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Article / Book Information

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Title(English)	Development of a micro-XRF system based on proton-induced quasimonochromatic X-rays and its applications
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
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In this research, a micro-XRF system based on proton-induced quasimonochromatic X-rays (QMXRs) in combination with a polycapillary X-ray half lens has been developed. To investigate the analytical performance of the system, elemental mapping capability and minimum detection limit (MDL) of a trace-level metal element deposited on the surface of a thick inorganic substrate made of a neighboring element were measured. In addition, in order to demonstrate the applicability of the micro-XRF system to in-vivo measurement of wet biological samples, the MDL of the heavy metal accumulated in living aquatic plants was investigated. The present research consisted of four chapters as follows.

Chapter 1 “Introduction” started with a brief review of trace element analysis of materials with high spatial resolution in science and engineering fields. The micro-XRF analysis is a powerful tool for non-destructive elemental mapping of small regions of sample surfaces. In conventional micro-XRF systems with an X-ray tube and a polycapillary X-ray lens, polychromatic excitation X-rays can cause an appreciable level of scattered continuous background in the XRF spectra. As a result, the MDL is deteriorated. Moreover, in in-vivo measurements, unnecessary radiation dose is given to living samples due to the continuous component which is not essential to the excitation of the elements of interest. To overcome these problems, this study proposed QMXR microbeam produced by a proton-induced X-ray technique and a polycapillary X-ray lens as a tool for micro-XRF analysis in order to increase the detection sensitivity and to reduce the radiation dose to living samples.

In Chapter 2 “Experimental methods”, we described the experimental devices and methods used for the present research. Instruments for the proton-induced micro-XRF experiment including a tandem electrostatic accelerator, beam line components, X-ray/proton detectors, multichannel pulse-height analyzer and a polycapillary X-ray half lens were explained in detail. For the experimental setup using a horizontal QMXR microbeam for analysis of the solid inorganic sample, a 2.5 MeV proton beam was used as the incident proton, and a pure Cu foil with a thickness of 30 μm, which was slightly larger than the penetration range of the 2.5 MeV protons in Cu, was utilized as the

primary target for producing Cu K X-rays (QMXRs) as the excitation source. In order to measure the focal spot size of the QMXR microbeam, a setup based on a knife-edge scanning method was constructed. A square grid pattern of Co thin films on a thick Cu substrate was used as a sample for evaluation of the performance of elemental mapping capability and the MDL of the system. For the setup using a 45-degree QMXR microbeam for analysis of wet biological samples, a horizontal beam of MeV protons was bent downward by 45° using a dipole magnet to produce the 45-degree QMXR beam. Taking into account the incident proton beam emittance, the pole face angles of the dipole magnet was adjusted to achieve the optimum beam optics condition. In addition, the monochromaticity and intensity of the QMXR microbeam as a function of the proton energy were measured in order to optimize the incident proton energy for the in-vivo measurement. A wire scanning device was prepared to measure the 45° microbeam profile. Distribution of Co accumulated in a duckweed leaf floating on a Co solution surface was measured to investigate the capability of the system for in-vivo measurement, and the MDL of Co in the duckweed leaf was quantitatively determined by using standard samples which simulated the duckweed leaf. Finally, the radiation dose to the wet biological sample was evaluated from the measured absolute intensity of the QMXRs.

Chapter 3 “Results and Discussion” contained the experimental results and detailed interpretations of these results. The measured focal spot size of the horizontal QMXR microbeam was 250 μm. From the two-dimensional mapping of Co distribution on the thick Cu substrate, the square grid pattern of Co thin films was successfully reproduced. In addition, the measured spatial resolution was consistent with the microbeam spot size. The MDL of Co on the thick Cu substrate of 2.3 ng was achieved. The monochromaticity of the QMXR microbeam generated by protons with energies of 2.0 - 2.75 MeV were higher than 90%, and this value was not degraded by increasing the proton energy. On the other hand, the intensity of the QMXR microbeam increased with the proton energy. Considering the monochromaticity and intensity of QMXR microbeam and the condition for the stable operation of the accelerator, 2.5 MeV was selected as the incident proton energy for the in-vivo measurement. The focal spot size of the 45-degree QMXR microbeam on the horizontal sample surface was evaluated to be 250 × 350 μm. The micro-XRF system using the 45-degree beam was successfully applied to the in-vivo measurement of distribution of Co accumulated in the duckweed leaves floating on the Co solution, and the MDL of Co in the duckweed leaf was evaluated to be ≈ 250 ppm. Total radiation dose of the QMXRs to the duckweed leaf for each measurement was only ≈ 70 mGy.

In Chapter 4 “Conclusion”, we summarized the overall performance as well as the limitation of the micro-XRF system based on proton-induced QMXRs as an emerging micro-analytical technique. In addition, prospects for improvement of the performance of the micro-XRF based on the proposed technique were presented.