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Status of Directional Dark Matter Search with Nuclear Emulsion

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We are advancing the R&D of new nuclear emulsion for directional dark matter search. This is the only idea of directional dark matter search with solid detector.

We have already confirmed the possibility to detect the nuclear recoil tracks. However, as nuclear recoil tracks have submicron length, automatic readout has been very difficult.

In this talk, we could develop the new readout technique of nuclear recoil tracks by using expansion technique with swell characteristic of emulsion and image processing. By this technique, it will be possible to readout automatically and large volume scanning. Moreover, we demonstrated the X-ray microscope readout as final analysis tool for candidate tracks after readout and selection with optical microscopy.

In addition, we set up the production facility of nuclear emulsion in our laboratory, and we have started to product the new emulsion R&D. By this system, we will be able to get the nuclear emulsion freely and develop the new emulsion without depending on the company.

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1.Introduction

Nuclear emulsion is a kind of photographic film and 3D solid tracking detector. Standard nuclear emulsion has the resolution of some μm.
We are doing the R&D for directional dark matter search with nuclear emulsion. So far the scale of experiments using the nuclear emulsion has been more than 1000kg. The high speed automatic scanning system enabled the large scale experiment with nuclear emulsion. Therefore, for the directional dark matter search with the ton scale, automatic scanning system is very important.

2. New high resolution nuclear emulsion

For directional dark matter search with nuclear emulsion, we should detect submicron tracks of recoiled nuclei induced by dark matter because nuclear emulsion is a solid detector.

However, the ordinary nuclear emulsion cannot detect the tracks shorter than 1μm because it has the mean silver halide crystal size is 200nm and line density of crystals is about 2.3crystals/μm. These crystal sizes and line density of crystals decide the resolution of nuclear emulsion.

We succeed to develop the higher resolution nuclear emulsion by downsize the silver halide crystal and increasing the number of silver halide crystal. This detector is called “Nano Imaging Tracker: NIT”[1]. NIT has the mean crystal size of 40nm, and the line density of crystals is about 11crystals/μm. The electron microscope images of ordinary and NIT emulsion were shown in Fig.1

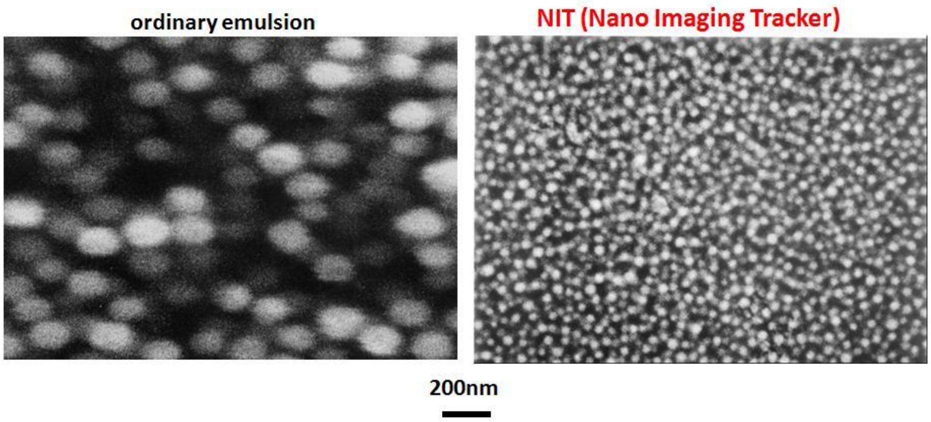

Fig.1 Electron microscope images of ordinary emulsion and NIT emulsion. Left image shows the ordinary emulsion. Right image shows the NIT emulsion. In this image, white spheres indicate the silver halide crystal. Here, both images are same scale, and silver halide crystal size is about 200nm for standard emulsion, but NIT has the silver halide crystal of about 40nm.

3. Tracking of recoiled nuclei

Nuclear recoil tracks can be demonstrated by low velocity ion. Here we used the ion implant system to expose the low velocity Kr ion. Kr ion corresponds to the demonstration of Br recoil because each other’s atomic numbers are neighboring.

Nuclear recoil tracks in NIT emulsion can be observed by scanning electron microscope (SEM) like Fig2. The detected tracks with nuclear emulsion are observed as the line of silver grains more than two grains like Fig.2.

Automatic scanning system for nuclear emulsion should be based on the optical microscope because high scanning speed is necessary for the ton scale detector. However the discrimination of direction of submicron tracks with the optical microscope is difficult for optical resolution. On the other hand, electron microscope is impossible to scan the large volume.

