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A new external microbeam system in Fudan University

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ABSTRACT

A cost-effective and removable external beam system is set up based on the Oxford Microbeam system in Fudan University. In our external beam system, 7.5-μm-thick Kapton film is used as exit window with a diameter of 3.5 mm. The spatial resolution is about 18 μm full width at half maximum (FWHM) on a copper grid. As an example, calcium distribution in otolith is present by the external micro-PIXE. In addition, little change can be done to the external system mentioned above for radiobiology experiments. The exit window can be changed from the focal plane to the observation window of vacuum chamber. By calculation, the beam spot size can reach less than 30 μm. Since the Oxford type octagonal target chamber is popular among the nuclear microprobe facilities, this method can be provided to easily replace the in-vacuum system with the external system, extending the in-vacuum analysis to external beam analysis.
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1. Introduction

PIXE is a powerful ion beam analytical technique that can be applied in various fields for its high sensitivity and non-destructiveness. However, the vacuum chambers used in traditional PIXE have limitations on some kinds of samples, such as hydrated biological samples and large art works, because wet samples would be dehydrated in vacuum and art works with larger size than vacuum chamber cannot be measured with integrity. These samples need to be measured in air atmosphere. Thus, external beam system has been developed to solve this problem. Compared with PIXE in vacuum chamber, the external beam setups provide some advantages, such as requiring no special sample preparations in vacuum, reducing damage by heating and charging, avoiding wet sample dehydration in vacuum and easier handling the sample. In the past ten years, external microbeam setups have been widely built in ion beam facilities [1–6,8] and have been applied to analysis of art works, archaeological artifacts [5–7] and recently applied to biomedical research with beam spatial resolution of about 1 μm [1].

The major factor limiting beam spatial resolution of an external microbeam system is the ion scattering by the exit window and the molecules of the ambient gas [9]. At present, two different methods have been proposed to reduce the ion scattering, which leads to two kinds of external microbeam system available in the world, respectively. One method is to use a thin polymer or metal foil as the boundary between vacuum and air, which is popular among the numerous external microbeam systems. For example, a Mylar foil exit window was housed on the vacuum chamber in the external micro-PIXE system. Proton beam was focused to the exit window, which was attached by the sample holder [1]. This offers the advantage that beam scattering and emitted X-ray attenuate only happen in the exit window. Some other studies reported that proton beam was extracted in air through a Kapton or silicon nitride square window housing on a nozzle. Sample was set several millimeters away from the exit window for detector geometry [4,10]. This offers the advantage that large samples (e.g., paintings) can be analyzed, while the disadvantage is that additional distance is needed for detector geometry, and hence spot size decreases. The other method is to introduce ion beams to atmospheric environment by a novel technique [11]. Glass capillary optics was applied to work as a differential pumping orifice as well as a focusing lens. The only disadvantage is that proton beam scanning cannot be performed because of the glass capillary size limit.

In this work, we built an external microbeam system based on Oxford Microbeam system in Fudan University, which is simple, economic and convenient to remove for in-vacuum experiment. As an example, we measured calcium distribution in otolith by our external microbeam system.

2. External microbeam system design

The microbeam facility of the 3 MV tandem accelerator has been running at Fudan University for years. The key parts, including triplet quadrupole lens (model OM-150), collimator slits, scanning system, target chamber, and data acquisition system, were bought from Oxford Microbeams Ltd., whose products have

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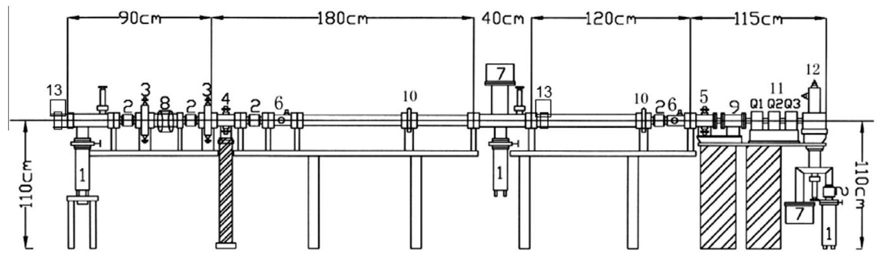

Fig. 1. Schematic of the microprobe facility. (1) Turbo molecular pump; (2) Bellows; (3) Slits; (4) Object slits; (5) Anti-scattering slits; (6) Observe window; (7) Sputter ion pump; (8) Deflection; (9) Scanning loops; (10) Valve; (11) Triplet quadrupole; (12) Target chamber; (13) Pneumatic gate valve (for external beam system).

