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THE DESIGN AND CONSTRUCTION
OF AN ELECTRON LENS FOR USE IN A
LOW ENERGY ELECTRON DIFFRACTION SYSTEM

by

Rodney S. Krieger, Jr.

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Submitted to the
Faculty of The Graduate College
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Rodney S. Krieger, Jr.
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INTRODUCTION

Low Energy Electron Diffraction

Explanation of low energy electron diffraction

Low energy electron diffraction, commonly referred to as LEED, concerns the observation of crystal surface characteristics by the examination of patterns produced by diffracted electrons in the 10 to 500 eV energy range. This contrasts to more the commonly used high energy electron diffraction (HEED) techniques utilizing energies from 10 to 100 keV. The types of diffraction encountered with LEED are (a combination of) surface diffraction and deeper bulk diffraction. The ratio of surface to bulk diffracted electrons is inversely related to the incident electron energies, therefore making the lower electron energies more useful in doing surface, or two-dimensional diffraction studies.

The LEED process can be explained with the use of the simplified schematic shown in Figure 1. Basically it consists of an electron beam production and focusing system, target (specimen to be studied) and a fluorescent screen to observe the diffraction pattern. More specifically, the electron source and optics may be of a variety of types and designs so long as the beam energy is below 500 eV. Beam currents generally range from a fraction of a microampere to ten microamperes. Beam diameter at the target may be as large as 1 mm. After primary acceleration and focusing the electrons are sent through a drift tube which shields the beam from the fields produced by the
FIGURE 1
Schematic of Low Energy Electron Diffraction Apparatus
grids and phosphor screen. Upon striking the target surface some of the incident electrons are elastically scattered, suffering little or no loss of kinetic energy. The remainder of the incident electrons are inelastically scattered, meaning that the incident electron, either by exciting the target atom or by ejecting one of the target atom's electrons, undergoes a considerable energy loss. The elastically scattered electrons contain the diffraction information desired. The inelastically scattered electrons contain no diffraction information. Separation of the two types of electrons is achieved by the placement of a repeller grid in front of the phosphor screen. A potential is then applied to this grid to repel the lower energy inelastically scattered electrons while allowing the more energetic elastically scattered electrons to pass. A second, or neutralizing, grid is placed in front of the repeller grid and its potential is maintained at, or close to, that of the target. Its function is to shield the target from the fields produced by the other components therefore producing a field-free region in front of the target.

LEED studies can provide investigation on the structural arrangement of surface atoms and presence of contaminants; it can also be used to observe the chemical reactions that take place at the crystal surface. In addition, nucleation, epitaxy, thin film growth, and surface diffusion can also be conveniently studied by LEED.\(^5\) It can easily be applied to any crystalline materials, whether a metal, semiconductor or an insulator.

Although first discovered in 1927\(^6\) LEED has only recently enjoyed somewhat widespread use. The reasons are that (1) hard vacuums
in the $10^{-8}$ to $10^{-10}$ torr range are now routinely achieved (these low pressures are necessary to maintain sample surface cleanliness), and (2) there has been significant growth of interest in solid state electronic devices, the physical investigation of which can easily be achieved using LEED techniques. Varian\textsuperscript{7} is presently the only manufacturer of commercially available LEED apparatus. Three models (120, 240, and 360) are available, the least expensive of which costs $24,200.

The intent of this work, therefore, was to construct a LEED system at a reasonable cost, but from available components to complement present analytical techniques used in the Western Michigan University Spectroscopy Laboratory. To do this, an obsolete RCA model EMC electron microscope was converted to LEED use. The electron microscope contained a vacuum system, a vacuum chamber with a viewport, an electron gun and a high voltage power supply, all of which are basic to any LEED system. Missing, however, was an electron optics system of the proper design for LEED and the necessary control circuitry.

A simplified cross section of the electron microscope can be seen in Figure 2.
CHAPTER I

Initial Design and Performance of Electron Optics

Background

Contact was made with Varian in an attempt to purchase the electron optics assembly presently used in their LEED system. Price inquiries resulted in an estimated cost for the optics assembly and its control of approximately $2,500. This, in turn, resulted in a request for detailed information on the design of the Varian optics assembly which was turned down because of the proprietary nature of this information.

