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Detailed Alignment Procedure for the JEOL 2010F Transmission Electron Microscope

by Wendy Sarney

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14. ABSTRACT

The transmission electron microscope (TEM) allows lattice-resolution imaging of specimens. At ARL, we rely on TEM imaging for detailed structural characterization. Typical experiments involve examining the crystalline structure, interface quality, and defect morphology of semiconductor materials. The TEM consists primarily of an electron gun, electromagnetic lenses, apertures, stigmators, deflectors, and a viewing system. The alignment affects the propagation of the beam down the column and its interaction with the specimen and lenses. This in turn affects the quality of the image and the ease of obtaining it. This report discusses the alignment procedure for the JEOL 2010F TEM.

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1. Introduction

The Sensors and Electron Devices Directorate (SEDD) operates two transmission electron microscopes (TEMs). One is a JEOL 2010 with a thermionic electron gun using a LaB6 filament and the other is the JEOL 2010F with a field emission gun. Both TEMs normally operate at 200 keV. The 2010F also contains a scanning image observation device (ASID) and an energy dispersive x-ray detector (EDAX). The TEMs support numerous projects throughout the directorate, but primarily in the Electro-Optics & Photonics and the RF Electronics divisions.

Typical experiments involve examining the crystalline structure, interface quality, and defect morphology of semiconductor materials. Characterization at the nano-scale requires high-resolution imaging. Some alignments, particularly the objective lens astigmatism and the high voltage centering, are critical to the TEM's performance and are touched up throughout a single TEM session. Other alignments, such as shift and tilt purity adjustments, are done less frequently. We typically check the less-critical alignments when it becomes difficult, but not impossible, to obtain a high-resolution image. Since the TEM sample tends to degrade with prolonged exposure to the electron beam, it is important to keep the microscope aligned so that we can minimize the amount of time needed to obtain a quality image. For that same reason, when performing the alignments that require the sample to be in the path of the beam (such as the objective lens astigmatism and the high voltage centering), we select an area of the sample that is near, but not the exact region to be examined during the experiment. JEOL service engineers check all customer and engineer alignments at least twice per year during a routine maintenance visit as part of the service contract.

2. Definitions and Related Figures

2.1 2010F Column Schematic

Figure 1 shows a schematic of the lenses, deflectors, and apertures pertinent to the alignment of the 2010F. Refer to the JEOL manual for more detailed schematics.

