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Development of X-ray Micro-CT System using Open Type Microfocus X-ray Source for Rock and Mineral Samples.

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X-ray micro-tomography is one of the best technique for investigate internal structures of rock and mineral samples. There are many developments for X-ray micro-tomography system with microfocus X-ray source, however, they are treated as a general system for various kind of materials including metals and soft materials. A system with a flexibility is required for Earth and planetary materials' science. They are energy selectivity, high efficiency (measurement speed) and spatial resolution around 1 μm at most.

It is essential to increase the measurement speed. This is because the measurement time of several hours is necessary in the high spatial resolution systems. The stability of light source position and the temperature change could be problems in those systems [1]. Some techniques to correct the instability of the light source have been proposed to solve those problems [2]. However, when the measurement time becomes sufficient short, those corrections could be unnecessary. In this study, samples up to several millimeters in diameter are targeted. As the result, a detector having sufficient spatial resolution and sensitivity from 10 keV to 60 keV can be used.

The system consists of light source, high precision stage, X-ray image detector and experimental hutch (Figure 1). The light source is open type microfocus X-ray source L10711-04 (Hamamatsu photonics, Japan). The range of voltage is between 20kV and 100kV with tungsten or silver target. There are three mode of focal spot size. They are small mode (S), intermediate mode (M) and large mode (L) with different spot size of 0.8μm, 2μm and 5μm, respectively. The X-ray power is restricted by the focus mode and tube voltage. The target is cooled at 25ºC ± 0.1ºC by a water chiller (HRS012-A-10, SMC, Japan). High precision stages are made and assembled by Kohzu precision. All linear translation stages have resolution better than a micro-meter. The wobble of the rotation stage for the sample is less than 1.0 micro-meter. The X-ray image detector is visible light conversion type using fiber optics plate (C12849-102U, Hamamatsu Photonics, Japan) [3]. As a representative specifications, the scientific CMOS (sCMOS) based detector has the format of 2048 x 2048 pixels, the dynamic range of more than 18000 (16 bits ADC), the pixel size of 6.5μm and 20μm thickness of powder type P43 ($Gd_2O_2S:Tb^+$) phosphor screen. The detector has 2 x 2 binning mode to increase the efficiency. There is a linear translation stage to change the magnification factor of the X-ray image on the detector. The effective pixel size can be changed between 0.30 μm/pixel to 9.15 μm/pixel with the 2 x 2 binning mode, which is correspond to 43.3 and 1.42 as a magnification factor. Those pixel sizes and field of view are fit to investigate micro structures in rock and mineral samples including meteorites. The measurement time is about 35 minutes with focus mode M and 1800 projections for 360 degrees (0.2 degree step) with the exposure time of 1 second for a projection. The temperature of the experimental hutch is controlled by air flow. A diaphragm blower (JDK-30, Taiko, Japan) is used to generate air flow. An air stone (#100 Ibuki, Japan) is placed on the experimental table. There is a double pipe type heat exchanger (NH-S2, As one, Japan) between the blower and air stone. The temperature of the air flow is adjusted to 25ºC ± 0.1ºC by the water chiller for target. As the result of those air flow system, the temperature in the hutch is stabilized at 28.3ºC ± 0.1ºC during a measurement.

The tomographic reconstruction software was made for this system based on Feldkamp method [4]. The software runs on multi-core CPU system. It takes 20 minutes for whole reconstruction of 1024 x 1024 pixels and 1800 projection /360deg data set with 8 threads of Intel Core i7-7700 CPU. All images are loaded on main memory, therefore about 8 giga byte memory is required to the processing in the typical condition. The phase retrieval technique can be applied before the tomographic reconstruction to increasing the signal-to-noise ratio in CT images [5]. The phase retrieval needs about 17 minutes to process 1800 images on the same CPU system.

Figure 2 shows the center part of CT images of pumice. The measurement has been done in medium spatial resolution mode, 2.1 μm /pixel. 0.5mm-thick aluminum plate was used to eliminate lower energy X-ray. Other measurement conditions are the same above. The signal-to-noise ratio could be successfully increased by the phase retrieval.

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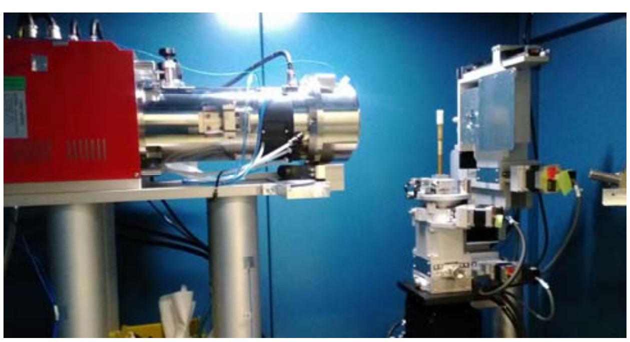

Figure. 1. Experimental setup. Light source, sample, sample stages and X-ray image detector are shown. The distance from source to the detector is around 29 cm.

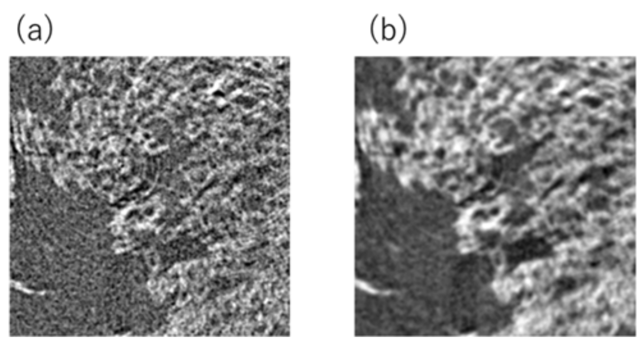

Figure. 2. A part of CT images of pumice. The image size is 0.46 mm x 0.46 mm. (a) Normal tomographic reconstruction only. (b) Tomographic reconstruction with phase retrieval.

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