A search of the literature was then conducted to see if detailed optics design information was available. Most authors\textsuperscript{9, 10, 11, 12, 13} provided only simplified schematics of the optics system that they employed in their work. Others\textsuperscript{14, 15, 16, 17} went one step further and did provide the potentials applied to each lens element. None, however, described the construction techniques, materials used, or the exact geometry and dimensions of their optics system. The majority of these authors used the univoltage, or Einzel type, lens. For this reason it was decided to utilize this type in this work. This type of lens is shown schematically in Figure 3. Cosslett\textsuperscript{18} also describes this type of lens as a "symmetrical" lens, this term being used because the outside elements are at the same potential hence the equipotentials are entirely symmetrical about the mid-plane of the lens. The inside lens element potential can be changed to produce
FIGURE 3
Three Element Einzel Lens
a divergent or convergent beam.

**Initial lens construction**

The modification of the electron microscope included mounting the electron gun, via a new gun mount, directly to the microscope viewing chamber (see Figure 2). By doing this, the focal point of the lens assembly was limited to a range of between 75 mm and 125 mm from the electron gun. Also, the optics assembly must be installed through a 70 mm diameter opening in the rear of the viewing chamber.

With these constraints the design shown in Figure 4 was chosen. Actual lens element dimensions were obtained from examples detailed by Septier. These included a center lens element 2.3 mm thick, 63.5 mm outside diameter with a center aperture 3.2 mm in diameter. Outside lens element dimensions were: 0.8 mm thick, 63.5 mm outside diameter and a center aperture diameter of 1.0 mm. The distance \( f_1 \) between the lens and the target plane was kept at a minimum because as \( f_1 \) increases it becomes extremely sensitive to small changes in the voltage ratio of the inside lens element to the outside elements. Because of this, the lens could not be placed any closer than approximately 25 mm from the cathode cap of the electron gun. For this reason it was also necessary to add an initial accelerating anode of the same dimensions of the center lens element spaced 3.2 mm from the cathode cap. This anode also served to mask out the effects of spherical aberration from the beam cross-over due to the thickness of the cathode cap. The anode plate and lens elements were all constructed from stainless steel sheet stock.
FIGURE 4
Electron Gun, Einzel Lens and Phosphor Screen Assembly
In addition to the center aperture of the lens plates and anode, three 6.4 mm holes were drilled 120° apart and 22.9 mm from the center of the plates. These allowed the plates to be moved on the three Mykroy insulating rods shown in Figure 4 that served as mounting rods for the entire optics system. This type of mounting provided good insulating characteristics between lens elements and allowed for easy adjustment of lens plate positions.

The construction of the lens plates and anode required the use of several specially made jigs and fixtures to insure accurate placement of all holes. This was necessary so all center apertures would line up coaxially.

Electron gun

The electron gun from the electron microscope was used as mentioned above. It consists of a hairpin type tungsten cathode (filament) enclosed by a cathode cap. The cap is maintained slightly negative with respect to the cathode to collimate the electrons into a beam through the cathode cap aperture. The gun was originally mounted on a ceramic rod in a large ceramic cone (see Figure 2). This cone could not be properly attached to the LEED chamber and still provide a good vacuum seal using any type of conventional gaskets. Therefore, a new mount, illustrated also in Figure 4, was made. A brass collar was made to which the cathode and cap assembly was bolted. A length of 12.7 mm diameter Mykroy insulating rod was drilled lengthwise for the electrical leads and cemented into the collar with Ve-Seal epoxy. The other end of the ceramic rod was cemented into a 12.7 mm...
hole in the center of a cup shaped base which took the place of the old ceramic cone. A special jig was used to insure that the gun was properly centered while the cement cured.

