Binocular scanning electron microscope for simultaneous stereography

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Abstract

Binocular scanning electron microscope (SEM) has been developed. A pair of coils is set between the objective lens and a specimen of the ordinary SEM. The upper coil deflects the electron beam outward. The lower coil return it to the original focus. For this detour of the path, the beam irradiates a specimen from the direction oblique to the optical axis. The binocular SEM has double scanning lines, as compared with the ordinary one. The beam leans leftward at odd scans, while rightward at even scans. The odd scanning image is displayed on the left CRT, while the even image on the right CRT. Looking both images using a stereoscope, we can observe the 3-D shape of an object in real time.

When we cannot observe a 3-D shape in real time, we must decide whether to take a stereophoto pair or not, on the basis of 2-D image. Unless by chance, we may fail to find such an interest 3-D pattern that is recognizable only by the stereography. On the contrary, the binocular SEM enable to keep out this failure. Consequently, the binocular SEM surely contributes to give more interesting informations to the research works using the SEM.

Introduction

The stereographic image of a material is recognized by a pair of figures which is observed from different visual points. The most common is the stereography of aerial photographs. The binocular optical microscope has been developed for the stereography of fine materials. The minimum size to be observable is a few tens μm . It is not applicable for the finer materials because of its small depth of focus. On the other hand, the scanning electron microscope (SEM) has a large depth of focus.

Fig. 1 shows schematically three methods to produce stereo-image pairs in the SEM: 1) horizontally shifting an object, 2) tilting an object, and 3) leaning the electron beam. The first is the same method in the stereography of aerial photographs, though the viewpoint shifts in the aerial photographs. The visual angle of this method is uniquely determined by the magnification, and decreases with its increase. When the working distance is 48 mm, and an object is taken on one half of each photograph, the

FIG. 1. Three methods to produce stereophoto pairs in SEM: (a) shifting an object, (b) tilting an object, and (c) leaning the electron beam.

optical angle is 16° at 35X, 6° at 100X, and 0.6° at 1000X. The second method enables the stereography by taking a pair of photos of a scene before and after tilting an object. The most unprofitable point of this method is to set the scene in the range of vision after tilting the specimen. Kolednik (1981) examined both of the above-mentioned methods, and concluded that the tilting method was advantageous to produce stereophoto pairs for quantitative topography of an object. On the contrary, Kramarenko (1985) stated that the first method was more effective and easier with a high measurement accuracy.

Leaning the electron beam is the third method to observe an object stereographically. The detailed principle of this method is shown in Figs. 3 through 5, and is explained in the next chapter. Sakai *et al.* (1983) showed a stereophoto pair produced by this method. Their apparatus, however, cannot display a stereo-image pair in real time.

Fig. 2 is a stereophoto pair of fly ash, taken by the tilting method. There are small spheres on the surface of a large sphere. Could one recognize the topological relation between the large sphere and two small spheres indicated by an arrow? Most of persons will probably consider that both of the small spheres contact directly with the large one. By the stereography, however, only the left sphere contacts with the large one, and the right sphere is put on the left one. When we cannot observe a three-dimensional (3-D) shape in real time, we must decide whether to take the stereophoto pair or not, on the basis of a two-dimensional image. Unless by chance, we fail to find such an interesting 3-D pattern that is recognizable only by the stereography. In order to keep out such a miss, we must have the facility to observe a 3-D image in real time. The binocular SEM has been developed for this purpose. Vasichev and Abramov (1979) showed

FIG. 2. A stereophoto pair of fly ash, taken by the tilting method. Notice the topological relation between a large sphere and two small spheres indicated by an arrow.

FIG. 3. Electron paths in (a) the ordinary SEM, and (b) the binocular SEM. In (b), solid and dashed lines represent the electron paths in the odd and even scans, respectively. O.A. = optical axis; O.L. = objective lens; S_1 and S_2 = scanning coils; L_1 and L_2 = leaning coils; θ = optical angle.

the illustration similar to Fig. 3, and suggested the simultaneous display of 3-D information. It is not written, however, whether they have succeeded in making the apparatus or not.

