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High Performance Measurement System of Large Area Solid-State Track Detector Array for Ultra Heavy Cosmic Rays

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Abstract: In the handling of solid-state track detector (SSTD), a long period and many human powers has been historically required for a long period and many human powers to scan and analyze etch pits produced on the detector. Because a large area greater than a few m^2 detector is required to observe ultra heavy nuclei in galactic cosmic rays, a high speed scanning system is practically important to realize the analysis of our observation data. The apparatus to locate quickly the position of UH event produced in the large SSTD using optical methods was developed, and it allows us effectively to trace incident particle trajectory in cosmic ray detector telescope. We have developed the fast automated digital imaging optical microscope (HSP-1000) to scan and analyze the etch pit produced on the detector, whose image acquisition speed is 50-100 times faster than conventional microscope system. Furthermore, analyzing massive cosmic ray track data produced in extremely large exposed area requires a completely automated multi-sample scanning system. The developed automated system consists of a modified HSP-1000 microscope for image acquisition, a robot arm to replace the sample trays, a magazine station for storing sample trays, and a scanning and analyzing computer to control the whole system. Moreover, since the thickness measurement accuracy in local area of SSTD was improved to achieve high charge and mass resolutions, the new system has been developed to measure the SSTD thickness located adjacent to etch pit in SSTD with an excellent resolution of $\pm$ 0.2 μm.

Introduction

Large scale observation program of ultra heavy nuclei ($Z \geq 30$) in galactic cosmic rays (UH-GCRs) is planned with the use of high performance solid-state track detector (SSTD) such as CR-39 plastic and BP-1 glass on board long-duration balloon [1]. The handling of SSTD historically requires a large number of year $\times$ person to scan and analyze the etch pits produced on the detector. It is due to the manual or semi-automatic analysis using the conventional optical microscope system. In the previous cosmic ray observation using SSTD, for example UHCRE [2], it is the actual condition that the analysis of the SSTD, exposed to UH-GCRs and recovered in 1990, is finished only about 36 % of the total exposure area until now. We plan to use the cosmic ray telescope with the large exposure area of $\sim$ 16 m^2 made of the SSTD stacks. Hence, its handling is more difficult than before.

It is necessary for the SSTD analysis to solve the following three major problems: 1) how to determine the locations of penetrated etched holes as soon as possible, 2) how to precisely analyze the tracks obtained over a short period, and 3) how to precisely measure the thickness of SSTD which is an important parameter to obtain high charge and mass resolution. In this paper, we present the current status of developments of high speed microscopic measurement system and peripheral high performance measurement techniques for the observation of UH-GCRs.

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Determination of locations of penetrated etched holes

When we get the information of particle trajectory in large-scaled experiments made so far using SSTD, it is important to locate more effectively and quickly UH events produced in the large SSTD. The ammonia gas was generally used as a typical method to find the penetrated etched holes. However, this requires at least several minutes to perform and presents a serious health hazard. Therefore, we have developed two ”optical methods” in place of ”ammonia gas method”. One uses vacuum ultraviolet (VUV) light, and the other uses visible light as a light source [3].

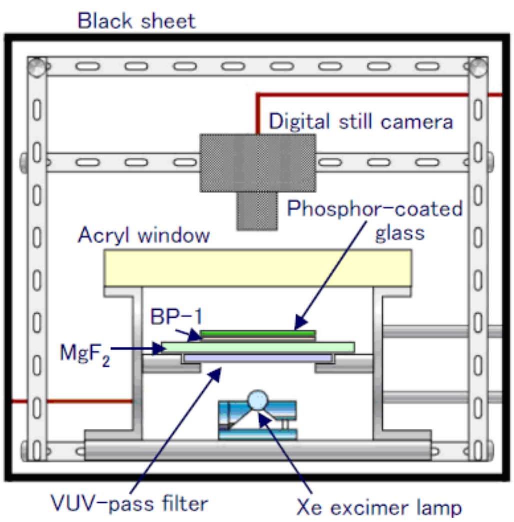

Figure 1: A cross-sectional view of an apparatus for determining the locations of penetrated etched holes in BP-1 detector using VUV light [3].

