USE OF AN ELECTROMAGNETIC LENS WITH DOUBLE FOCUSING FOR OBTAINING MICROELECTRON DIFFRACTION PATTERNS

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Abstract

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USE OF AN ELECTROMAGNETIC LENS WITH DOUBLE FOCUSING FOR OBTAINING MICROELECTRON DIFFRACTION PATTERNS

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In electron microscopy, to observe an enlarged image of an object and the diffraction pattern from a selected region of the specimen (microdiffraction), the Bersch–Le Poole method (1) is used. It consists in changing the focal length of the intermediate lens so as to project into the object plane of the projection lens either the image of the object formed by the objective lens, or the primary diffraction image formed in the rear focal plane of the objective. The locality of the microdiffraction is determined by the size of the probe on the object or by the size of the selector aperture, which limits the region of the object that gives the diffraction pattern. To reduce the size of the probe, Riecke (2) proposed using an objective lens with increased excitation and placing the object in the gap between the poles. In this case, the part of the objective field located above the object plays the role of a strong condenser lens, producing a reduced image of the electron source. An illumination system using a condenser-objective lens made it possible for Riecke to obtain on the object a probe about 100 Å in diameter. The diffraction pattern from such a region, as usual, arose in the rear focal plane of the objective and was projected onto the screen by means of the intermediate lens. Because of the large aperture of the illuminator obtained in this case, the resolution of the microdiffraction was not high.

At the same time, a detailed examination of the properties of the condenser-objective lens shows that it can be used to obtain electron diffraction patterns from local regions of the object with high resolution and without using an intermediate lens.

Usually the objective lens of an electron microscope produces a reduced image of the electron source in the region of the rear focus. When the excitation in the lens is increased, the plane of the image of the electron source will move toward the center of the lens, and at a certain value of the excitation double focusing of the electron beam by the objective lens will occur. In this case, the part of the lens field nearest the illuminator produces a reduced image of the cathode

Figure 2

Figure 1: Figure 2

Figure 3

Figure 2: Figure 3

approximately at the field maximum, while the second part of the field projects this probe with magnification into the object plane of the following lens or onto the screen. If the object is placed above the plane of the first image of the electron source by the lens, then a diffraction pattern arises in this plane and is subsequently projected by the second part of the field into the object plane of the following lens (Fig. 1a). The resolution of the diffraction pattern, as in the case of an ordinary electron diffraction camera, is determined by the size of the electron probe in the diffraction plane and can prove to be sufficiently high (the probe diameter can be reduced to 0.1–0.01 μ). The locality of the diffraction pattern is determined by the size of the electron spot on the object in the diffraction mode. To switch to observation of an enlarged image of the object, it is necessary to reduce the excitation of the objective lens so that the object plane of the objective coincides with the specimen (Fig. 1b).

Fig. 2

Fig. 3

On the EM-5 microscope (3) we mocked up the layout of an electron microscope consisting of an electron gun, a condenser-objective lens, and a projection lens. By gradually immersing the object (a replica with a diffraction grating) in the field of the lens and focusing it on a fixed screen by increasing the current in the lens, we obtained curves for the dependence of the focal distance of the objective lens, the diameter of the electron spot on the object, and the position of the object plane on the excitation for a series of pole pieces with channel diameters from 1 to 6 mm and gaps between the poles from 2 to 6 mm. A pole piece with aperture diameters in the upper and lower pole shoes equal, respectively, to 6 and 3 mm, and with a 5 mm gap between the poles, focuses an electron beam with an energy of 60 keV into a probe 0.2 μ in diameter at 6300 ampere-turns at a distance $z_0 = 2.5$ mm from the end face of the lower pole. The lower part of the lens field images this probe onto the screen. Consequently, at 6300 ampere-turns the object plane of the objective field coincides with the image plane of the condenser field.

Fig. 1. Operating scheme of the objective-condenser lens: *a*—imaging mode, *b* —diffraction mode. 1—cathode, 2—diaphragm, 3—condenser lens, 4—object, 5—electron diffraction pattern, 6—objective lens, 7—screen or object plane of the following lens

If, without changing the excitation, the object is placed at a distance $z_0 > 2.5$

mm, for example at $z_0 = 2.75$ mm, then in the plane $z_0 = 2.5$ mm a diffraction pattern arises from the region of the object illuminated by the electron probe; this pattern is imaged into the object plane of the projection lens by the lower part of the field. The size of the diffraction region depends on the parameters of the illuminator and on the position of the object. When the excitation is reduced to 5400 ampere-turns, the object plane of the objective field shifts from $z_0 = 2.5$ mm to the plane $z_0 = 2.75$ mm and, consequently, a focused image of the object appears on the screen. Since in this case the strength of the condenser field also decreases, the size of the electron spot on the object increases in comparison with that in the diffraction mode, and the increase of the probe occurs symmetrically with respect to the center of the image.

The latter is confirmed by Fig. 2, which shows regions of the object (a replica with a diffraction grating of 600 lines/mm, gold-shadowed) illuminated by the beam in the imaging mode (A) and in the diffraction mode (B). The size and position of the probe on the object in the diffraction mode can be noted in this photograph from the appearance of a layer of hydrocarbon contamination, which forms intensively under a narrow beam. The electron diffraction pattern corresponding to such a region of a single-crystal silver film is shown in Fig. 3.

Thus, in the considered operating mode of the electron microscope, either the object or its diffraction pattern is located in the object plane of the objective lens. In the latter case, an image of the object is formed in the rear focal plane of the objective. This primary image of the diffraction pattern, magnified by the intermediate and projection lenses, was observed by us on the final screen. In addition, the use of the objective-condenser lens and the single-lens condenser available in the EM-5 microscope makes it possible to reduce the size of the region of the object illuminated by the electron beam to 2 μ, i.e., to the same size as when working with a double condenser.

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