Principle

The electron beam irradiates a specimen from the direction approximately parallel to the optical axis in the ordinary SEM (Fig. 3a). On the other hand, the incident direction of the binocular SEM should be oblique to the optical axis (Fig. 3b). A pair of coils, named leaning coils, is set between the objective lens and a specimen (Fig. 3b). The upper coil (L_1) deflects the electron beam outward. The lower coil (L_2) returns it to the original focus. Because of this detour of the path, the beam irradiates a specimen from the direction oblique to the optical axis.

The binocular SEM has double scanning lines, as compared with the ordinary one (Fig. 4). The beam leans leftward at odd scans, while rightward at even scans. The odd

FIG. 4. Scanning densities in (a) the ordinary SEM, and (b) the binocular SEM. In (b), solid and dashed lines represent the odd and even scans, at which the electron beam leans leftward and rightward, respectively.

FIG. 5. A block diagram showing the relation among scanning, leaning and secondary electron signals. θ = optical angle.

scanning image is displayed on the left cathode ray tube (CRT), while the even image on the right CRT. We see both images using a stereoscope. We can observe, therefore, the 3-D shape of an object in real time.

Fig. 5 shows schematically the relation among scanning, leaning and secondary electron signals. The system of the binocular SEM is composed of two units. The one is an ordinary SEM consisting of a scanning signal controller, scanning coils and a CRT, in addition to an electron gun, and condenser and objective lenses. The other is binocular unit consisting of a leaning signal controller, leaning coils and a pair of CRTs.

The optical angle of the binocular SEM (θ in Figs. 3b and 5) is changeable as 1.5° , 3° , 5° , 6° and 10° independently of the magnification. When a sphere is viewed with an optical angle less than 5° , it looks like a flat ellipsoid (*e. g.* a reversed dish). On the other hand, it looks like a long ellipsoid (*e. g.* an oval) in case of the optical angle of 10° .

FIG. 6. Two pairs of stereophotos of hydrothermally synthesized garnet, which were taken by the binocular SEM. The lower pair was taken after tilting the specimen holder upward 30° against the upper pair.

Application

The operation of the binocular SEM is very easy. The procedure is quite the same as that of the stereography of aerial photographs. The right image is movable laterally and vertically on the CRT. The operator displays his desiring scene on the left CRT, and shift the right image, as he can observe the stereographic shape of the scene.

The stereography is also possible by another procedure. Both of the left and right images are able to be displayed on the CRT of the ordinary SEM unit at the same time. When a specific point of the right image overlaps the same point of the left image on the CRT, a stereo-image pair of an object is produced on the CRTs of the binocular unit.

Unfortunately, we cannot demonstrate the simultaneous stereography based on the binocular SEM in this paper. Two pairs of stereophotos are shown in Fig. 6 as the second best presentation. The object is grandite garnet synthesized hydrothermally from a chemical mixture of CaCO_3 , Al_2O_3 , Fe_2O_3 and SiO_2 at 500°C and 100 MPa. The second pair was taken after tilting the specimen holder upward 30° against the first one. In practice, we can observe these stereophoto pairs not by taking photos, but

FIG. 7. Two pairs of stereophotos of hydrothermally synthesized garnet. The lower pair is high magnification images of the rectangular of the upper pair.

on the CTRs in real time. This implies that we can see the object easily from the direction most suitable for the observation.

Fig. 7 shows another example. The lower pair is the enlargement of the upper pair. Such enlargement of stereophoto pair is impossible in the method shown in Fig. 1c, because the optical angle varies with the magnification.

The stereography of images of SEM has been applied in many fields of science and engineering, such as mineralogy, biology, fracture mechanics, and so on. Some of the studies are photogrammetry of a scratch, a diatomaceous earth and a diaphragm (Kimoto *et al.*, 1969), goniometry of galena and SiC (Nishida *et al.*, 1973), photogrammetry of paper surfaces (Hamada, 1975), analysis of etching cracks on a metal surface (Kobori *et al.*, 1980), photogrammetry of a fossil diatom (Okubo, 1983), fractography of impact cracks (Sakai *et al.*, 1983), morphology of weddellite from a sialolith (Sakae *et al.*, 1984), and fractography of fatigue cracks of an aluminium alloy (Kramarenko, 1985). In all of these studies, the stereographic observation was carried out not in real time, but after taking a stereophoto pairs. We expect that the binocular SEM is able to give more valuable informations to the studies of these fields.

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