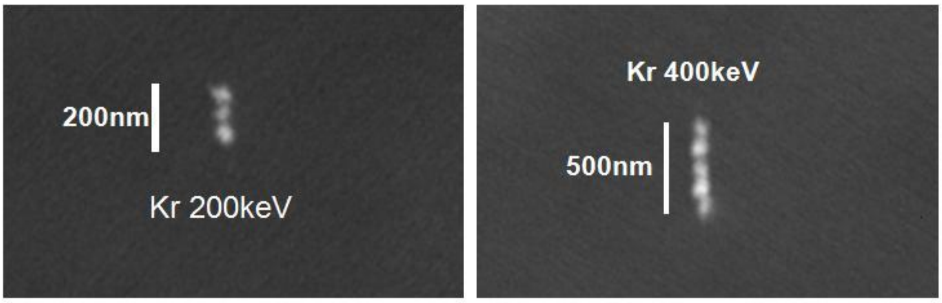

Fig.2 Scanning electron microscope (SEM) image of low velocity Kr ion (200 and 400keV) tracks demonstrated the nuclear recoil tracks. White spheres are silver grains generated by development treatment. This line reflects the track of an ion (or a recoil nucleus).

4. The techniques for the readout of submicron track

The ideal resolution for the optical microscope is about 200nm, while it depends on the NA (numerical aperture) of object lens and wavelength. Especially the epi-illumination dark field optical microscope has the resolution near the ideal one and good contrast even though the usual effective resolution is lower than ideal resolution. However direction of submicron tracks can be recognized as elliptical configuration. Therefore, if 100nm order tracks are elongated by the twice expansion of emulsion [2], you can recognize as the image of elliptical signal. The major direction of ellipse reflects the direction of nuclear recoil track. This concept was shown in Fig.3. This expansion technique developed here enabled the isotropic expansion and keeping the stable condition by using the swell characteristic and poly-acrylamide. The angular uncertainty is about 1.8 degree.

For the upper right figure in Fig.3, nuclear recoil tracks can be observed as the elliptical configuration. That elliptical event can be discriminated by image processing. By elliptical fitting with image processing, you can draw the distribution between major and minor length of ellipse like Fig.4 left. As noises are almost sphere, the ratios of major to minor length are almost one (black dots in Fig.4), and the high ellipticity events (red dots in Fig.4) are expected to be candidate events. In Fig.4 left, minor length cuts are also included because large minor events reflect the dust, and almost events of small minor length are small noises. For candidate events, angular distribution is shown in Fig.4 right. From the distribution, you can see the directionality of the tracks with 100nm order lengths. By this method, we can select and analysis nuclear recoil tracks with automatic scanning system.

Now, we are going forward the development of the automatic scanning system using that technique.

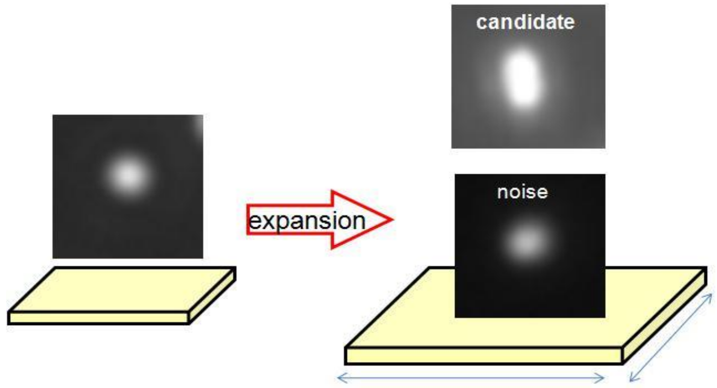

Fig.3 The concept of expansion technique. Before expansion of emulsion plate, it is difficult to recognize the nuclear recoil signals as tracks or to distinguish the track from noise with optical microscope like left image. By using expansion, if the signal is track, you can recognize the track as elongated signal like the upper right figure, but if the signal is just noise, you cannot recognize the direction like the bottom right figure because noises are composed of only one grain.

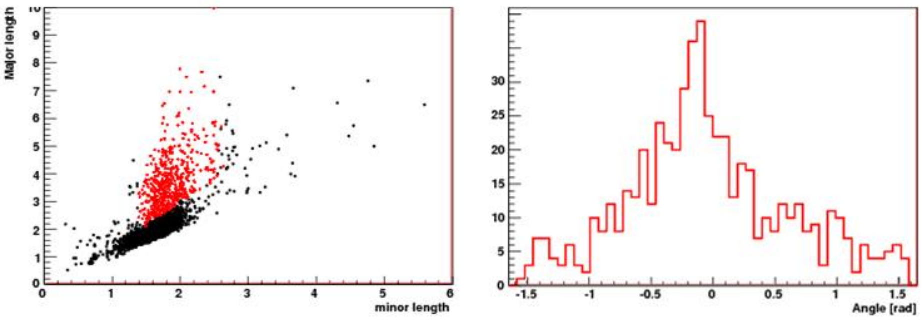

Fig.4 The result of image processing for the selection of submicron tracks. Left figure shows the distribution between major and minor length (arbitrary pix unit) for the elliptical fitting of event. Red points are candidates tracks in the preliminary signal region. Right figure shows the angular distribution of selected signals (red points) at the left figure. Here 0 degree is the center of low velocity Kr ion beam direction.

