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Performances of capillary X-ray optics for confocal three-dimensional micro-X-ray fluorescence technology

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ABSTRACT

The performances of capillary X-ray optics (CXRO) for confocal three-dimensional micro-X-ray fluorescence (3D Micro-XRF) technology are presented. In particular, the energy dependence of the collecting angle and input focal spot size of the polycapillary parallel X-ray lens (PPXRL), and the energy dependence of spatial resolution of the confocal 3D Micro-XRF spectrometer based on the CXRO are reported. In order to obtain the input focal spot size of the PPXRL, the source scan method was used. The size of the input focal spot of the PPXRL was 25.5 μm at 13 keV, and it was close to that of the output focal spot of a polycapillary focusing X-ray lens (PFXRL) at the same energy. The collecting angle of the PPXRL was 110 mrad at 10 keV, and it decreased with the increasing energies. The depth spatial resolution of the confocal 3D Micro-XRF spectrometer based on the CXRO was 29.3 μm at 17 keV, and it decreased with the increasing energies. The minimal detection limit of this confocal 3D Micro-XRF spectrometer was 101 ppm for the Ti-Kα, when the operating voltage and current of the Mo X-ray tube were 36.0 kV and 800.0 μA, respectively.

1. Introduction

There are some X-ray technologies that can provide the depth distributions of elements of samples. For example, a depth sensitive Micro-XRF spectrometer based on a polycapillary focusing X-ray lens (PFXRL) in the excitation channel and a sharp edge of strong absorbing material in the detection channel can be realized relatively easily, and it does not require a fine adjustment as in the case of a confocal method with two optical elements [1]. Using this method, both the depth distributions of elements and sample surface profiles can be measured, but it is difficult to obtain the 3D mapping images of samples. Another depth sensitive Micro-XRF spectrometer based on a needle-type collimator in the excitation channel and another needle-type collimator in the detection channel may be used to perform 3D elemental analysis [2]. However, the needle-type collimator used in this method is not focusing X-ray optics, and therefore, the data detection time is long. The capillary X-ray optics (CXRO) is widely used in X-ray analysis technology. A polycapillary parallel X-ray lens (PPXRL) can collect a divergent X-ray beam to form a quasi-parallel beam for X-ray diffraction analysis [3,4]. Moreover, the order of magnitude of the input focal spot size of the PPXRL is 10 μm, and therefore, it is widely used in micro X-ray analysis [5–7]. A PFXRL can focus a divergent X-ray beam into a micro output focal spot. The order of magnitude of this output focal spot size and the gain in power density of the PFXRL is 10 μm and 10^3, respectively. Hence, also the PFXRL is widely used in micro X-ray analysis [8–10]. The principle of the confocal technology based on the CXRO was first proposed in the early 1990s by Gibson and Kumakhov [11]. In recent years, the confocal technology based on the CXRO has become popular, and widely used in 3D Micro-XRF analysis [12–15]. Moreover, it has potential applications in 3D Micro X-ray absorption fine-structure (XAFS) analysis.

In this paper, the performances of the CXRO for confocal three-dimensional micro-X-ray fluorescence (3D Micro-XRF) technology are fully studied.

2. Experimental setup

Fig. 1 schematically shows the realization of a confocal 3D Micro-XRF spectrometer based on a PFXRL in the excitation channel and a PPXRL in the detection channel. The X-ray source used here was a metal-ceramic X-ray tube (MCBM 50-0.6B) and a Mo anode whose spot size was about 50.0 μm. The detector system was an XFlash® Detector 2001 RÖNTEC and RÖNTEC MAX

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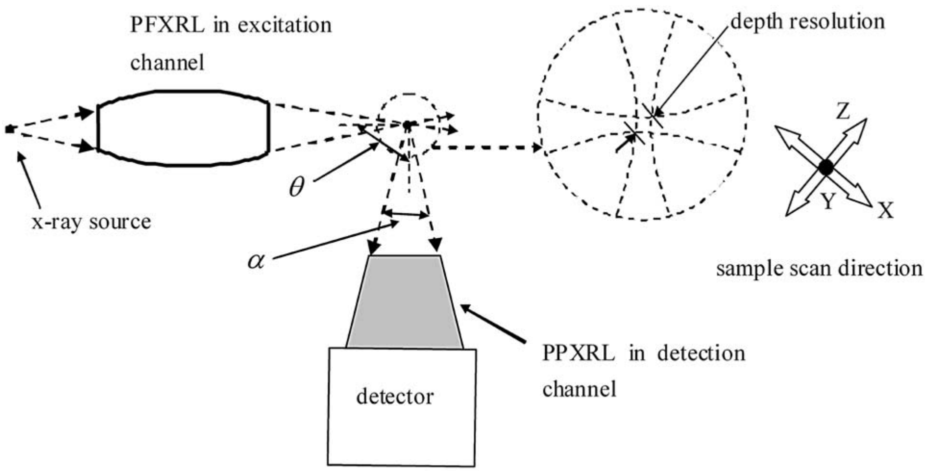

Fig. 1. Scheme of confocal 3D micro-XRF spectrometer.

