EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

eMMA - Development of an emission Mössbauer apparatus at ISOLDE for the investigation of magnetic materials

[8.01.2020]

Peter Schaaf [1], Dmitry Zyabkin [1] and Juliana Schell [2,3]

[1] Chair Materials for Electrical Engineering and Electronics, Institute of Materials Science and Engineering, Institute of Micro and Nanotechnologies MacroNano, TU Ilmenau, Gustav-Kirchhoff-Strasse 5, 98693 Ilmenau, Germany
[2] Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 45141 Essen, Germany
[3] European Organization for Nuclear Research (CERN), CH-1211 Geneva, Switzerland

….

Spokesperson(s): [Peter Schaaf] [peter.schaaf@tu-ilmenau.de], [Dmitry Zyabkin] [dmitry.zyabkin@tu-ilmenau.de]

Local contact: [Juliana Schell] [juliana.schell@cern.ch]

CERN-INTC-2020-008 / INTC-I-211
08/01/2020

Abstract

The project aims towards the development of a new Mössbauer chamber, where Mössbauer spectroscopy can be applied in situ to the investigation of innovative magnetic materials statically at each point of the hysteresis loop and dynamically in running through the hysteresis loop at various frequencies. Such a system is of extreme importance for getting insights into the underlying atomic effects of the domain effects in magnetic materials.

Request of shifts: no shifts are required this time

Mössbauer Magnetic Analyzer

For the energy transition there is a huge demand of new innovative hard magnetic materials (motors, generators, wind power, e-mobility, etc.) with a large hysteresis loop area and high saturation magnetization while in soft magnetic materials (transformers, sensorics, e-mobility) with a very small hysteresis area [JO11]. Current materials contain either non-abundant materials (rare earth elements) or ones, which are difficult to manufacture. Thus, novel magnetic materials containing only uncritical and available elements have to be developed and new manufacturing routes have to be found for them, e.g. additive manufacturing, superstructuring. There are some promising candidates for both directions, e.g. High Entropy Alloys (HEA), stress engineered materials, or hierarchically designed materials in the hard-magnetic branch, and e.g. MAX phases or compositionally complex alloys for the soft magnetic materials [ZH12, KU18].

High atomic sensitivity of Mössbauer spectroscopy to magnetic properties makes this a versatile method to understand the nanoscale effects on magnetic materials. Due to low quantities of implanted isotopes, the local structure remains almost intact. Therefore, these properties can help in designing the urgently needed novel magnets.

The new Magnetic Mössbauer Analyzer (eMMA) will be adopted and attached to the existing new Mössbauer emission setup at ISOLDE (eMIL). Construction of eMMA, in fact, could benefit significantly from the experience of the Mössbauer collaboration at ISOLDE/CERN [ISO01]. Currently, such magnetic measurements in high fields and in defined hysteresis states at defined temperatures are not feasible. The new setup will include a close to the sample high field magnet with a fast field variation, a heater and a sample manipulator stage, that will highly help to identify the atomic and nanoscale effects causing the macroscopic magnetic properties of the novel magnets. This allows one to design and manufacture the innovative magnetic materials urgently needed for the energy transition. However, refinement of the current magnets trying to get rid of costly Dy and Tb and further investigating of recently developed types of hard magnets such as stacked $FePt_2MnGa_2$ [MA17] or MnGa(Al, Bi) [CO14] compounds may allow one to find a reasonable cheap compromise between ferrites and NdFeB magnets filling the niche from 50 to 400 kJ m^{-1}. Moreover, recently proposed candidates based on MAX-phases could likely fill this niche [IN16]. Especially, considering an opportunity to produce layered MAX-phase-structures.

Advantages of having the eMMA setup at ISOLDE

The setup is financed by the Federal Ministry of Education and Research (German BMBF) [BM01], which aims at the development of innovative and versatile instrumentation for applied interdisciplinary research at the online isotope separator ISOLDE (CERN). The instrumentation described in the project extends the user options at ISOLDE, in particular by the option to perform measurements directly under the in-fluence of an external magnetic field. This is in line with the important objective of developing the experimental infrastructure in the field of charged particles (nuclear probes, ions and positron) in order to increase the capacity of existing large equipment and to optimally exploit the peculiarities of the almost unique online isotope separator worldwide ISOLDE.

