Physics 410/510

Experiment O-4

Optical Constants of Metals and Semiconductors

Objects:

1. To adjust and calibrate a Babinet Compensator.

2. To prepare the metal mirror by evaporation.

3. To measure the phase shift difference and the ratio of amplitudes of the two usual components of polarized light reflected by a mirror as a function of the angle of incidence. Do this visually at the red and green wavelengths of mercury, and photoelectrically at the green and blue wavelengths of mercury. Begin by making the same measurement visually in the green for a glass surface.

4. Calculate n and k for the metal and compute its conductivity. (We're neglecting bound charges so the conductivity calculation is not very good.) Repeat the same for the semiconductor (silicon).

References:

* F.A. Jenkins and H.E. White, Fundamental of Optics, McGraw Hill 1976, Ch. 25, Reflection. (For more details, see Fundamentals of Physical Optics, McGraw 1937.)

* M. Born and E. Wolf, Principles of Optics, Pergamon Press 1980, Ch. 13, Optics of Metals.

* For some recent results of Al see E, Shiles et al., Phys. Rev. B 22, 1612 (1980); on Si see E. Schmidt, J. Appl. Optics 8, 1905 (1969), and Phys. Stat. Solidi 27, 57 (1986); for an example of modern ellipsometry, see K. Vedam, et al., Appl. Phys. Lett. 47, 339 (1985).

glass $n \simeq 1.51$
gold $n \simeq 0.47$
Si − $n \simeq 4.01$

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<u>Notes on O-4 (Optical Constants of Metals and Semiconductors)</u>

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The optical constants of a metal can be determined if the principal angle of incidence is known (that is where the reflectivity of the electric field parallel to the plane of incidence goes through its minimum value) and if the ratio of the amplitudes of the parallel and perpendicular components at that angle is known (the tan of the principal azimuth is the ratio of one to the other). It so happens that the above minimum occurs at the incident angle at which the relative phase shift between the parallel and perpendicular components goes through 90°. We determine in this experiment the phase shift as a function of incident angle and we determine at each angle of incidence the ratio of the components directly.

If the constants are the only point of interest, one can do it by sending circularly polarized light on to the metal surface. At the principal angle of incidence the reflected light will become plane polarized, not at 45° to the plane of incidence as might be expected (this would only occur at normal or at grazing incidence, neither of which angles are feasible to reach) but at some other angle since the two reflectivities are different. A polarizing analyzer can be used to determine the angle of the plane polarization and thus the ratio of the two components through the tangent of the observed angle.

In this experiment we will, however, look at the phase shift over the range of incident angles we can reach. This is done by measuring the shift in the fringes in a Babinet compensator. Further, we will also determine the amplitudes ratio at each angle by maximizing the fringe contrast in the Babinet field, by the angle through which the analyzing polarizer has to be turned to maximize the contrast. We will do this on gold at three wavelengths of the mercury spectrum: in the red at 6234A and in the green at 5461A, both visually, and in the green again at 5461A and in the blue at 4358A, both photoelectrically. The blue is really tough to do visually, the red is not to be done with our photocell in the red, but the green is convenient with either technique. The Babinet compensator has to be calibrated at each wavelength. Wavelength selection is by glass filter combination.

We first determine the plane of polarization passed by the polarizing prism. We mount on the spectrometer table a glass plate, black backed so as to provide reflection from only the front surface. Remove the Babinet compensator by undoing the two knurled nuts holding it in place. It would be a good idea to set the collimator for parallel light by taking out the eyepiece (if the photocell is in place, remove it with the four knurled head screws) and replacing it with the low power telescope set on infinity by focusing on McGraw Hall cupola ornamentation across the Arts quadrangle. Magnification is not high but get the best image of the entrance slit by moving the latter in and out. The mercury arc (glass covered so there is no UV to worry about) can be attenuated by putting some translucent paper in where the filters fit. Simply slide the slit in and out for best focus.

Take out the arc attenuation and mount on the table the glass plate, centered on the platform so the inscribed circles and their reflection in the glass make "symmetrical" circles. Find the reflection of the arc near Brewster's angle and minimize the reflection by turning the polarizer. You are looking at the mirror directly, no optics in front of the eye. Trim the incident angle and polarizer to get the deepest minimum. It does not quite go to zero, probably because there is some reflection from the back surface, in spite of our attempt to index match and absorb at that surface. At any rate you now know the position of the polarizer for one plane of polarization. The angle can be read off; 90° away will be the other plane. Notice that the polarizer can be separately turned. Thus it should be manipulated only by the arm with the ivory handle.

