the energy absorber in a bolometer scintillates at low temperatures, the simultaneous detection of scintillation light and heat provides a very powerful tool to identify the nature of the interacting particle and therefore to suppress background. A recently developed technique to grow large high quality radiopure zinc molybdate (ZnMoO₄) crystal scintillators makes this material advantageous for low temperature bolometric experiments. This is the case for LUMINEU program which aims to perform a pilot experiment on 0ν2β using radioupe ZnMoO₄ crystals operated as scintillating bolometers. Growing high quality radiopure crystals is a complex task, since there are no commercially available molybdenum compounds with the required levels of purity and radioactive contamination.

Here we present further progress in deep purification of molybdenum, growing natural and enriched of ZnMoO₄ crystals and new results about their optical, luminescent, thermal and bolometric properties.

Production of ZnMoO₄ crystals

Purification

Purification and crystallization were performed at Nikolaeiev Institute of Inorganic Chemistry (NIIC). To purify molybdenum by sublimation for ZnMoO₄ crystal growth we have added up to 1% of high purity zinc molybdate to the MoO₃ prepared for sublimation. The sublimates were then annealed in the air atmosphere to obtain yellow color stoichiometric ZnMoO₄.

Characterization of ZnMoO₄ crystals

Optical absorption

The measured absorption cross section includes visible and near infrared wavelengths. The absorption at the range of 0.4 to 0.98 cm⁻¹ in the range of 3.0 mm to 2.5 µm.

The absorption coefficient α is calculated as α = (log(T)/ln10)/t, where t is the thickness of the crystal and α is in the range of 1.47 to 0.89 cm⁻¹ in the wavelength region from 400 nm to 2 µm.

- The absence of a broad absorption band around 440 nm shows a low contamination due to Fe³⁺/Fe⁺.
- The refractive index at 650 nm is 1.96 in agreement with the literature.

Luminescent under X-ray excitation

The luminescence of ZnMoO₄ crystal was investigated in the temperature interval 8–290 K under X-ray excitation. A broad band in the visible region with a maximum at 610 nm was observed at room temperature. At 8 K luminescence exhibits an emission band with a maximum at 625 nm.

The light output grows with decreasing temperature, reaches a maximum around 110–140 K and then drops with further cooling. This result is in agreement with the data of previous investigations.

- The crystals are transparent to their emitted light.

Specific heat measurement

Specific heat measurements were made on a 3x3x2 mm³ single crystal. The specific heat could be approximated for temperatures higher than ~23 K using high temperature-series expansion:

Cₚ = 1 + Σ Bₖ Tᵏ / (1 + Σ Cₖ Tᵏ)

- The inset shows C(T) as a function of T at 8 K to evidence the absence of any low range order down to 4 K.
- Delays temperature measurement was performed for the first time for ZnMoO₄ and it’s favourable for bolometric application.

Conclusions and Perspectives

- We developed a technique for the production of high quality large mass ZnMoO₄ crystals.
- We proved the possibility to use enriched material in large experiments for the search for 0ν2β of ¹⁰⁰Mo.
- A new bunch of enriched Zn¹⁰⁰MoO₄ crystals with masses of the order of 300–400g is in production at NIC.
- The crystal properties are fully characterized and they are favorable for bolometric experiments.
- 2 large natural and enriched ZnMoO₄ scintillating bolometers are now under investigation in the underground laboratory of Modane (France).

References

[1] A. Goncharuk et al., Production of high-quality crystals of the molybdenum compound ZnMoO₄, submitted to the LUMINEU program.
[2] J. A. Gatovich et al., Enriched Zn¹⁰⁰MoO₄ crystal scintillators for use in 0ν2β decay of ¹⁰⁰Mo.