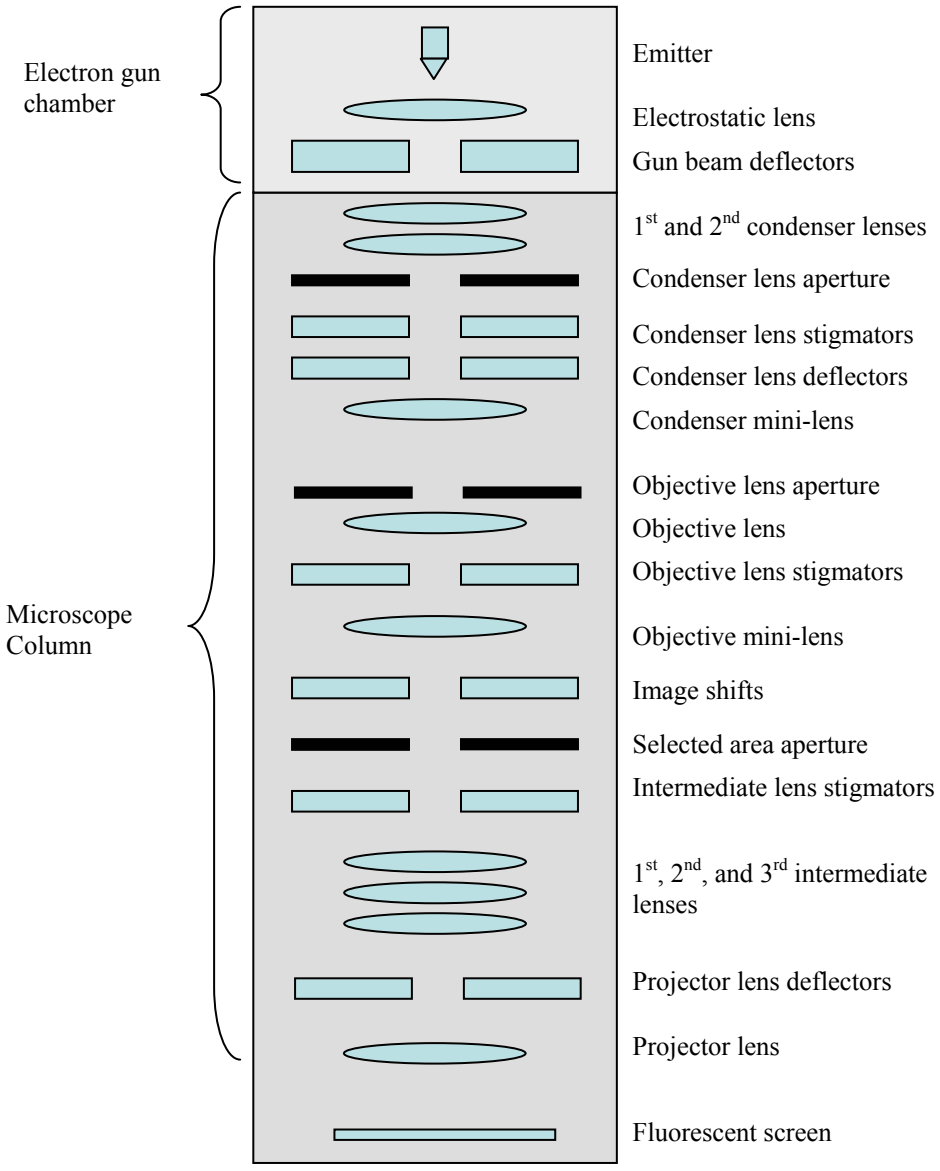

Figure 1. Schematic of lenses, apertures, stigmators, and deflectors pertinent to the TEM alignment.

2.2 Index of Knobs, Dials, and Levers

In this section, we define the user controls necessary for alignment.

α SELECTOR knob	Controls the current through the condenser mini-lens (CM), which in turn affects the angle of incidence of electrons on the specimen.
Beam SHIFT X and SHIFT Y knobs	Shifts the electron beam by controlling the current in the condenser lens beam deflectors.
BRIGHTNESS knob	Allows the variation of the second condenser lens (CL3) current. This modifies the beam intensity.
BRIT TILT	Used with the DEF X,Y knobs on the panel to tilt the beam.
Condenser lens apertures	Restrict the number of electrons traveling down the column and striking the specimen. Reduces the maximum allowed angle between the traveling electrons and the optical axis. Restricting the quantity and the incidence angle of electrons in the beam reduces the number of x-rays generated by electrons striking parts of the column. There are 5 condenser lens aperture sizes having diameters of 10, 20, 50, 70, and 150 μm.
Deflector coils	Allow the beam to be shifted or tilted, to correct for mechanical misalignments in the column or to achieve special conditions, such as dark field imaging.
Gun DEF X and Y knobs	Tilts the beam by varying the current in the electron gun beam deflector coil. Select the Gun DEF knobs by depressing the GUN deflector button, located inside the right hand drawer.
Gun SHIFT X and SHIFT Y knobs	Translates the beam by varying the current in the electron gun beam deflector coil. The shift knobs are selected by depressing the GUN deflector button. These controls are located inside the right hand drawer.
DIFF FOCUS knob	Varies the current in the 1st intermediate lens.
FOCUS knob	Controls the focus of the image by modifying the current in the objective lens.
WOBBLER-HT	Varies the high voltage, used for high voltage centering.
SPOT SIZE switch	Changes the first condenser lens (CL1) current. The spot size refers to the size of the converged electron beam obtained for maximum BRIGHTNESS. Larger numerical size numbers refer to smaller spot sizes (Spot size 1 is the largest, spot size 5 is the smallest).