Phosphor screen and wire grids

Figure 5 shows a cross section of the construction of the screen-grid assembly. The screen was made from the same 2.3 mm thick stainless steel sheet stock as were the anode and center lens element. The outside diameter was turned down in a jig to 63.5 mm so as to fit into the opening in the viewing chamber. Three 1.6 mm diameter by 10.2 mm long stainless steel pins were pressed into the back of it so as to fit into holes drilled into the ends of the three Mykroy mounting rods. Also, a 7.6 mm diameter hole was drilled and reamed in the center of this assembly to accommodate the drift tube and insulator (see Figure 4). The front of the finished disk was sanded with successively finer grades of emery cloth to a near mirror finish. The disk was immersed in a detergent-water solution and placed in a small ultrasonic washer for 30 minutes. It was then rinsed in deionized water and acetone and air dried. Two grams of cadmium sulfide phosphor powder was then thoroughly mixed with 3cc of a 10% nitrocellulose in amyl acetate solution. This phosphor-binder solution was then poured over the clean face of the disk and allowed to dry in a horizontal position under an inverted petrie dish. This provided an even, smooth, tightly bound fluorescent surface.

A large Mykroy washer was constructed with an outside diameter of 63.5 mm, an inside diameter of 57.2 mm, and a thickness of 2.5 mm.
Phosphor-coated screen
Repeller and neutralizer grids
Ceramic washers
Electrical leads

FIGURE 5
Cross Section of Phosphor Screen and Grid Assembly
The washer was cemented to the phosphored face flush with the edge of the coated disk. Another insulating washer with an outside diameter of 12.7 mm, an inside diameter of 7.6 mm, and a thickness of 2.5 mm was made and cemented around the center hole of the disk. A 75 mm by 75 mm square of 100 mesh nickel screening was cemented to the top of these two washers. Another washer-screening layer was then cemented to the top of that unit with a thin aluminum washer cemented on top of the last screen. Electrical leads were sandwiched in with the coated disk and the two mesh screens at each step. The excess screen in the center hole and around the outside was then trimmed off with a knife.

Drift tube and shield

The drift tube consisted of a stainless steel rod which was 31.8 mm long with an outside diameter of 3.2 mm. The rod was bored axially to an inside diameter of 1.6 mm. The tube was cemented inside a 7.6 mm outside diameter, shouldered, Mykroy tube. This was then cemented into a center hole in the end of a 'can' shaped shield. The shield end was also drilled to fit over the ceramic mounting rods in the same manner as the lens elements. The open end of the shield slid into the gun mount base to provide a grounded shield for the entire gun-lens assembly. The shield and drift tube could also be axially adjusted through approximately a 13 mm range.

Power supply and control circuit

The electron microscope power supply was used with minor modifications to decrease the output from 30,000 volts DC to 5,000 volts.
DC. Also, a 5 megohm, 2 watt potentiometer was used to replace the original fixed resistance in the cathode auto-biasing circuit.

Figure 6 is a schematic of the optics and the optics control circuit. The potentials shown are essentially those outlined by Lander with the addition of the anode plate. All voltages shown are positive with respect to the cathode cap.

Figure 7 shows the control chassis mounted atop the right hand control panel of the electron microscope cabinet.

Performance of initial lens

The gun, anode, lens and drift tube-shield were assembled. The cathode distance from the rear surface of the cathode cap was set at zero and the apex of the cathode was centered in the cap aperture by bending it. The anode was spaced 3.2 mm from the front surface of the cathode cap. The three lens elements were installed with an inter-element spacing of 1.3 mm and the first element spaced at 25 mm from the cathode cap. The drift tube was then spaced 12.7 mm from the exit plane of the lens. These element positions were somewhat arbitrary in that it was expected that final positioning would depend on lens test results. All components were rinsed in isopropyl alcohol before assembly to remove any residual grease or oil.