As an example, the eMMA instrumentation for ISOLDE addresses a highly topical scientific issue in the field of new materials, including nanomaterials, and energy. Magnetic materials for high performance magnets should first be considered as examples. This should result directly in numerous subsequent applications, particularly in the fields of energy research, materials science, or life and environmental sciences, and will benefit remarkably from the new instrumentation.

The Mössbauer apparatus of ISOLDE should make this possible and can be profitably used for the investigation and further development of magnetic materials. The materials for such magnetic applications must be developed and optimized. The basic mechanisms that take place in the relevant materials, however, are not fully understood. The Mössbauer apparatus for ISOLDE should make this possible and be profitably used for the investigation and further development of magnetic materials. Prerequisite is the technical goal to extend the existing infrastructure at ISOLDE, here the existing Mössbauer equipment, with a powerful option for combined magnetic measurements, enabling access to a large number of isotopes for Mössbauer spectroscopy. The applicants have many years of experience in the development and construction of Mössbauer equipment. A combined Mössbauer magnetometer "eMMA" is being constructed and will be tested with conventional Mössbauer sources ^{57}Fe and then installed for final commissioning at ISOLDE. eMMA is seamlessly attached to the modular Mössbauer equipment "eMIL" installed by the applications in a previous project. The construction and applications of eMMA is the main goal here:

Combined in-situ Mössbauer magnetic analysis*:* In order to investigate novel magnetic materials, a combined magnetometer will be developed. By using the tuneable field of the magnetometer, the atomic mechanisms responsible for the hysteresis behaviour can be simultaneously studied by the nuclear probes of Mössbauer. Usually offline setups can only use Fe, Dy, Sn containing materials and need days and weeks for the measurements. Nevertheless, ISOLDE facility allows the use of a wide range of isotopes implanted in any magnetic material and the spectra can be obtained within 20 minutes.

Fast sample change: Online measurements at ISOLDE place high demands on the sample exchange system, so that the isotope separator can be optimally use for the Mössbauer spectroscopy.