Stigmators	Allow for the correction of lens imperfections. We can adjust the condenser, objective, and intermediate lens astigmatism.
Z CONT switch	Moves the specimen upward and downward and provides rough focusing.

3. 2010F TEM Alignment Procedure

For full details, please see the JEOL manual. Some alignments are done infrequently, and some are usually only done by the JEOL engineers when they service the microscope.

1. Press the VALVE button to allow the beam to come down the column.
2. Check the DV reading (on the screen). Adjust the FOCUS knob until DV=0. The microscope is calibrated at DV=0. It is very difficult to obtain a high quality image if you deviate far from DV=0.
3. Focus the image with the Z control. To avoid deviating far from DV=0, perform all rough focusing with the Z control rather than the FOCUS knob.
4. Using the SPOT SIZE lever and the α-SELECTOR knob, set the spot size to 1 and the convergent angle to 3. The first page on the TV screen will display TEM1-3.

3.1 Gun and Condenser Lens Alignment

The 2010F has a three-stage condenser lens system consisting of the 1st (CL1), 2nd (CL3), and mini condenser lens (CM). It is important to note that this is different from the 2010, which has a four-stage condenser lens system consisting of a 1st, 2nd, 3rd, and mini condenser lens. The 2010F needs one less condenser lens because the size of the original beam from the field emission gun is smaller than can be generated from the LaB_6 filament in the 2010. This causes discrepancies and confusion in the JEOL 2010F manual. They inconsistently refer to the second condenser lens as CL3, the third condenser lens, or CL2. This happened because the 2010F manual is an expanded and modified 2010 manual, resulting in several inconsistencies. In this document, we will always refer to it as CL3, since that is the convention used by the JEOL service engineers. We control the current through CL3 with the BRIGHTNESS knob. We perform most of the condenser lens alignments at a magnification of 40000X.

1. Align the electron gun axis.
    a. Select the BRIT TILT button on the panel.
    b. Press the ANODE WOBBLER button.
    c. Use the TILT knobs on the panel to make the beam expand and contract concentrically.
2. Alignment of the gun to the condenser lens – this step aligns the illumination along the optical axis.

a. Insert a condenser lens aperture.
b. Decrease the spot size to 5 (TEM5-3) using the SPOT SIZE switch.
c. Adjust CL3 to obtain crossover and center the spot with the SHIFT knobs on the right and left side console panels.
d. Increase the spot size to 1 (TEM1-3) and adjust CL3 to obtain crossover.
e. Center the spot with the GUN SHIFT knobs located in the drawer
f. Repeat steps b-e until the spot stays centered whether CL1 is minimized or maximized. If the beam does not remain centered or look like it is improving after a few iterations, repeat the gun alignment described in section 3.1 and then retry steps a-e.

3. High Voltage Centering
    a. Select an easily recognizable feature in the sample. Increase the magnification to 100X. Make sure that the Z-height is correct.
    b. Press the WOBBLER-HT button.
    c. Raise the view screen.
    d. Select the BRIGHT TILT.
    e. Minimize the motion of the specimen by adjusting the panel beam deflectors (DEF x and y).
4. Condenser aperture alignment
    a. Insert the condenser lens aperture that you plan to work with.
    b. With the BRIGHTNESS knob, obtain the smallest possible beam (crossover). Center the beam with the SHIFT knobs on the panel.
    c. Spread the beam until it is about 10 cm wide. Center the beam with the x and y condenser aperture controls (two knobs located next to the condenser lens aperture).
    d. Repeat b-c until beam remains centered as CL3 is maximized and minimized.
5. Condenser lens astigmatism correction (correct at each spot size needed during the session).
    a. Press the COND STIG button on the panel. Slightly turn the BRIGHTNESS knob back and forth from crossover. Correct the ellipticity of the beam with the DEF knobs on the panel.
    b. Before continuing with other alignments turn off the COND STIG by pressing the BRIGHT FIELD key.
6. Beam tilt purity alignment (adjusts the current balance in the condenser deflectors, done only as needed). This alignment ensures that the beam does not shift and tilt simultaneously.
    a. Set the magnification at 100,000X.
    b. Set the SPOT SIZE to TEM1-3. Obtain crossover with the CL3 knob. Center the beam with the COND SHIFTS knobs in the drawer.
    c. Depress the COND DEF ADJ TILT button and turn the TILT X/Y switch to the X side. These knobs and switches are in the right hand drawer.
    d. Make the separated spots overlap using the SHIFT X and DEF X knobs in the drawer.
    e. Turn the TILT X/Y switch to the Y side and adjust the SHIFT Y and DEF Y knobs until the separated spots overlap.