The 100 mm diameter view port glass was coated on the inside with phosphor powder in much the same way as described before. Although not necessarily in the focal plane for the beam, the coated window served as an indicator for beam centering, homogeneity and axial symmetry.
FIGURE 6
Control Circuit for Einzel Lens LEED Optics

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FIGURE 7
LEED Optics Control Unit Mounted on Electron Microscope Cabinet

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After installing the optics system and the glass window on the LEED chamber, the chamber was evacuated down to approximately $10^{-5}$ torr. This pressure was adequate to prevent arcing between closely spaced components due to ionization of gas molecules.

When all leads were connected and the power applied to the optics system some arcing did take place initially. This was believed due to contaminants left on the insulators because the arcing soon stopped.

The focal length $f_i$ (the distance between the center lens element and the image plane) of an Einzel lens is a function of the ratio

$$\frac{R_e}{\frac{V_i - V_o}{V_o - V_a}}$$

where $V_i$ is the potential applied to the center lens element; $V_o$ is the potential applied to the outside lens elements; and $V_a$ is the potential of the electron source. The electron source can be considered as the anode aperture. The relationship between $f$ and $R_e$ for the particular lens dimensions used is shown in Figure 8. The distance between the center lens element and the target of the LEED apparatus is 60 mm. The desired beam diameter at that distance was approximately 0.5 mm therefore making the actual focal length larger than 60 mm. It can be seen that, according to Figure 8, the value of $R_e$ must either be approximately 0.03 or somewhere close to 1.0 for an $f_i$ greater than 60 mm. Septier points out that when $R_e$ is less than 1.0 the beam converges; when $R_e = 1.0$ the beam is paraxial; and when $R_e$ is greater than 1.0 the beam will diverge. For this reason $R_e$ had to be maintained at a value of less than 1.0 to produce a
FIGURE 8
Relationship Between the Focal Length of an Einzel Lens and the Voltage Ratio of the Center Lens Plate to the Outside Lens Plates
convergent beam with a focal distance in excess of 60 mm.

The bias voltage $V_b$ was set at zero by adjusting the bias resistor to zero. The anode potential $V_a$ was set at 100 volts and the outside lens element potential $V_o$ was adjusted to 500 volts. The center lens element potential $V_i$ was set at 400 volts to an $R_e$ value of 0.75 as a starting point. With the room lights out and even with the drift tube potential at zero, a dim, irregular spot was observed on the phosphorescent glass screen. As the drift tube potential, $V_t$, was adjusted from zero to the maximum of 300 volts the spot intensity greatly increased until $V_t$ reached approximately 200 volts. Between a $V_t$ of 200 and 300 volts the intensity appeared to increase only slightly. The reason for this leveling off is unknown. The spot as initially observed, was off-axis approximately 12 mm and as $V_t$ was increased to maximum, it moved closer to the axis by approximately 6 mm. The spot was off-axis in the 9 o'clock direction (looking into the beam) and was oval in shape with its major axis measuring roughly 10 mm and minor axis 5 mm with $V_t$ set at 100V. The size of the spot would decrease as its intensity increased when $V_t$ was adjusted higher. The intensity of the spot would also increase as $V_b$ and $V_a$ were increased, but the spot size, shape and position with respect to the center of the optical axis remained unchanged. $R_e$ was adjusted from 0.0 to 2.0, yet the spot size would not decrease below approximately 3.0 mm. Various other combinations of electrical adjustments were made to provide a centered, round spot with a diameter of less than 1.0 mm. No success was achieved.

The system was shut off, brought back to atmospheric pressure,
and the optics system was removed for inspection. Small burn spots, produced by oxidation of surface contaminants by the electron beam, were noticed off-axis on the entrance side of the first lens plate and drift tube. It was apparent that the beam exiting from the anode was not paraxial. It was discovered that the cathode cap, which was threaded to the cathode mount (see Figure 2) had an excessive amount of play in the threads. Since the cathode had been centered in the cap aperture while in a vertical position the cap would "sag" when placed in the operating (horizontal) position. A collar was made to fix the position of the cap with respect to the mounting rods for better beam centering, but perfect centering was still not achieved. Further efforts to center the cathode and to remove irregularities in all plate apertures still did not provide a round, centered spot.