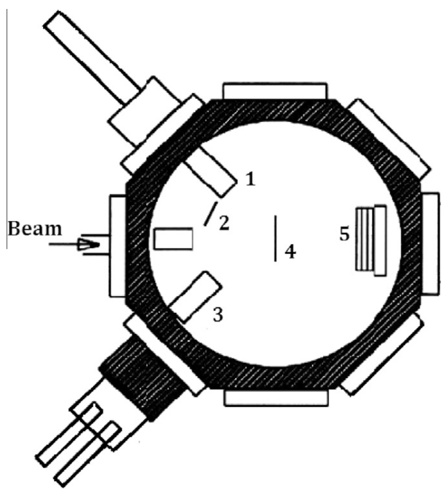

Fig. 2. Schematic of the vacuum chamber. (1) Si (Li) PIXE detector; (2) RBS detector; (3) Zoom microscope; (4) Target holder; (5) STIM detector.

been supplied to universities and laboratories throughout the world. The microbeam facility and the vacuum chamber at Fudan University are schematically shown (Figs. 1 and 2). In Fig. 2, a Si (Li) detector with an active area of 80 mm^2 is set at 135° along the direction of incidental ion beam. A Si-PIN photodiode is situated at about 165° of the beam direction for RBS measurement. For STIM measurement, another Si-PIN photodiode is situated behind the target holder. A microscope is set at minus 135° connected to a CCD video camera. To obtain the best spatial resolution of this system, target holder is positioned in the focal plane.

The new external system is shown in Fig. 3. Comparing to the vacuum chamber, Si (Li) detector, RBS detector and the microscope remain the same, but STIM detector and the target holder are removed. An aluminum cylinder with a removable lid is equipped to introduce focused ion beam in air. The aperture on the lid is made cone-shape in the vacuum side and is glued with exit window in the air side. The Exit window is set to just overlap in the focal plane of in-vacuum experiment.

The quality of the exit window is the key for external beam system. It should meet good mechanical resistance to sustain the pressure, resistance to radiation damage, minimum energy loss and energy straggling [12]. Table 1 shows the calculation of 2.0 MeV proton beam (20 thousand protons) lateral straggling after traversing different exit windows and gas atmosphere respectively using SRIM2008 [13]. For 2.0 MeV proton beam, the lateral straggling is 2.3 μm after traversing 1 mm air. It is two orders higher that after 3-μm-thick Mylar or 8-μm-thick Kapton and even four orders higher than that after 100-nm-thick silicon nitride, respectively. The lateral straggling after traversing helium is improved, but it is still one order higher than that after Mylar or Kapton films. The calculation indicates that the proton beam diameter is mainly dominated by gas scattering. We take the idea [1] that a sample holder was stuck to the exit window directly to avoid beam spreading in the air. Thus,

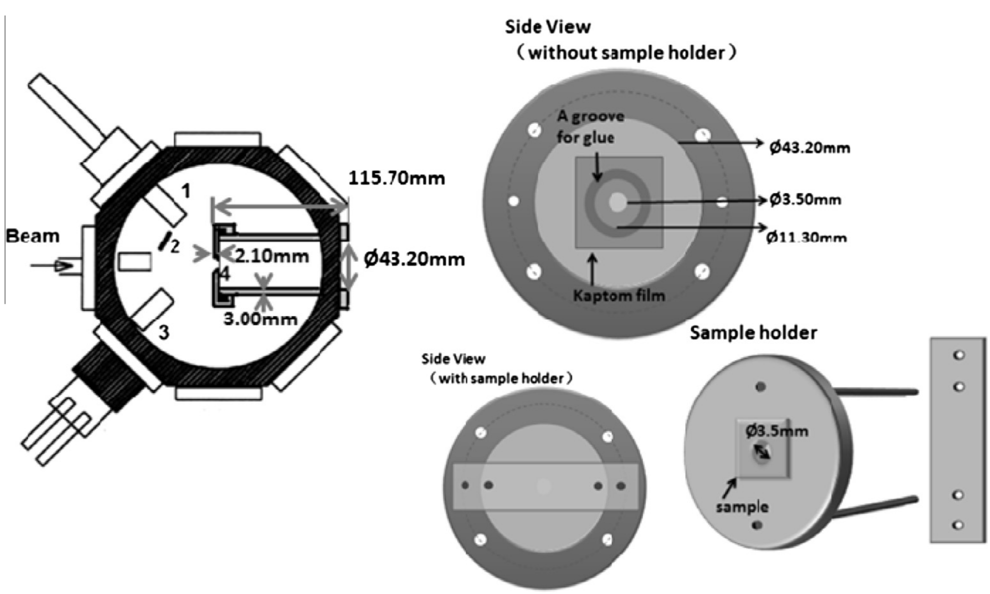

Fig. 3. Schematic of the target chamber of external beam system. (1) Si (Li) PIXE detector; (2) RBS detector; (3) Zoom microscope; (4) Exit window (focal plane of the system).

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