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200 kV TEM with a Zernike phase plate

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Many years has passed since the light phase contrast microscope was developed. However, this effective tool for the biological field had not been realized in a transmission electron microscope (TEM). The basic scheme of applications of a phase plate in TEM has been reported recently [1, 2]. A Zernike phase plate makes the phase shift of scattered electrons by $\pi/2$ radians. Finally a sine-type contrast transfer function (CTF) changes into a cosine-type one. Sine-type CTF (Is) and cosine-type CTF (Ic) are described respectively by

$$Is(k) = 2\sigma v_p(k)\sin(\chi(k)) \quad (1)$$

and

$$Ic(k) = -2\sigma v_p(k)\cos(\chi(k)), \quad (2)$$

where σ is the interaction parameter, $v_p(k)$ is the Fourier transform of the specimen potential and $\chi(k)$ is the wave aberration function. In other words, it takes effect on a remarkable contrast improvement at a low frequency region of CTF [3]. First, we developed a phase plate system applicable to the JEM-1200EX (120kV TEM). A transfer doublet Mini Lens (TML) was built in it. TML forms the conjugate plane of the back focal plane of the objective lens at the plane below 120 mm. Since the space around the conjugate plane is wide, a precise alignment mechanism and a heating holder of the phase plate can be introduced [4]. Next, we applied the phase plate system to the JEM-2010 (200kV TEM) to obtain a higher transmissivity, resolution and extendibility. Table 1 shows the performances of a 200kV Zernike phase contrast TEM.

The amorphous carbon film is adopted for the phase plate of the 200kV TEM. The relation of the thickness of an amorphous carbon film (Z) and the phase shift (φ) is described by

$$\varphi = -\sigma V_{av} Z \quad (3)$$

$$\sigma = e/(\hbar V_e), \quad (4)$$

where V_{av} is the averaged inner potential of amorphous carbon, e is the elementary electric charge of an electron, $\hbar$ is Plank's constant and V_e is the velocity of an incident electron. The averaged inner potential of amorphous carbon is 7.8 V [5] and σ for 200keV electrons is 0.00728 $(V\bullet nm)^{-1}$. With these values, the thickness of a carbon phase plate is calculated as 28 (nm) for a phase shift of $\pi/2$. The carbon film was made by vacuum evaporation. A hole ofφ1μm in diameter to pass the direct beam was made with a focused ion beam (FIB).

Figure 1 shows an exterior view of the 200kV Zernike phase contrast TEM. The phase plate is supported on a heating holder and is kept at ~300˚C to avoid contaminations. Figure 2 (a) and (b) show the power spectra from amorphous Germanium. The left one was obtained with the phase

plate, and the right one is obtained without the phase plate. The contrast transfer function of sine-type fits well with the right spectrum and that of cosine-type fits well with the left spectrum. We demonstrate an observation of a high-resolution image. A clear 0.34 nm lattice of carbon graphite was obtained (Fig. 3). This work was supported by a contract development of Japan Science and Technology Agency (JST).

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Acc. Voltage	200 kV	
Objective lens	Cs = 1.0 mm	
	Cc = 1.55 mm	
	fo = 2.3 mm	
Point resolution:	0.23 nm	
Phase Plate:	amorphous Carbon film	
	Thickness	~28nm
	Hole diameter	~1μm
	Heating temperature	~300°C

Table 1 performances of a 200kV Zernike phase contrast TEM

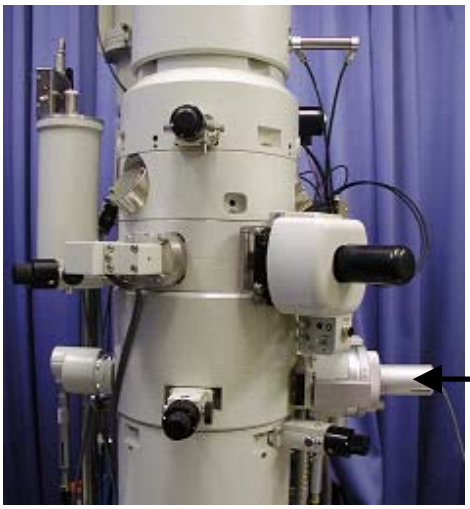

Fig.1 An exterior view of the sample stage and the phase plate stage of the phase contrast TEM

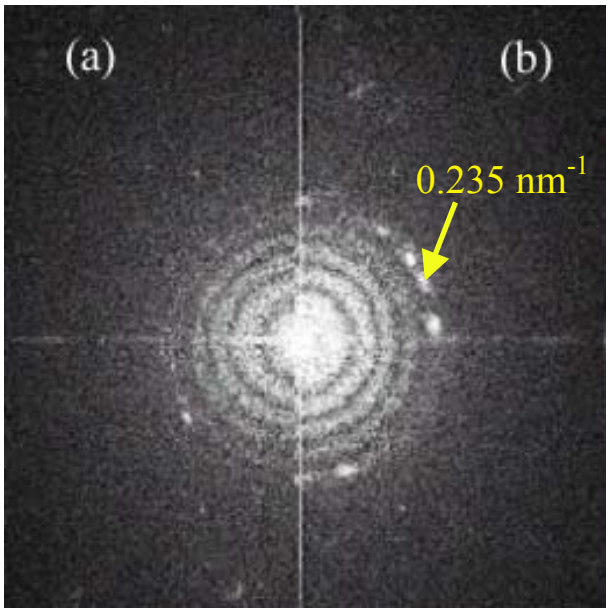

Fig. 2 The power spectra from amorphous Germanium; defocus Δf = 155 nm (under) (a) the image taken without the phase plate (b) the image taken with the phase plate

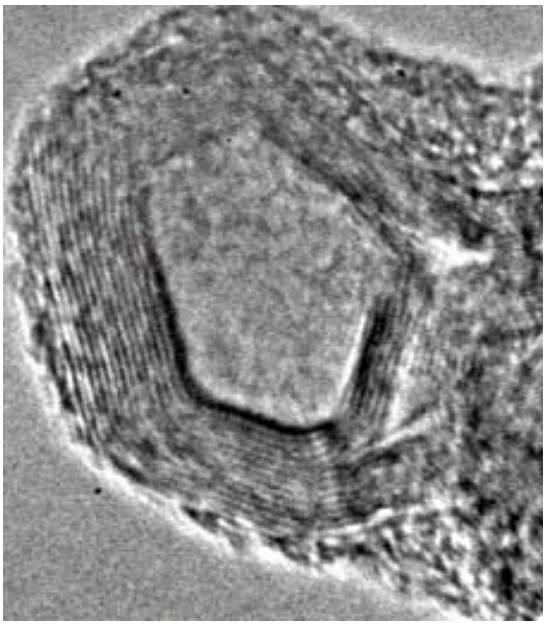

Fig.3 A 0.34 nm lattice image of carbon graphite.

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