It was apparent at this point that the "working distance" between the object (cathode) and image (target) planes was far too great for the utilization of a lens of this design. A search was begun for a different, perhaps "thicker" lens configuration that would better lend itself to use with an object-image distance on the order of three to four inches.
Final Lens Design

The immersion lens

Cosslett states:

Properly speaking, an immersion lens is formed by any system in which object and image are in regions of different refractive index, and in this sense both the two-cylinder and aperture lens are of the immersion type....

The term "immersion" is applied here as it is in light optics when talking about an oil immersion microscope where the object is immersed in a transparent oil. In our case we intended to "immerse" the cathode of our system in a potential field that differs from that which exists at the target in our LEED chamber. This type is used in such applications as cathode ray tubes where the beam spot diameter must be small in relation to the image focal length $f_i$. Thus, it was decided to construct a two-tube immersion lens.

Lens design

El-Karah describes in detail the necessary parameters of design of a two tube immersion lens. The critical parameters of design (see Figure 9) are the axial distance $f_i$ between the lens principal plane (exit plane of first tube) and the image plane; the distance $f_o$ between the electron source (object) and the principal plane; the spacing $s$, between the tubes; the inside radius $r$, of the tubes; and the voltage ratio of the two lens tubes, $V_2/V_1$. The re-
The relation of focal length to voltage is:

\[ \frac{f_o}{f_i} = \left(\frac{V_2}{V_1}\right)^{1/2} \]

With the use of computer-generated tables and the knowledge of the total distance \((f_o + f_i)\) a choice of tube radius \(r\), and tube spacing \(s\), was made. A tube radius of \(r = 3.2\) mm was chosen and a spacing of \(s = 0.5r\). Data from the table for this choice of \(r\) and \(s\) was then plotted (Figure 10) to determine the location of the lens principal plane with respect to the cathode. The length of the first lens tube could then be calculated.

Curve A in Figure 10 represents the relationship between the lens voltage ratio and the object (cathode) distance from the principal plane. Curve B is the relationship between the voltage ratio and the image (target) distance from the principal plane. Curve C is the sum of curves A and B.

To determine the length of the first tube the vertical line \(D\) was drawn such that it intersected the point on curve \(C\) corresponding to the total \(f_i + f_o\) distance (distance from the cathode to the target) of 92.8 mm. The ordinate corresponding to the intersection of \(D\) and curve \(A\) then gave the actual distance between the electron source (object) and the principal plane (exit end of first tube) as 36 mm. The electron source (cathode tip) is in the plane of the rear of the cathode cap the thickness of which is 2.3 mm. An arbitrary cathode cap-lens tube gap of 1.7 mm was chosen. These two measurements were subtracted from the actual \(f_o\) distance of 36 mm to give the design length of the first tube of 32 mm.

The length of the second lens tube is unimportant so long as
FIGURE 10
Relationship Between Lens Tube Voltage Ratio and the Object and Image Focal Lengths
the length is greater than the inside diameter of the lens tube. A length of two diameters (12.8 mm) was chosen as satisfying this criterion and also providing room for the drift tube mounting plate in Figure 11. Thus the intersection of line D with the abscissa yields a $V_2/V_1$ ratio of 2.64 to 1.0.

**Lens construction**

The lens elements were constructed from a 50 mm diameter stainless steel rod turned down so the elements would slip-fit between the ceramic mounting rods. The center holes (tubes) were drilled and reamed to 6.4 mm. All surfaces of the lens elements were sanded with successively finer grades of emery cloth and the tubes were given a final polish to a mirror finish with #600 grit aluminum oxide powder mixed with water. This final polishing provided a smooth enough electrode surface to maintain good electron beam homogeniety.

The drift tube and mounting plate were constructed of 6.4 mm outside diameter stainless steel tubing and 2.3 mm thick stainless steel sheet, respectively, press-fit together. These components were also polished as above with only the drift tube interior getting the final aluminum powder polish.

A hole was drilled and tapped on the outside surface of each of the two lens elements and the drift tube mounting plate to accommodate small brass screws. These screws served as electrical terminals to which the lens element leads could be connected.

