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Conceptual Design of Korea Neutron In-beam Mössbauer Spectroscopy

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1. Introduction

Mössbauer spectroscopy is a powerful tool for precisely measuring the hyperfine interactions of nuclei, and is utilized in various fields such as solid-state physics, materials science, chemistry, and earth science. Traditionally, the method of analyzing resonance absorption phenomena using a gamma-ray source was mainly used, but this has problems such as the limitation of the gamma-ray source and the dependence on specific isotopes. Some Mössbauer nuclides are rarely used because they are difficult to produce, have short half-lives, or have low abundances of radioactive nuclides. To solve this problem, Korea neutron in-beam Mössbauer spectroscopy was proposed, which uses neutrons generated in the HANARO research reactor to induce gamma-ray emission from specific nuclei. Therefore, we discuss the conceptual design of a neutron in-beam Mössbauer spectroscopy, and present the theoretical basis, experimental approach, and optimization method for it. This system will overcome the limitations of existing gamma-ray source-based spectroscopy and enable precise analysis of a wider range of elements and in various environments.

2. Conceptual design

2.1 Theoretical method

Neutron in-beam Mössbauer spectroscopy is a method that uses a neutron capture reaction to excite a specific nucleus and measure the resonance absorption phenomenon of the gamma rays emitted in the process. The gamma rays emitted in this process have specific energy, and can be analyzed through resonance absorption. By controlling the resonance conditions using the same doppler shift as the existing Mössbauer effect, the hyperfine structure of the nucleus can be analyzed in various environments.

2.2 Experimental method

2.2.1 Neutron guide design

A cold neutron source using liquid hydrogen is installed in the Korea Atomic Energy Research Institute's HANARO research reactor. Among them, the Prompt Gamma Activation Analysis using neutron capture reaction is being developed and operated at the end of the CG2B guide, and the development of an In-beam Mössbauer spectroscopy is being planned by branching this neutron guide. In order to facilitate neutron transportation, the cross-section was set to 1.5×1.5 cm^2, but in order to reduce the gamma-ray background, a plan to reduce it to 1.0×1.0 cm^2 is being considered as the design progresses.

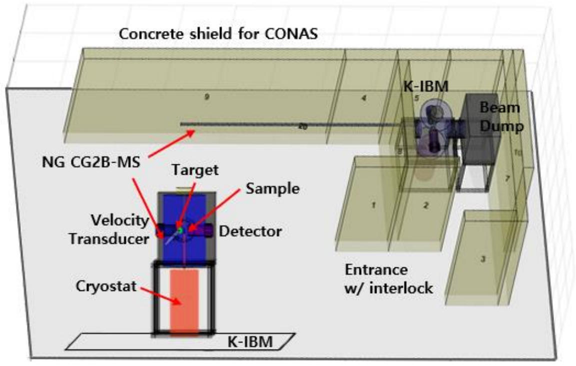

Fig.1 Schematic drawing of the in-beam Mössbauer equipment

2.2.2 Gamma-ray detection and spectroscopic system

A velocity transducer is used to analyze the resonance absorption of emitted gamma rays. A high-resolution HPGe, a silicon drift detector (SDD), a CdTe detector, and a Xe proportional counter are used depending on the situation to measure the gamma-ray spectrum.

2.2.3 Data analysis and optimization

The spectrum is obtained by measuring the gamma-ray absorption rate while changing the doppler velocity. The data acquisition device uses the Wissel CMCA-550 USB pulse height analyzer, and the spectrum is optimized using Wissoft software. The experimental design is optimized using Monte Carlo simulation (MCNP, Geant4, etc.) and the interaction between neutrons and gamma rays is predicted. The electronic structure, magnetism, and crystal structure of the material are studied by analyzing the internal magnetic field and electric field distribution.

2.2.4 Shielding design

^{6}Li enriched polyethylene shielding is used to absorb neutrons, and lead shielding effectively shields gamma rays. In addition, shielding is applied around the

Mössbauer device to prevent neutrons from affecting the device.

3. Expected effects and applications

The Korean in-beam Mössbauer spectroscopy is designed to utilize active Mössbauer radiation sources not only for online experiments but also when the reactor is not in operation.

Promising Mössbauer nuclides include ^{40}K, ^{66}Zn, ^{157}Gd, ^{155}Gd, ^{167}Er, ^{163}Dy, ^{171}Yb, ^{179}Hf based on prompt gamma rays, and short-lived active elements include ^{153}Er, ^{166}Er, ^{175}Lu, ^{186}Os, ^{191,192}Ir, ^{195}Pt, and ^{197}Au. In addition, long-lived reactor-active elements include ^{141}Pr, ^{127}I, ^{129}I, ^{181}Ta, and ^{182}W. These nuclides are used in a variety of applications, including ^{40}K for biological studies, ^{197}Au and ^{196}Pt for catalytic reactions, ^{141}Pr for high-temperature superconductors, and Gd, Er, Dy, and Yb for granite and magnetic layers.

In new materials and nanoscience research, it can play an important role in investigating the magnetic and electrical environment at the nuclear level in nanostructures materials. In addition, in space and earth science research, it can contribute to geological and astronomical research through elemental analysis of meteorites, planetary materials, and crustal components.

4. Conclusions

The development of a neutron in-beam Mössbauer spectroscopy is an innovative method that overcomes the limitations of the existing Mössbauer spectroscopy and enables more precise and extensive elemental analysis. To this end, a conceptual design was proposed that utilizes the gamma-ray emission mechanism using neutron capture and applies a high-resolution gamma-ray detection and doppler shift system. Optimizing this system will enable nuclear-level research in areas that the existing Mössbauer technique cannot access. In future studies, it is important to perform more precise interpretation of gamma-ray spectra through experimental verification and to expand the applicability to various materials. In conclusion, this technology can be utilized as a key analysis tool in various fields such as new materials, nuclear physics, and earth science, and will be established as a next-generation experimental technique utilizing neutron-based research facilities.

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