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Construction of External Beam PIXE Beamline for Cultural Heritage Analysis

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1. Introduction

The importance of preservation and restoration of cultural heritage is increasing, and the need for a scientific approach for cultural heritage research is also increasing. Considering the value and importance of cultural heritage, the importance of non-destructive analysis using radiation and the need for development are also bound to increase continuously. Several European countries, including France [1], have been actively using external beam PIXE (Proton Induced X-ray Emission) for cultural heritage research because it has the advantage of non-destructive analysis compared to conventional destructive analysis methods and more precise analysis compared to XRF (X-ray fluorescence). At the Korea Atomic Energy Research Institute (KAERI), the Korea Multi-purpose Accelerator Complex (KOMAC) is currently constructing an external beam PIXE beamline dedicated to the analysis of cultural heritage using a 1.7 MV tandem accelerator. In this presentation, we would like to discuss the current status of the beamline construction and future utilization plans.

2. Methods and Results

The overall configuration of the external beam PIXE beamline and the characteristics of the key components are described in this session. The external beam PIXE beamline consists of two micro slits to adjust the beam size, a Faraday cup to measure the beam current, two sets of electromagnet steers to adjust the beam transport direction, a nozzle with a beam window to extract the proton beam into the air, a fast closing valve to protect the vacuum system in case of destruction of the beam window, and detectors for measuring X-rays from samples, etc.

Fig. 1. External beam PIXE beamline based on 1.7 MV Tandem Accelerator of KOMAC.

2.1 Beam Nozzle

The most important thing in the outdoor beam PIXE is to allow the proton beam accelerated by the Tandem accelerator to leave the vacuum. When analyzing cultural heritage, it is necessary to enable PIXE analysis in the atmosphere to prevent various problems that occur when samples are put in a vacuum. In order to extract the proton beam accelerated to about 3 MeV from the vacuum to the outside air, a beam window that withstands a pressure of more than 1 atmosphere is required, and it is necessary to minimize the energy loss and spread of the proton beam that inevitably occurs while passing through the beam window. The elements constituting the beam window need to be composed of elements that do not overlap with those to be analyzed through PIXE. In consideration of these various requirements, the beam window was manufactured in four types using three types of materials, and it was manufactured to be easily replaced using a vacuum fitting clamp. The reason why various types of beam windows are necessary is that for more precise analysis when performing PIXE analysis, it is necessary to use a beam window composed of elements that do not overlap with the elements in the sample to be analyzed as much as possible. The photograph of the beam nozzle is shown in Figure 2, and it is made of 4 μm thick Havar foil, 25 μm thick Kapton foil, and 200 nm and 500 nm thick Si_3N_4. The sizes of the holes through which the beam can pass were 4 mm in diameter and 1.5 mm x 1.5 mm, respectively.

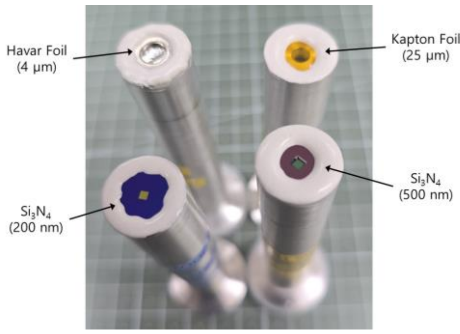

Fig. 2. A picture of a nozzle made of four types of beam window material.

2.2 Detectors for X-ray Detection

In order to analyze various elements generated from cultural heritage samples, a detector system capable of simultaneously measuring low energy and high energy

X-rays is required. In order to minimize energy loss in the process of reaching the sample surface by the proton beam drawn from the beam nozzle, it is better to measure the beam nozzle as close to the sample surface as possible. In addition, in order to measure the X-rays generated from the sample as efficiently as possible, it is better to measure the detector as close to the sample surface as possible. As shown in Figure 3, two types of X-ray detectors are installed on both sides of the beam nozzle to form an angle of 45 degrees with the beam nozzle. The detector on the left is a Silicon Drift Detector (SDD) for low energy measurements, and the detector on the right is a Cadmium Telluride (CdTe) detector for high energy X-ray measurements, all of which are sold by Amptek.

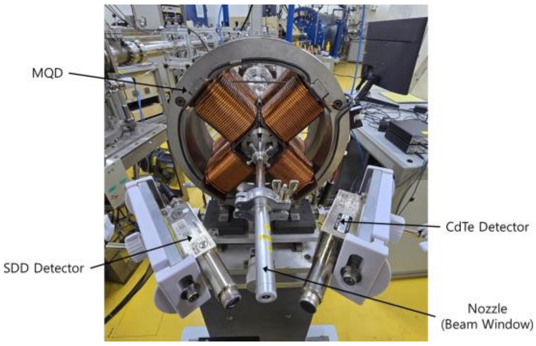

Fig. 3. Two types of X-ray detectors installed on both sides of the beam nozzle.

2.3 Beamline Components for Sub-mm Beam Size

For PIXE analysis, the process of irradiating a proton beam to the surface of the sample is essential, and at this time, a proton beam with a size of less than mm is required in order to minimize the effect on the sample and enable more precise analysis. Beam optics calculation was performed for this, and it was concluded that two micro-slits were installed at a distance of 2.9 m or more and a quadrupole electromagnet doublet (MQD) was needed to adjust the size of the beam at a position 25 cm away from the beam nozzle. Micro-slits were installed on the granite plate to enable precise beam size adjustment by removing the influence of vibration.

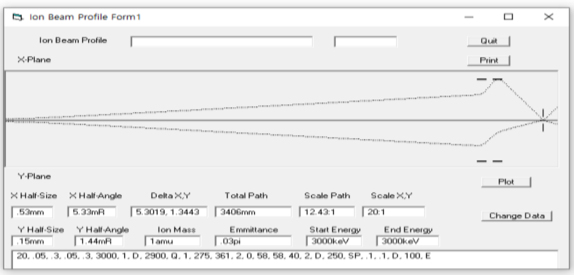

Fig. 4. Results of beam optics calculation for the sub-mm proton beam.

2.4 Fast Closing Valve

The thickness of the beam window is very thin from several hundred nm to several tens of um, and there is a possibility of being damaged by the proton beam or for other reasons during the PIXE analysis process. If the beam window is broken, the vacuum of the entire accelerator, including the vacuum of the beamline, cannot be maintained at a certain level, which may lead to a sudden stop of operation of the accelerator. In order to prevent such a sudden accident, a vacuum gauge was installed near the nozzle, and a high-speed closing valve was installed to isolate the beamline and nozzle part within a short time of tens of msec or less if the vacuum value was poor below a certain level.

2.5 Ion Source

Previously, SNICS ion sources were used to extract the proton beam, but there was a problem that stable operation for a long time was impossible due to frequent cathode replacements. To solve this problem, the ion source system was changed so that the proton beam could be extracted using an alphatross ion source.

3. Conclusions

For component analysis for cultural heritage research, the 1.7 MV Tandem accelerator-based external beam PIXE beamline was constructed to be operated exclusively for cultural heritage analysis. Using the constructed beamline, a proton beam accelerated to 3 MeV will be irradiated to the sample, X-rays generated from the sample will be measured, the energy spectrum will be analyzed, and used for precise component analysis of cultural heritage.

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