f. Do a rough voltage center alignment – spread the beam, center it, press WOBBLER – HT, and minimize the beam motion with the gun deflectors located on the panel.

7. Shift interlock adjustment (adjusts the current balance in the condenser deflectors, done only as needed). This alignment ensures that the beam does not shift and tilt simultaneously.
    a. Press the DIFF button and set the camera length to 200 cm.
    b. Press the COND DEF ADJ SHIFT knob and switch the SHIFT X/Y switch to X.
    c. Adjust the SHIFT X and DEF X knobs (drawer) until the separated caustic spots overlap.
    d. Switch the SHIFT X/Y switch to Y.
    e. Adjust the SHIFT Y and DEF Y knobs (drawer) until the separated caustic spots overlap.

3.2 Objective Lens Alignment

1. The JEOL manual describes a procedure for obtaining the proper objective lens current. This current was determined at the installation, and we should not need to make adjustments.
2. Objective lens astigmatism correction
    a. The best magnifications for correcting objective lens astigmatism falls in the range of 150-200kX.
    b. Find and center an area of the specimen with an amorphous edge
    c. Raise the screen and view the image on the TV monitor.
    d. Slightly under-focus the image and examine the bright Fresnel fringes at the edge.
    e. Select the OBJ STIG button and adjust X and Y DEF until the contrast at the edges becomes sharp.
    f. Adjust the FOCUS knob closer to optimal focus and repeat step e.
    g. The objective lens astigmatism is optimized when very little contrast is seen at the sample edge.
    h. After completing the entire alignment procedure, touch up the astigmatism at the magnification needed for the current TEM session by repeating steps b-g.

3.3 Intermediate Lens Alignment

1. Diffraction focus alignment (This alignment is needed when an unusual number of diffraction spots seem to fit through the objective lens aperture)
    a. Press the DIFF button and set the camera length to 200 cm.
    b. Maximize CL3.
    c. Minimize the diameter of the caustic spot by adjusting the DIFF FOCUS knob.
2. Intermediate lens astigmatism correction (Needed when the diffraction spots are not perfectly round).
    a. Select the STIG INT button in the drawer and adjust the deflectors until the caustic spot is round.

b. Slightly under and over focus the caustic spot with the DIFF FOCUS knob to make sure it stays round. If the spot does not stay round as it passes through focus, repeat step a.
c. Minimize the diameter of the caustic spot by adjusting the DIFF FOCUS knob.

4. Conclusion

The TEM is ready for high-resolution imaging after completing the alignment procedure. The high voltage centering and the astigmatism may have to be touched up throughout the session. If the alignment ever seems to become very bad, it is usually best to push the N button and then the DEFLECTOR, STIGMATOR, and/or COND DEF ADJ buttons to return to the alignment conditions set by the service engineer. These computer-stored alignments serve as a good starting point for small alignment modifications. If the alignment is still unrecoverable, there is likely a larger problem. In this situation, call the service engineers.

5. Reference

JEOL 2010F Instruction Manual

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