The assembly, including the electron gun and lens system can be seen in Figure 12.
FIGURE 11
Electron Gun, Two-Tube Immersion Lens and Phosphor Screen Assembly
FIGURE 12
Two-Tube Immersion Lens With Drift Tube
Changes in screen-grid assembly

Skinner\textsuperscript{29} reports that a phosphor powder-binder coating such as the one already described caused a surface charge to accumulate because of its insulative value. The method described by Skinner was followed in recoating the screen in the following manner.

First the screen-grid assembly was taken apart and the screen cleaned as described above and then placed above a benzene flame from a spirit (alcohol) lamp. This allowed a thick and relatively even coating of woolly soot to coat the surface. An extremely thin layer of phosphor was then deposited on top of the carbon (soot) by spraying it dry with a small pressurized can-powered venturi-type sprayer. This gave a yellow-gray appearance to the screen when observed with the naked eye. Observation at 50X under a stereo microscope showed that the phosphor particles were distributed evenly and at an approximate 50\% coverage.

This technique is claimed\textsuperscript{30} to display excellent diffraction patterns and provide a larger electron absorption efficiency than cast phosphor coatings.

The screen and grids were then reassembled and can be seen in Figure 13.

Changes in lens control circuit

Figure 14 shows the changes that were made in the optics control circuit to adapt to the new immersion lens. Since the old anode plate was no longer used, the number of controls was reduced from seven to
FIGURE 13
Phosphor Screen and Grid Assembly
FIGURE 14
Control Circuit for Immersion Lens LEED Optics
six. Also, to provide a wider voltage range for each optics element, 10-megohm, 2-watt potentiometers were used throughout. This gave a full 0 to 1000 volt potential range to each element.

In addition, a 200K-ohm multi-turn potentiometer was placed in the feed-back DC amplifier that regulates the power supply output voltage. This served as a fine adjustment for setting the -5000 volts DC output required.
CHAPTER III

Performance Characteristics of New Lens

Construction of test apparatus

A special device, as shown in Figure 15, was constructed to de­termine the shape, centering and focal point of the electron beam. It was mounted in place of the leaded glass view port on the LEED chamber. It consisted of a round aluminum disk with a small leaded glass window mounted in its upper half. Through this disk was an axially adjustable, polished, 12.7 mm diameter stainless steel rod. An O-ring sliding type seal was constructed for the rod to slide through. This type of seal proved adequate because a pressure of only 10^{-5} torr was needed to test the optics without production of arc-over between high voltage components. A rack gear was fitted to the rod which meshed with a knob-driven set of gears on the frame enclosing the external end of the rod. The gearing was necessary to prevent the rod from being sucked into the chamber and to allow fine adjustment. Attached to the internal end of the rod was a 25 mm diameter wire mesh screen coated with phosphor. This was positioned such that its center coincided with the designed beam axis. Also, a six-inch scale was mounted on the external frame parallel to the rod. A pointer was affixed to the rod so that the distance between the phosphor screen and lens components could be measured. The phosphor screen was held at ground potential which was +5,000 volts DC with respect to the cathode cap.
FIGURE 15
Test Apparatus With Moveable Phosphor Screen
to Test Electron Beam Characteristics
Electron gun characteristics

The first step taken was to determine the ability of the electron gun to collimate the electron beam. Since an immersion lens of this type is designed to "immerse" the cathode in its attractive field, then one need not apply any bias voltage between the cathode and cathode cap. However, the bias voltage has, basically, the effect of changing the aperture size of the cathode cap. This, in turn, decreases the "size" of the electron source (object) that the lens has to focus. Another way of decreasing the effective size of the object is to move it farther from the lens.

Both of these techniques were used to determine their effect on the solid angle subtended by the beam. Figure 16 shows the results of this experiment. The horizontal error bar lines through each point denote a possible ± 2 mm accuracy in measuring the spot diameter. Small marks were put on the movable phosphor screen to determine the spot diameter but they could not be placed accurately without destroying portions of the phosphor coating.

