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Automation of TEM Alignment using Python Scripting

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In recent years, image processing technology has been greatly improved, and people in various fields have developed automated operations based on image processing technology. In the field of electron microscopy, automated functions and software have been developed that can be used in the fields of materials and biology [1]. Transmission electron microscopes (TEM) of JEOL can be operated using a scripting language with PyJEM, a JEOL made Python module (Python is a trademark or registered trademark of the Python Software Foundation.). By using PyJEM, one can read the information on a TEM and send operational commands to it without a direct operation. In addition, the combination of lots of computation and image processing modules enables users to simplify the operation of TEM together with the acquisition of experimental data. Moreover, users who are not familiar with microscope operation can perform TEM alignments with the same accuracy as an experienced user in a short time by combining useful functions in Python. In this report, we introduce examples of automated microscope alignments by PyJEM.

Examples of TEM alignments that can be automated are finding electron beam, centering apertures, centering the beam, centering the transmitted wave in the diffraction pattern, correcting astigmatism in the illumination and the image-forming systems, adjusting voltage center, adjusting specimen height, and correcting TEM image distortion. These alignments can be performed automatically with high speed and high accuracy by using advanced image processing functions by PyJEM.

Here, we introduce how to automate the correction of the TEM image distortion. The image distortion caused by the microscope optics, which is observed in TEM images, can be corrected by changing the excitation values of the stigmator coils in the image-forming system. The TEM image distortion is measured by using the Si [110] sample. Fig. 1 shows the FFT pattern of a [110] lattice image of Si acquired with a JEM-ARM200F microscope at a magnification of x2.0 M. Let the lengths of (002), (1-11), and (1-1-1) from the center in the FFT pattern in Fig. 1 be x, y, and z, respectively, and the angle between (002) and (1-11) be β, and the angle between (1-11) and (1-1-1) be γ. Then, the values of y/x, z/y, β, and γ are measured, and the deviation from the ideal value is calculated as distortion. To correct the distortion of the TEM image, the conventional process is to manually set the excitation values of the stigmator coils in image-forming system, acquire an image, and measure the distortion. The process is repeated until one finds values of coils with a distortion less than 1.0%. This repetitive process takes an enormous amount of time since it is operated all manually. In addition, for TEM image distortions above a certain magnification (x1.0M or higher in the case of the JEM-ARM200F), it is sometimes necessary to use one more kind of coils to correct the distortions, which requires an even greater amount of time since the number of combinations gets greater. Using PyJEM, the process can be scripted to measure distortion values at finite combinations of the excitations of coils. Then they are fitted with a parabolic function to find the excitation values which has the lowest distortion. By automating the distortion correction of the TEM image, it is now possible to find the lowest distortion value in a short time and with high accuracy, which has been difficult using the conventional method.

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Fig. 2 shows TEM images before and after focus adjustment by automatic sample height adjustment. The process is as follows: capture the first image, change the tilt of illumination beam, and capture the second image. Then calculate the image shift between the first and the second images by template matching. Finally, change the sample height so that the shift value will be zero. The relationship between the image shift and the height change is measured and calibrated in advance. Even when the specimen height is largely deviated from the ideal position, the focus is adjusted with high speed and high accuracy. Other automatic alignments are also designed to operate faster and with higher accuracy than manual operations.

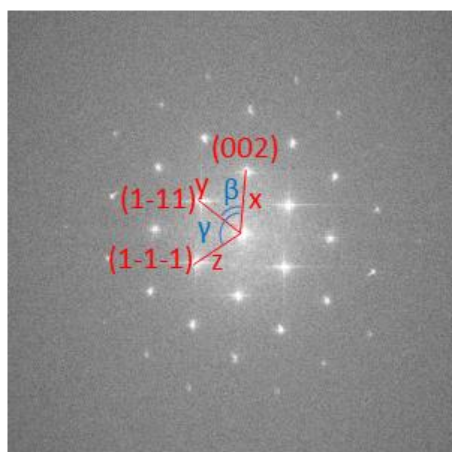

Fig. 1. FFT of Si [110] TEM image. In this case, y/x = 0.869, z/y = 1.004, β = 54.55°, and γ = 125.71°. Ideal values of y/x, z/y, β, and γ are 0.866, 1.000, 54.735°, and 125.264°. If the distortion is less than 1.0%, the following conditions are satisfied: $0.859 < y/x < 0.873$, $0.990 < z/y < 1.010$, $54.23° < \beta < 55.17°$, $124.83° < \gamma < 125.77°$.

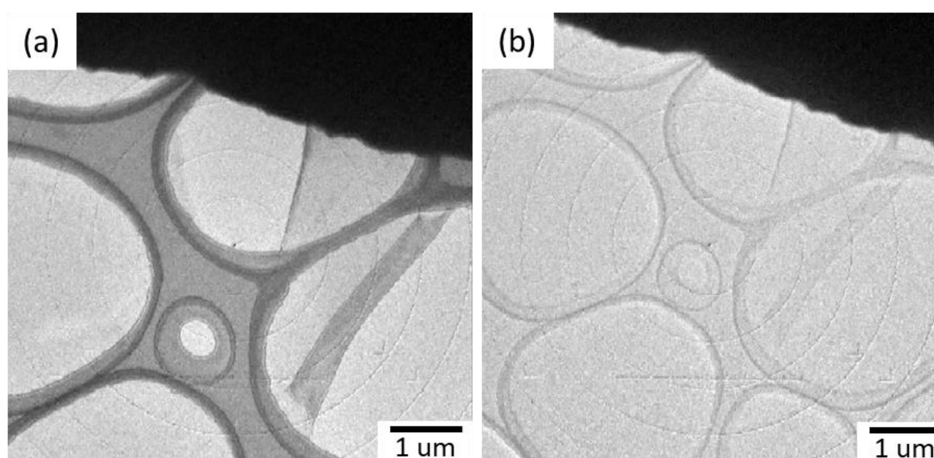

Fig. 2. Automatic focusing with sample height alignment. (a) before and (b) after the alignment.

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