PROCEEDINGS OF SCIENCE

# Fabrication of an Absorber with $^{163}$Ho implanted for the Neutrino Mass Searches in the HOLMES project

**G. Pizzigoni**[*][†]
*Dipartimento di Fisica, Università di Genova, Genoa, Italy*
*Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Genova, Genoa, Italy*

*E-mail:* `giulio.pizzigoni@ge.infn.it`

$^{163}$Ho Electron Capture Decaying isotope as probe for direct neutrino mass search, is presently the most appealing option for a calorimetric measurement in the framework of the micro calorimeter technology that has been developed. A small amount of $^{163}$Ho atoms per detector, at a level of $10^{11}$ - $10^{13}$, is enough for making high statistics measurements with micro-calorimeters with "*standard*" metallic absorbers. TES micro calorimeter with gold absorber containing $^{163}$Ho isotopes can achieve spectral resolution as good as the ones developed for X-ray astrophysics. Respect to the former TES calorimeter they can be fabricated with in order to minimize the absorber volume, optimize the absorber-TES coupling in order to achieve a higher signal rise time. But the most important issue is the chemical forms in which Ho can be incorporated in the Absorber. As already stated, we show that the most easy method for $^{163}$Ho production is the neutron irradiation of enriched $^{162}$Er samples, which is typically in for of oxide, therefore the final product is composed mainly by Ho and Er oxides. The high precision required by the neutrino mass measurement need the knowledge of the chemical status of the $^{163}$Ho, in order to study the effect of the chemical bound on the end-point energy. Ho-oxide and Ho-metal in metal absorber are here considered. Both are incorporated in metal absorber and studied form the chemical an structural point of view.

*XVI International Workshop on Neutrino Telescopes,*
*2-6 March 2015*
*Palazzo Franchetti, Istituto Veneto, Venice, Italy*

---

[*] Speaker.

[†] on the behalf of the HOLMES Collaboration

PoS(NEUTEL2015)079

## 1. Introduction

The HOLMES experiment [1] aims to measure the neutrino mass with an accuracy of 0.4 eV by studying the calorimetric spectrum of $^{163}$Ho electron capture (EC decay) near the end point. The $^{163}$Ho will be contained in a metallic absorber (Bi:Au, [2]) thermally coupled with a transition edge sensor (TES). An embedding system has been designed and set-up at the Genoa INFN laboratory: it consists of a holmium evaporation chamber to produce the metallic target and an ion implanter to embed the isotope in the absorber.
$^{163}$Ho is produced via neutron radiation of $Er_2O_3$ powder enriched at 30% in $^{162}$Er

$$^{162}Er(n,\gamma)^{163}Er \rightarrow^{163} Ho + \nu_e, \tag{1.1}$$

where $^{163}$Er decay via EC with a half-life of 75 min and $\sigma$(n,$\gamma$) is ∼20 barns for thermal neutrons. The irradiation will be performed at the nuclear reactor of the Institute Laue-Langevin (ILL, Grenoble, France) with a thermal neutron flux of about 1.3 $10^{15}$ n/s/cm$^2$ [1]. The isotope is produced in an oxide form ($Ho_2O_3$), which could modify the end-point shape. In order to avoid this effect we need to reduce the holmium in the metallic form by means of a reduction-distillation technique [3, 4] which will be described in section 2.

## 2. Holmium reduction distillation technique and results

Holmium oxide is mixed with metallic Y in a Knudsen cell and the system is heated at temperature of $\sim$ 1700° C. In this condition oxygen is captured by metallic Y via the reaction:

$$Ho_2O_3 + 2Y \longrightarrow Y_2O_3 + 2Ho, \tag{2.1}$$

because the Y standard enthalpy of oxide formation ($\Delta_f H^o$) is lower than Ho one. The operation temperature is chosen in such a way to have a Ho partial pressure higher than oxides and metallic Y ones [5, 6]. Thus it is possible to collect the evaporated material by simply using a cold plate. This test is done using $Ho_2O_3$ powder with natural isotope composition. The cell is fixed between two rheophores, inside a vacuum chamber (pressure $10^{-6}$ mbar) and, in order to measure the temperature, a type C thermocouple is placed in thermal contact with the Knudsen cell.

The condensed material (show in figure 1) is analyzed by X-ray Photoelectrons Spectrometry (XPS) to establish the chemical state obtained for its compound [7].

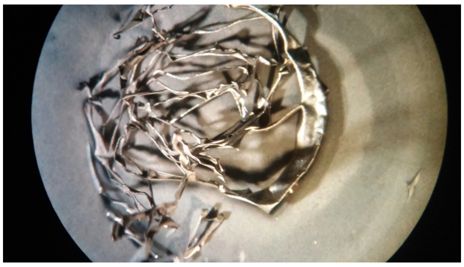

**Figure 1:** Condensed material on the slide after reduction distillation, weight 10 mg

The strongest peak of the holmium is the 4f shell and for the yttrium is the 3d shell (both at $\sim$ 160 eV). For this peak the background has a strongly dependence form shake-up peak: these are multielectron processes in which an atom is left in an excited state following a photoionization or Auger electron process, so that the outgoing electron has a characteristic kinetic energy slightly smaller than that of the parent photoelectron. To analize the chemical composition of the distilled material we have used the linear superposition hypothesizing that the spectrum measured from the distilled material (M), for each energy ($E_i$), is the linear sum of the spectra: holmium oxide ($Ho_{oxide}$), yttrium oxide ($Y_{oxide}$), metallic holmium ($Ho_{metallic}$) and metallic yttrium ($Y_{metallic}$) (shown in figure 2,3):

$$M(E_i) = \alpha Ho_{metallic}(E_i) + \beta Ho_{oxide}(E_i) + \gamma Y_{metallic}(E_i) + \delta Y_{oxide}(E_i) \tag{2.2}$$