5. Observation system with X-ray microscope

X-ray microscope is useful as the final check of candidate tracks because it is high resolution and non-destructive observation is possible. We started the development of X-ray microscope system for the analysis of nuclear recoil tracks.

The purpose of X-ray microscope is to check the candidate tracks selected by optical microscope like the elliptical signals in Fig.3. Our first test of this system is the confirmation to be able to match between optical and X-ray image. The first result was shown in Fig.5. By printing the mark as the original point and making the common coordinates, this matching with event by event became possible. In Fig.5, selected events with optical microscopy are confirmed as tracks because more than two silver grains are lining. If those would be composed the one silver grain, they are noise events. This result is verification of realistic test for the readout of nuclear recoil event.

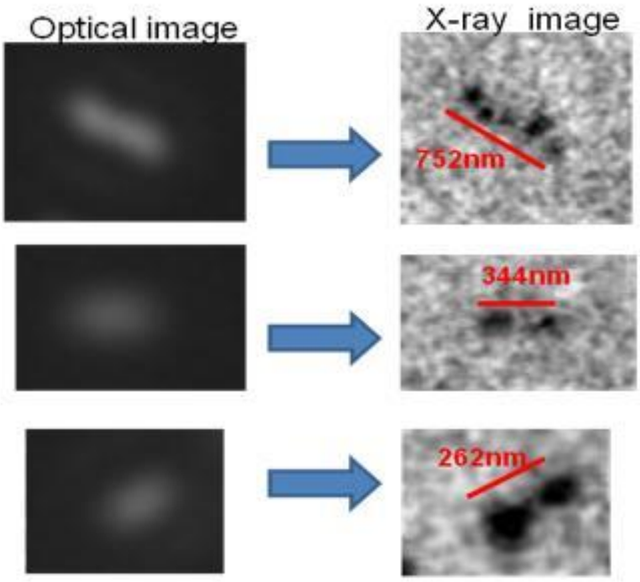

Fig.5 The matching of the images between optical and X-ray microscope. Left image show the optical microscope images and right images show the X-ray microscope images for same signals.

6. Nuclear emulsion production facility

So far nuclear emulsion has been produced by Fuji Film. However, for this project, we need studying and tuning of emulsion for sensitivity, crystal size and background rejection more. Finally production at underground laboratory is required. Therefore, emulsion production in laboratory scale ourselves is important and essential for this project.

At this opportunity, we set up the production facility for nuclear emulsion, and we have already started to product the new emulsion for dark matter search. This work is collaborating with the retired Fuji Film engineer. Therefore we can produce it preferentially, and we can start the R&D of new finer grain emulsion, high background rejection and sensitivity tuning.

We aim to produce the practical emulsion for the test running until 2011.

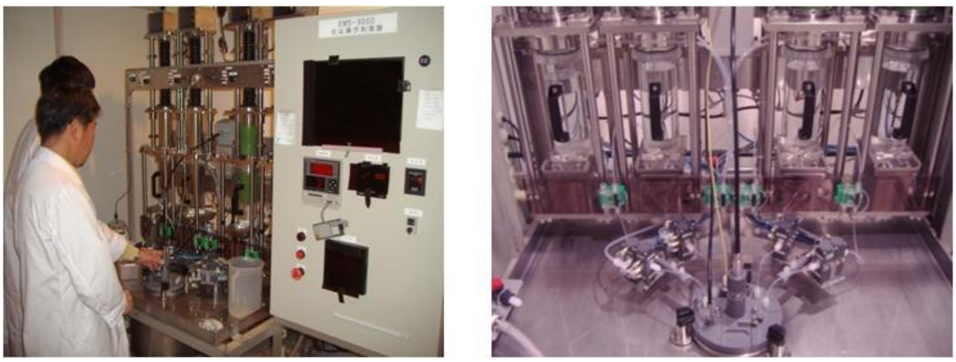

Fig.6. The installed machine to produce the nuclear emulsion in laboratory.

7.Conclusion and Prospect

So far the development of automatic readout system for nuclear recoil tracks with nuclear emulsion was a roadblock to start the test running. However we could develop the new readout technique in this study. Therefore we will prepare the realistic system for test running. From 2011, we will start the neutron study, develop the scanning stage for automatic readout, and the background run. In future, we aim the directional dark matter search with the ton scale detector.

Reference

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[2] T.Naka et al,. *Nucl. Inst. Meth A* 581 3(2007)761