Figure 1 shows a schematic cross-sectional view of the apparatus for determining the locations of penetrated etched holes, using a xenon excimer lamp with a wave length of 172 ± 15 nm as a light source. Figure 2 shows the curve of transmittance versus wave length for a 1.2 mm thick BP-1 detector. The transmittance in the wave length region from 140 nm to 185 nm is almost zero. Thus, we can detect the location of penetrated holes from VUV light passed through the BP-1 detector. The detection threshold for penetrated holes is estimated to be a diameter of 40 μm.

In the second method, the surface of an etched BP-1 detector was coated with silver. We measured the penetrated light distribution for visible light using this apparatus. We concluded that the detection threshold of this method was less than 30 μm.

These digitizing images are automatically analyzed with high speed to catalog the spot location and its size to computer storages. These location data are used to trace particle trajectory in cosmic ray detector telescope.

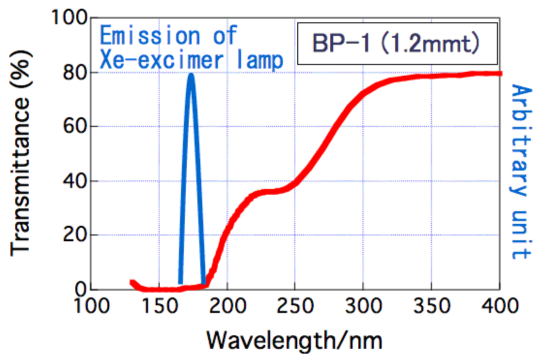

Figure 2: The curve of transmittance as a function of the wavelength of light and the wavelength spectrum for the Xe excimer as a VUV-light source. [3].

Improvement of high speed imaging optical microscope

In order to analyze massive nuclear track data in the large area exposure experiment, a high speed system for the analysis is absolutely indispensable. We have developed the automated digital imaging optical microscope (HSP-1000) to scan and analyze the etch pit produced on the SSTD [4]. We succeeded in a great increase of imaging speed using a line sensor in place of the traditionally used CCD camera and using a real time auto-focusing optical pickup system. The auto-focus unit uses an optical pick-up system consisting of a diode laser and photodiode array to detect the sample surface. The auto-focus system controls the distance between the image plane and the objective, via feedback control, by continuous adjustment of the tilting table during image capture by linear sensor.

As a result of the use of a line sensor, continuous stage motion and continuous focusing, we attained image acquisition speeds that are 50 to 100 times faster than that of a conventional CCD-based microscope system.

This microscope system uses a monochrome line sensor to acquire an image at a line rate of 32.6 kHz. The line sensor has a sensitive area of 4096 $\times$ 1 pixels and a resolution of 7 μm $\times$ 7 μm per pixel. At a total magnification of x200 (x20 objective lens), each pixel corresponds to a 0.35 μm $\times$ 0.35 mum field of view. The microscope also uses a linear motor type stage (120 mm $\times$ 120 mm, 0.1 μm resolution) with linear scales as a feedback encoder for X- and Y- movements. The stage is mounted on a tilting table equipped with three shafts that are independently controlled in the Z-direction by three ultrasonic stepping motors with 0.25 μm resolution. A typical imaging time for monochrome images is $\sim$ 20 sec/cm^2, when we use a transmission light source with a x20 objective lens (0.35 μm/pixel $\times$ 0.35 μm/pixel). It is then possible to scan the large area of 16 m^2 within 2$\sim$3 yr for our observation program.

Furthermore, we have developed the etch pit analysis software (PitFit) to obtain the physical quantities from etch pit image after the microscopic scanning. The edge of each etch pit is detected by the noise reduction and binarization of the image after the setting of a grayscale threshold. Then, image analysis algorithms attempt to extract the information to size and shape of each etch pit using the ellipse fitting with the least-square technique for a second order polynomial function. The fitted ellipses are shown on the raw image as an overlay and numerical data for the etch pit position, major and minor axes, etc. are also displayed on the screen, as shown in Fig. 3. Moreover, after automated analysis, the user can modify the result, selecting the edge of the etch pit manually.