The results were as expected. The six curves developed for a cathode-to-cap spacing of zero show the beam solid angle decreasing with each 5-volt, stepped increase in bias voltage. The two curves representing the smallest beam angles came about by changing the cathode-cap spacing to .8 mm plus operating at the two highest bias voltages of 20 and 25 volts. It is interesting to note that little change in angle occurs until the bias voltage is increased above 10 volts. The reason for this is unknown since it appears that the
FIGURE 16
Effect of $V_b$ and Cathode Cap Spacing on Spot Size
(Without Lens Tubes Installed)
effects are opposite to those expected from space charge. It is also apparent that the beam angle increases as the phosphored screen is moved away. This is to be expected because the equipotentials produced by the screen (which is also the anode) would be spaced farther apart resulting in less beam convergence. Also, according to Figure 17, the phosphor screen has a rather marked effect on the bias voltage. The effects appear to minimize, or stabilize, at a spacing of approximately 25 mm distance. Here the bias control was simply set at maximum.

Next, the spot size, at a location 55 mm from the front of the cathode cap, was measured as a function of cap bias and plotted in Figure 18. It is apparent here, as it is in Figure 16 that there is also a slightly non-linear relationship between the beam divergence (or convergence) and the bias voltage. Here, however, the rate of change increases closer to the 20 volt bias level.

Since the immersion lens can focus a more convergent beam at lower voltages, it was decided to leave the cathode-cathode cap spacing at 0.8 mm and to utilize a minimum of 10 volts cathode cap bias.

For all of the above tests the cathode current was set at 1.66 amperes. This odd value comes about because the beam intensity (current) control is simply calibrated on an arbitrary scale of 1 to 10. Figure 19 shows the relationship between the scale and the actual current as measured by a Weston model 155, 0 to 2 ampere, AC ammeter. The relationship is linear with the exception of the lower currents, where the control apparently has no effect.
FIGURE 17
Effect of Phosphor Screen Position on Bias Voltage
FIGURE 18
Effect of Bias Voltage on Spot Diameter
FIGURE 19
Relationship Between Cathode Current and Control Dial Setting
The spot formed with just the cathode and cap was round but had two bright "petals" opposite each other along a line crossing through the 1 o'clock to 7 o'clock position (facing the beam). The length of each petal was equal to the radius of the beamspot. Since the cathode was oriented perpendicular to this imaginary line it was assumed that these petals were actually a distorted image of the cathode. An inquiry as to that question resulted in its confirmation and the suggestion that increasing the cathode current would eliminate the petals. The cathode current was increased from 1.66A to 1.8A and the increased brightness of the spot matched that of the petals and, in effect, made them disappear.

Lens performance

The first lens tube (see Figure 11) was installed by itself spaced 1.6 mm from the front of the cathode cap. This was done primarily to make a qualitative observation of its beam altering effects. A clean, round, homogenous spot approximately 6 mm in diameter could be produced 80 mm from the cathode cap when the bias voltage was set at 10 volts or above. With a bias voltage of less than 10 volts a halo would appear around the spot. This was a sign of spherical aberration occurring at the beam cross-over inside the cathode cap aperture. The cause of this is simply that the beam cross-over has some finite axial length instead of being just a point on the axis. This system creates two effects on the electrons leaving the cathode. First, the positive lens element potential serves to "pull" the electrons through the cap aperture and focus them in some way.
Secondly, the grid negative bias tends to "squeeze" the electrons leaving the cathode into a dense, paraxial bundle. When this squeezing effect is reduced or eliminated, the distribution of angles and therefore, velocities of exit from the cap increases causing some electrons to cross the axis closer to the cathode than the other, more paraxial electrons: hence, spherical aberrations occur.