The mirror can now be taken off and the slit viewed through the small telescope. The analyzing nicol (the polarizer is a Wollaston prism) is turned until the slit intensity goes to zero; it is pretty far down and not bad. The angular position of the crossed nicol can be read; the circle is inscribed on the ring in five degree intervals, every other one being longer than the others (that is, the inscribed lines).

Now the Babinet compensator may be placed in position and secured with the two knurled nuts. In general, fringes will appear. The angular position of the Babinet can be changed by loosening the clamp. It should be rotated until the fringes disappear and the field is almost uniformly dark. However, before the Babinet is put on, the cross wires should be in place (or a slit, in case of the photoelectric method). There is a small cylindrical insert with a knurled flange on it, on the other end of which are two parallel moderately fine wires. This is inserted in the recess at the back side of the Babinet and turned so the two wires are perpendicular to the length of the prisms (also perpendicular to the side frame carrying the screw and dial knob). The cross wires will be parallel to the fringes. We are now ready to go. ROTATE THE CROSSED POLARIZER AND ANALYZER BOTH THROUGH EXACTLY 45°, SAME DIRECTION.

We first calibrate the Babinet. We put a filter in front of the arc and position the zeroth order fringe (dark) between the cross wires. This will be the fringe that appears most neutral in the unfiltered arc. Adjacent fringes are strongly colored. Again back with the filter, the Babinet is cranked over so that an adjacent fringe comes between the cross wires; better that a second fringe is put there. The difference in the positions (dial plus scale reading--use the small hand magnifier) will tell one how far the Babinet has to be moved for a 360° phase shift between the two polarization components.

The mirror is now put in position. The exit optics can be set at selected angles and, with the small telescope replacing the eyepiece, the mirror turned until the slit image is aligned with the telescope cross wire. From the shift in the exit optics from the straight through alignment, the angle of incidence can be determined (the reflected angle turns through twice that of the incident angle). The eyepiece is replaced, the Babinet shifted with the dial until the central fringe is returned to its place between the cross wires, and the shift recorded. To get the ratio of the two reflected amplitudes, the analyzing nicol is now turned until the fringe is the darkest, there is maximum fringe contrast. The change in the angular position of the analyzer is determined. The tangent of the angle taken from the zero position earlier found, gives the desired ratio. And so it goes for a nice range of incident angles--over as large as the instrument allows. This is the visual method to be used in the red and the green.

The photoelectric method is essentially the same except that a photocell replaces the eye, and a slit replaces the two cross wires back of the Babinet compensator. A similar insert to that carrying the cross wires is used to provide a slit exit opening. The photocell current will be a minimum when a dark fringe is positioned directly in front of the slit, so we can still determine compensation. At the minimum of the photocurrent, corresponding to a fringe in front of the exit slit, the analyzing nicol is then turned until that minimum is itself a minimum. The angle of incidence is set by placing the exit optics at a selected angle and then turning the mirror until a signal maximum is reached. For this, you may have to shift either the Babinet position or the analyzer a little to have a non-zero photocurrent on which you can set for a maximum. But be careful: the photodetector is a photomultiplier tube and can be wrecked by drawing too much current from it when too much light falls on the photocathodes. Turn the power supply filaments on by moving switch #1 to the upper position; let warm up about a minute. Make sure the right hand knob voltage control is turned all the way counter-clockwise to make the voltage least--it will still be about 600 volts. Raise the METER switch to its upper position and then raise the POWER switch to its upper position. There should be a small meter deflection which can be increased by raising the voltage and by opening up the analyzer a bit. It is best to do this without a mirror in place and the exit optics looking directly at the collimator. Photocurrent should not exceed the 50 microamperes full scale for best stability. When setting on the minimum, however, you will probably want nearly full voltage--say 900 volts-on the tube. You may still be dissatisfied that the minima are too broad for accurate setting of the Babinet compensation or the analyzer angle. Improvement may be had in this way: Find the minimum of both Babinet and analyzer approximately. Turn the compensation off to raise the photocurrent say to 30 or 40 microamperes; read the dial and scale; turn into the minimum and then come out on the other side and bring the photocurrent up again to the same value--30 or 40 microamperes. Read the compensator. Half way between should be the best minimum. Then put the compensation at that value. Be sure that you approach each of these readings in the same direction--otherwise the considerable backlash in the screw driving the prism will get you in trouble. In fact you should approach all the settings on this thing from the same direction. We should perhaps spring load it; but it isn't. To find the best position of the analyzer use the same stunt. You're on the minimum with the Babinet; rotate the analyzer to make the photocurrent your 30 or 40 microamperes. Then go to the other side of its minimum and get the same current. Split the difference in the two angles as the correct setting of the analyzer for best minimum. And that's it.