Optics Laboratory #2

Goals:

- Reinforce understanding of the geometrical optics of transmission microscopes.
- Observe the effects of aberrations on image quality.
- Understand dark-field contrast in an optical analogue of a transmission electron microscopy measurement of a polycrystalline sample.
- To apply, in your own way, techniques you have learned in this course to characterize a colloidal crystal of your own creation.

Session #1

I. Growth of a colloidal crystal (for investigation in next lab session)

1. Create a parallelogram "pool" with the acute angle close to 60^{o} on a microscope slide using scotch tape for the borders. The colloid suspension will be trapped on the clean glass region bordered by the scotch tape. Place a drop of the suspension of polystyrene colloids—the diameter of the polystyrene spheres is approximately 160 microns—on the microscope slide. As the water evaporates, the colloidal particles will self-assemble into a thin colloidal crystal (we hope).
2. As the final exercise in the second lab session, you will use the techniques learned in MSE 405 to characterize the microstructure of this colloidal crystal; plan out your measurements before the start of the second session and turn in your experimental plan in as part of your homework.

II. Transmission light microscope.

3. Make the microscope as versatile as possible, accommodating all of the samples we will encounter in "Optics Laboratory #2" (read ahead to see what you will do). Consider the following in your design:

    a. Use a 25 mm lens to expand the laser so that you can evenly illuminate relatively large areas of samples.
    b. Be able to use different objective lenses to vary the image quality and magnification.
    c. Be able to switch from "microscopy mode" to "diffractometer mode", i.e., be able to switch between placing the image of the object on the CCD camera and placing the diffraction pattern of the object on the CCD camera.

d. Be able to position an aperture in the back focal plane of the objective to enable dark-field imaging and to improve the image quality by reducing aberrations.
e. You will want to send the laser beam along the short side of the table and then use a mirror to send the beam along the long side of the table; this approach is needed to provide enough optical path length for the experiments.

III. Aberrations, resolution, and image quality

4. Use your microscope to inspect a Cu grid (part of a transmission electron microscopy sample holder) that has been mounted on a microscope slide.
5. Experiment with the laser illumination and attenuators to create a relatively even intensity across the full field of view without saturating the CCD.
6. Record images using three configurations for the objective lens:

    a. The microscope objective
    b. The plano-convex (f=25 mm) lens with the flat side facing the sample
    c. The plano-convex (f=25 mm) lens with the convex side facing the sample.

7. For your report, include the following:

    a. A basic diagram of the lens setup and a description of the geometrical optics of your microscope (lens positions, magnification) for each of the three configurations.
    b. Quantitative support of your disussion of the image quality. Acquire and plot "line-scans" of the image intensity from each setup. Recall from the first optics lab how to load an image into MatLab and get an intensity profile:

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>> I = imread('imagename.bmp');
          >> imshow(I)
          >> c = improfile;
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    Which objective gives the sharpest edges to the image intensity?
    c. The three images you recorded with a discussion of the image quality obtained with each of the three configurations of the objective lens. Which objective gave the best image? Which gave the worst?

8. You should have observed that configuration (c) gave the worst image but you can improve the image quality (reduce the aberrations) by placing an aperture in the back-focal-plane of the objective lens.
9. For your report, include the image and a line-scan using an aperture that is 1/8" in diameter. (You can set the aperture diameter by gently closing the aperture around an 1/8" diameter allen wrench.) (This diameter should roughly balance the diffraction limits and aberrations for a plano-convex lens in this orientation.) Discuss whether or not you see an improvement in the image quality.

IV. Dark –field microscopy

10. Collect diffraction patterns of polycrystalline objects on the slides. Slide A has grains of the same orientation but different lattice constants; and Slide B has grains of the same lattice constant but different orientations.
11. Expand the laser beam using a 25 mm lens and allow the beam to propagate a long distance before illuminating the object.
12. Using the 160-mm lens as the objective lens, collect diffraction patterns from both slide A and slide B by moving the camera to the diffraction plane.
13. Because the illumination is diverging at the sample, the diffraction plane will not be at exactly 160 mm behind the objective, in this case, the distance from lens to diffraction plane will be approximately 200 mm.
14. For your report, include the following:

    a. A diagram of the setup to indicate positions and relative distances of each optical element (i.e., laser, object, lenses, aperture, camera).
    b. Use the diffraction pattern of slide A to estimate the ratio of the lattice constants for the different grains.
    c. Identify the plane lattice type of the reciprocal lattices in the diffraction pattern. Draw the base vectors on your image. Measure the lattice constants in reciprocal space and determine the ratio of the real-space lattice constants.
    d. Use the diffraction pattern of slide B to estimate the angle of rotation between the grains.
    e. Again, identify the plane lattice type and draw the base vectors for both sets of grains.

15. Create dark-field images of slide A and slide B using an 80-mm lens as the transfer lens: the image on the CCD camera will be at magnification m = −1/2 since the focal length of the objective lens is 160 mm. Use a 300-μm pinhole for the aperture

located at the diffraction plane. For your report, include a diagram of the setup to indicate positions and relative distances of each optical element.

16. Optimize the alignment of the dark-field aperture to maximize the contrast to the grains. For your report, include the following:

    a. Dark-field images of slide A and slide B showing all grains. How is the aperture positioned to produce this image?
    b. Dark-field images showing each set of grains in slide A separately. How is the aperture positioned to produce this image? Why is it that only one set of grains can be viewed when the aperture is in this position?
    c. Repeat (b) for slide B.

17. Explore the positioning of the dark-field aperture and find a location that produces strong contrast at the edges of each grain (but not within each grain). For your report, include dark-field images of the grain edges on slides A and B. How is the aperture positioned to produce this image? Discuss how this contrast mechanism works.

Session #2

V. Characterization of the colloidal crystal.

18. Use the optical instruments you constructed in Session #1 to characterize the microstructure of the colloidal crystal sample you created. This is an open-ended assignment; you will apply what you have learned about microscopy and diffraction to characterize a sample of your own creation. The only requirement is that you use all three techniques you used in Session #1: diffraction, bright-field microscopy, and dark-field microscopy. How you use these techniques is up to you. Your grade will be based on how well you use these tools and how accurate your analysis is. Collect your data in a manner so as to be as quantitative as possible in your analysis of the microstructure. A few things to consider in your measurements are:

    a. Are the colloidal particles all of the same size? What size(s) do you see?
    b. Is the colloidal film a single crystal, polycrystalline, amorphous, or a combination of these? If polycrystalline, what crystal structures do you see and what is the grain size distribution? If amorphous, is there any local order?
    c. Is the film a single layer or multilayered?
    d. What kinds of defects (vacancies, dislocations, grain boundaries) do you see and in what concentrations?
    e. These are only a few ideas to get you started; feel free to explore ideas of your own.
    f. Be sure to include detailed diagrams of all the optical setups used in your measurements.