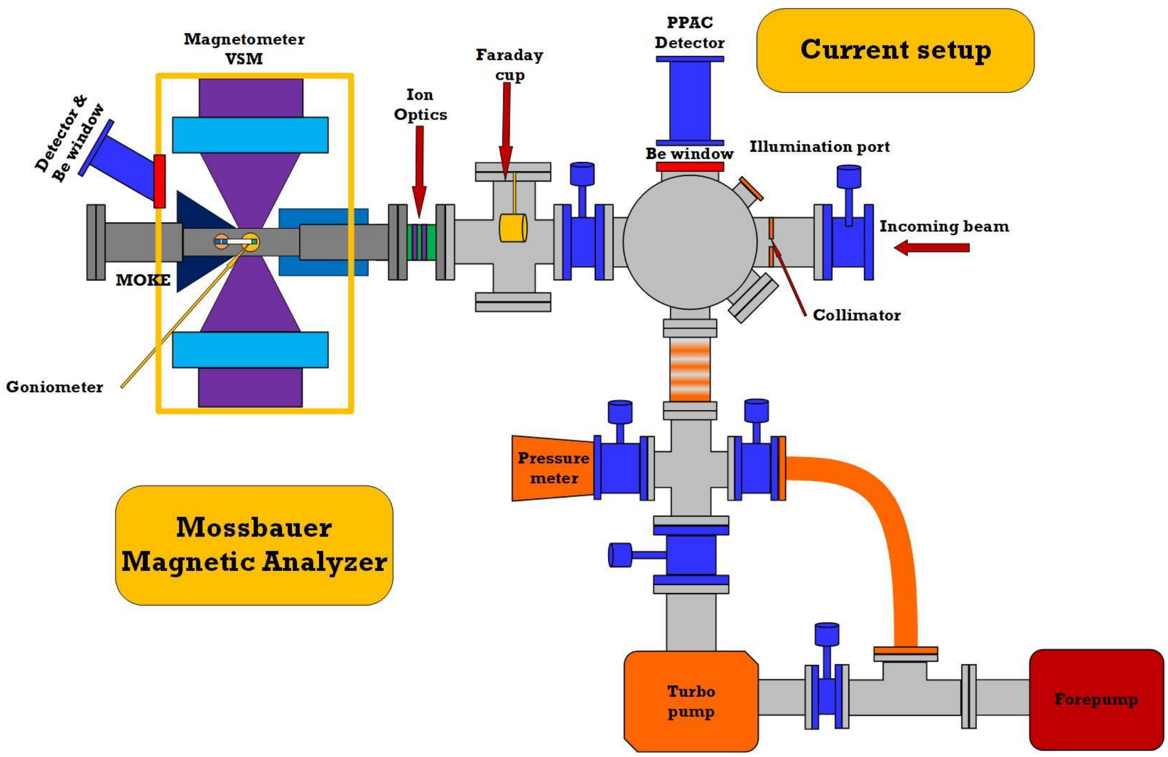

Figure 1. A fully versatile magnetometer (VSM, MOKE) will be attached to the current Mössbauer system eMIL allowing combined and correlated magnetometer and Mössbauer measurements at ISOLDE for the first time and this unprecedented measurements of magnetic materials with radioactive probes.

The approach is to contribute to the understanding of the atomic effects in novel magnets. In particular, the magnetic field at the sample and thus at the probe location can be varied during the measurement by means of variable external magnetic fields. Such online measurement is ideally feasible at ISOLDE. The new Mössbauer magnet analyser at ISOLDE will thus extend to a powerful component for magnetic measurements, which makes it possible to make a large number of isotopes with magnetic dipole moment accessible to Mössbauer spectroscopy. An essential part is the installation of a magnetometer and its combination with the Mössbauer setup. The current

Mössbauer setup is going to be extended and require approximately 3 m^2 more. VSM or MOKE are then simultaneously measured with the Mössbauer spectra. Corresponding developments mentioned in this letter are necessary in order to keep the instrumentation at ISOLDE (CERN) at the highest level.

References:

[JO11] Jones, N. Materials science: The pull of stronger magnets. Nature 472, 22–23 (2011).

[ZH12] Zhang, Y., Zuo, T., Cheng, Y. et al. High-entropy Alloys with High Saturation Magnetization, Electrical Resistivity and Malleability. Sci Rep 3, 1455 (2013).

[KU18] Kulkarni, R., Murty, B. S., & Srinivas, V. Study of microstructure and magnetic properties of AlNiCo(CuFe) high entropy alloy. Journal of Alloys and Compounds, 746, 194–199 (2018).

[ISO01] http://e-ms.web.cern.ch/

[MA17] Y. Matsushita, G. Madjarova, J. A. Flores-Livas, J. K. Dewhurst, C. Felser, S. Sharma, & E. K. U. Gross, "L10 Stacked Binaries as Candidates for Hard-Magnets: FePt, MnAl and MnGa", *Annalen Der Physik*, vol. 529, pp. 1600412, (2017).

[CO14] J. M. D. Coey, "New permanent magnets; manganese compounds", *J. Phys. Condens. Matter*, vol. 26 (6), pp. 064211, (2014).

[IN16] A. S. Ingason, M. Dahlqvist, & J. Rosen, "Magnetic MAX phases from theory and experiments; a review", *J. Phys. Condens. Matter*, vol. 28, pp. 433003, (2016).

[BM01] Research into condensed matter on large devices - Erforschung kondensierter Materie an Großgeräten https://www.bmbf.de/foerderungen/bekanntmachung-1079.html

[MA17] Y. Matsushita, G. Madjarova, J. A. Flores-Livas, J. K. Dewhurst, C. Felser, S. Sharma, & E. K. U. Gross, "L10 Stacked Binaries as Candidates for Hard-Magnets: FePt, MnAl and MnGa", *Annalen Der Physik*, vol. 529, pp. 1600412, (2017).

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	Availability	Design and manufacturing
SSP-GLM chamber	☒ Existing	☒ To be used without any modification
eMIL	☒ Existing	☐ To be used without any modification ☒ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
eMMA	☐ Existing	☐ To be used without any modification ☐ To be modified
	☒ New	☐ Standard equipment supplied by a manufacturer ☒ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH] installation.

Additional hazards:

Hazards	*SSP-GLM chamber*	*eMIL*	*eMMA*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]	Valve gates up to 10 bar	Valve gates up to 10 bar
Vacuum	10^{-6} mbar	10^{-6} mbar	10^{-6} mbar
Temperature	293 [K]	800 [K]	77 K - 800
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		LN
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field			2.6 [T]
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material			
Beam particle type (e, p, ions, etc)			
Beam intensity			
Beam energy			

Cooling liquids	[liquid]		Water
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser		Possible in the UV range	
UV light		Possible UV 365, 350	
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*