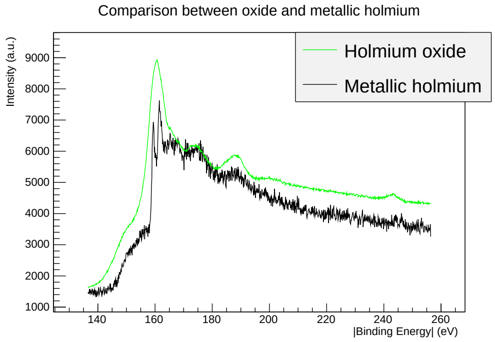

**Figure 2:** Oxide and metallic holmium 4f shell spectra. In both spectra ara showed the shake up peak

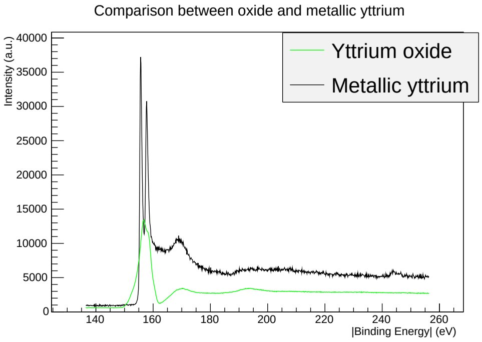

**Figure 3:** Oxide and metallic Yttrium spectra. In both spectra ara showed the shake up peak

As it is shown in figure 4 the XPS analysis on the distilled material showed a spectrum compatible with the metallic Ho one. In fact the linear superposition shows a presence of metallic holmium larger than 90%, the other compound is holmium oxide (in figure 1 are shown the metallic holmium and in figure 4 is shown the distilled material XPS spectra and the linear superposition comparison).

**Table 1:** Distilled material chemical composition

| **Molecular Formula** | **Chemical weight** |
|---|---|
| Ho($m$) | $0.947\pm0.004$ |
| $Ho_2O_3$ | $0.036\pm0.004$ |
| Y($m$) | $4\ 10^{-11}\pm4\ 10^{-5}$ |
| $Y_2O_3$ | $4\ 10^{-12}\pm6\ 10^{-5}$ |

## 3. Conclusion

As it was shown in section 2, we are able to produce metallic holmium starting from oxide holmium powder. This is a preliminary set-up and it allows us to think a new dedicated vacuum

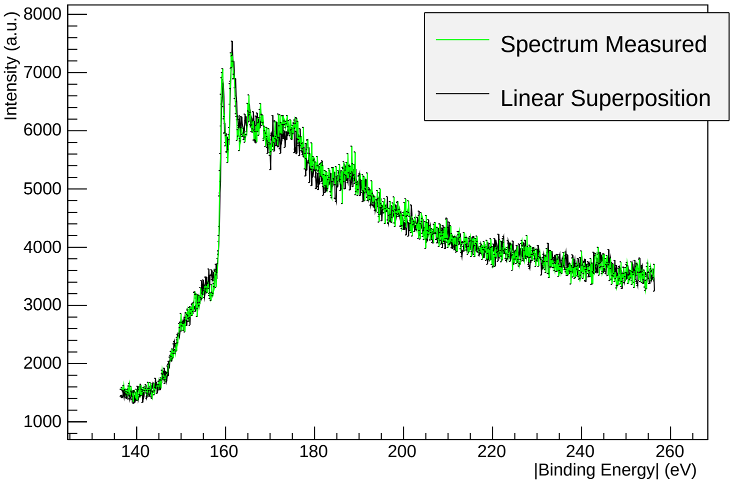

**Figure 4:** Comparison between distilled material vs linear superposition

chamber to improve this reduction-distillation technique. At the moment we are designing a new high vacuum chamber able to reach a pressure down to $10^{-10}$ mbar. In this way the oxide contamination, due to the vacuum in the current chamber, will drop close to zero. In this new system we think to use a pyrometer to measure the temperature of the oven, in which the Knudsen cell will be placed, in order to know with a higher precision this parameter. Another important parameter is the efficiency of the process. We plane to measure it in different temperatures in order to reach the highest value and to use those parameters for the reduction and distillation of the $^{163}$Ho.

## 4. Acknowledgments

The HOLMES experiment is funded by the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC Grant Agreement no. 340321.

We would like to thank Professor P. Manfrinetti for his useful contributions.

## References

[1] A. Nuccitti, Eur. Phys. J. C (2015) 75: 112

[2] See V. Ceriale in these proceedings

[3] F. H. Spedding and A. H. Daane, Metals 6, (1954), 504

[4] E. H. Kobisk and H. L. Adair, Nuclear Instruments and Methods 167, (1979), 153-160

[5] G. F. Wakefield, A. H. Daane and F. H. Spedding, Journal of Chemical Physics, 47, 12, (1967), 4994-4999

[6] C. E. Habermann and A. H. Daane, Journal of Chemical Physics, 41, 9 (1964), 2818-2827

[7] J. F. Watts, J. Wolstenholme, An Introduction to Surface Analysis by XPS and AES, Wiley, 2003