Table 1
The parameters of PFXRL and PPXRL.

	PFXRL	PPXRL
Length (mm)	60.1	18.2
Input diameter (mm)	5.2	2.1
Output diameter (mm)	2.6	4.2
Channel inner diameter of capillary at output end (μm)	4.5	8.9

Spectrometer. Some parameters of the PFXRL and PPXRL are reported in Table 1.

3. Results and discussions

3.1. Performances of capillary optics for confocal 3D micro-XRF technology

The energy dependence of the gain in flux density of the PFXRL is shown in Fig. 2. The high gain of the PFXRL will result in the decrease of the data detection time.

It is well known that a PPXRL accepts photons emitted within a finite region, i.e. an input focal spot and the input focal spot size can be measured using a source scan [5]. When the X-ray source positioned at the input focal distance of the PPXRL scans in a direction transverse to the axis direction of PPXRL, the counts on a detector as a function of the source displacement can be obtained. If the full-width at half-maximum (FWHM) of the counts curve is written as w, the input focal spot size Φ is

$$\Phi = \sqrt{w^2 - d^2} \quad (1)$$

where d is the diameter of the source spot. Fig. 3 shows the energy dependence of the input focal spot size for the PPXRL and the output focal spot size for the PFXRL.

As shown in Fig. 3, the size of the output focal spot of the PFXRL and the input focal spot of the PPXRL decreases with the increasing energies. This can be explained as follows. For the PFXRL and PPXRL, their focal spot size ϕ can be roughly written as

$$\phi \approx 1.3 f \theta_c \quad (2)$$

where f is the output focal distance for the PFXRL and the input focal distance for the PPXRL, and θ_c is the critical angle of total reflection. The increase of f with the increasing energies is very small as mentioned in the subsequent section. The decrease of the critical angle with the increasing energies is larger, because, for the borosilicate glass capillary, the critical angle of the total

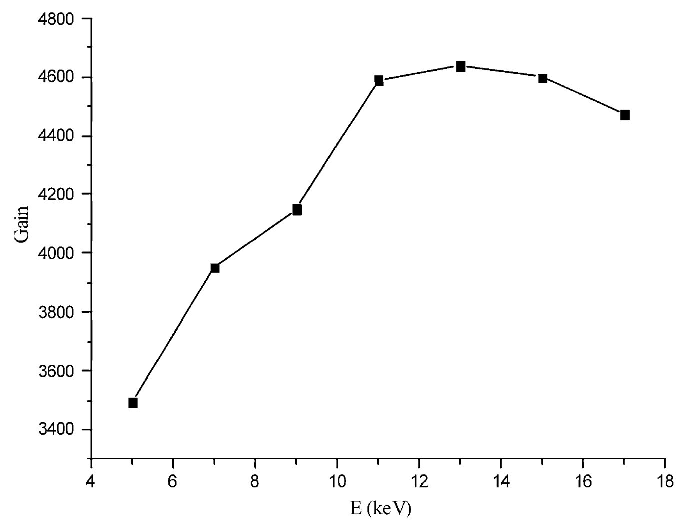

Fig. 2. The energy dependence of gain at focal spot of PFXRL.

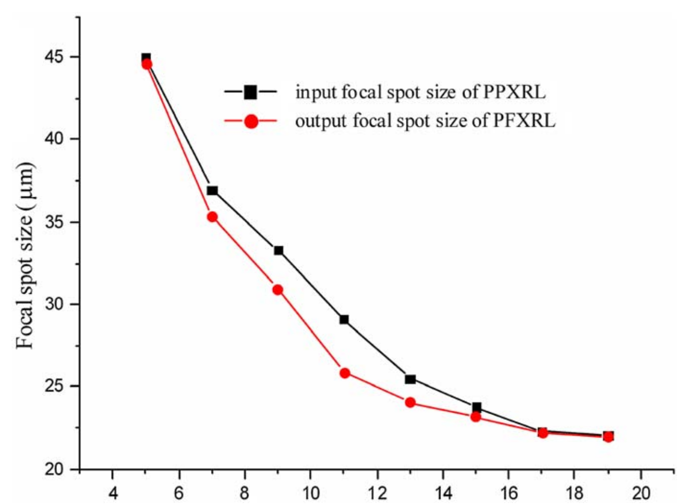

Fig. 3. The energy dependence of focal spot size for polycapillary X-ray lens.