Automated multi-sample scanning system with a robotic sample changer

Analyzing massive cosmic ray track data produced in extremely large exposed area requires a completely automated multi-sample scanning system. The automated system analyzing etch pit produce

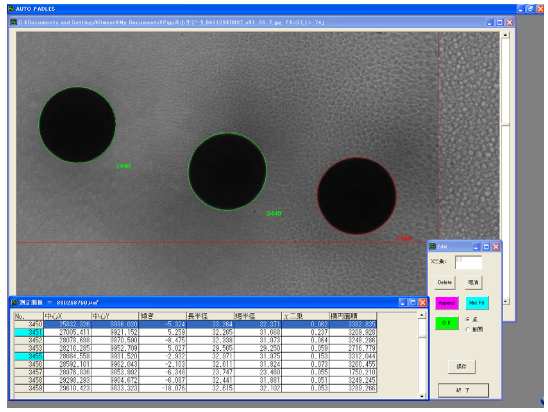

Figure 3: Photograph of analyzing etch pit using PitFit software.

on the SSTD surface has been developed [5]. As shown in Fig. 4, this system consists of a modified HSP-1000 microscope for image acquisition, a robot arm to replace the sample trays, a magazine station for storing a large number of samples to be scanned, a scanning computer to control the whole system, and an analysis computer for parallel image analysis and ellipse-fitting of etch pit.

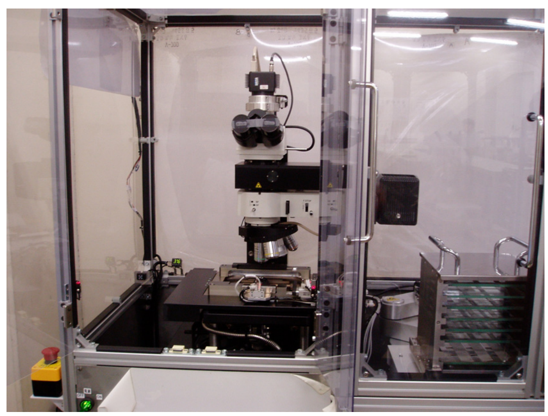

Figure 4: Photograph of HSP-1000 with the automated multi-sample scanning system.

New method of precise measurement of thickness for the SSTD

The measurement of detector thickness is a very important parameter to obtain high mass resolution [6]. The improvement of thickness measurement accuracy and the mapping of thickness in local area of detector plate will allow us to achieve higher charge and mass resolutions. The new optical system with an optical displacement sensor was developed to measure the local thickness of the SSTD, as shown in Fig. 5 [7]. The measurement accuracy of this method was found to be $\pm$ 0.2 μm. This accuracy is one order of magnitude higher than that of conventional methods, such as micrometer method, and is comparable to that of etch pit size measurement under the optical microscope.

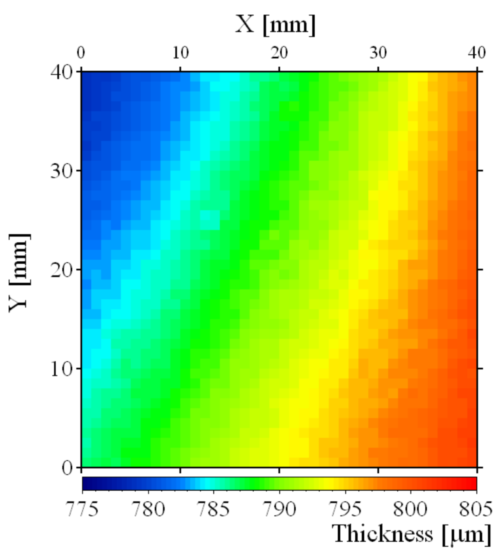

Figure 5: The contour map of detector thicknesses (before etching) for the local points measured according to a grid pattern with sampling distance of 1 mm [7].

Summary

In order to analyze speedily and precisely massive cosmic ray track data produced in the SSTD with an extremely large exposed area, we have developed an automated multi-sample scanning system with high speed imaging microscopic system and new optical thickness measurement system. The scanning system to detect and locate the penetrated etched holes produced in the SSTD utilizing VUV or visible light leads to reconstruct quickly the particle trajectory in the cosmic ray telescope. The automated system, analyzing etch pit produce on the SSTD surface which consists of a full-automated HSP-1000 microscope, a scanning computer to control the whole system and an analysis computer for parallel image analysis and ellipse-fitting of etch pit, makes to scan the large area of 16 m^2 within 2$\sim$3 yr for our observation program. Moreover, the new system with the optical displacement sensor makes the high precise measurement of local thickness in the SSTD. Thus, the high performance comic ray telescope and analyzing systems will allow us to make the first precise measurement of the elemental and isotopic compositions of UHGCRs with sufficient particle identification power and statistics.

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