Next, the second lens tube was installed at a distance of 1.6 mm from the first lens tube. The potential applied to both elements was 975 volts each to give a $V_2/V_1$ ratio of 1.0. $V_1$ was then decreased in 100 volts steps to 300 volts. Both potentials were then set at 800 volts and $V_1$ again decreased in 100 volt steps to 300 volts. The bias voltage was maintained at 10 volts during the procedure. At each decrease of $V_1$ the size and shape of the spot was noted. The results of this are shown in the curves of Figure 20. The displacement downward of the $V_2 = 800$ volts curve is believed to be caused by the same conditions described in the paragraph above. Namely, that the ideal spot diameter of 1 mm (denoted by the vertical line intersecting both curves) required a $V_2/V_1$ ratio of 1.4 and 2.25 for the $V_2 = 800$ volts and $V_2 = 975$ volt curves respectively. However, the $V_1$ voltage necessary for a $V_2/V_1$ ratio of 1.4 in the $V_2 = 800$ volts curve was 580 volts; whereas, for the $V_2 = 975$ curve, $V_1$ was only 433 volts. Thus the additional voltage on $V_1$, where $V_2 = 800$ volts provided greater acceleration and therefore collimation to give a smaller spot at a smaller $V_2/V_1$ ratio.

There are two reasons for the deviation of the actual $V_2/V_1$ ratios from the ratio of 2.64 to 1.0 determined from Figure 10.
FIGURE 20
Effect of Voltage Ratio of Immersion Lens Elements on Spot Diameter
First, the original \( f_0 + f_1 \) distance was calculated with a cathode-cathode cap spacing of zero. The increase of this spacing has the effect of greatly increasing the \( f_0 \) distance as measured from the apparent rather than real cathode position to the principal plane of the lens. In other words, the apparent point source object has moved farther back than the actual object due to the decreased beam solid angle resulting from the increased spacing. This in turn would make it necessary to shorten the first lens element to bring the principal plane back into proper position.

Secondly, the design is based on no consideration of a bias voltage. The addition of a bias between the cathode and cathode cap has the same effect as increasing the cathode-cathode cap spacing and producing those resultant affects discussed above.

The addition of the drift tube made it necessary to increase the \( V_2/V_1 \) ratio such that the focal point of the lens would be positioned somewhere near the entrance of the tube. The drift tube, therefore, could be kept at a lower voltage than \( V_2 \) and thus act as a negative, or divergent lens element. This is necessary to prevent masking of the beam by the drift tube entrance and in turn decreasing the beam's intensity.

A simple experiment was attempted with the phosphor screen and grid system in place. This involved taking a freshly cleaved portion of a single crystal of NaCl and placing it in the LEED apparatus sample holder. At a pressure of \( 2 \times 10^{-5} \) torr the electron beam was applied to the crystal with \( V_1 = 330 \) volts, \( V_2 = 1090 \) volts and \( V_t = 410 \) volts. The target potential was 60 volts. A pair of diffraction rings
appeared on the phosphor screen similar to those seen by Scheibner\textsuperscript{33} in his work with nickel crystals. The rings were probably due to the accumulation of oxygen and/or water vapor molecules on the crystal surface due to the low quality vacuum. These diffraction rings can be seen in Figure 21. The potentials on the neutralizer and repeller grids were 109 and 790 volts respectively.
FIGURE 21
Diffraction Rings From Amorphous Layer on NaCl Crystal Surface
CONCLUSIONS

This report has described the limitations of an Einzel lens for use in a low energy electron diffraction (LEED) apparatus requiring a long focal length electron lens. The primary limitation was found to be difficult lens plate aperture alignment along the optical axis when the focal length is on the order of fifty times the diameter of the lens aperture.

However, also described is the design criteria and construction techniques needed to make a two-tube immersion lens that was successfully used in the same LEED apparatus. The immersion lens provided an electron beam with the characteristics necessary to conduct LEED investigations. Furthermore, the immersion lens was found to obey, within certain limits, the theoretical criteria used for its design.

It has been shown that an actual LEED apparatus can be constructed for a minimum cost from a modified, obsolete electron microscope. This apparatus, with further refinement in the design of its vacuum system, can now be readily made into a workable LEED research instrument.
BIBLIOGRAPHY


2. ibid.


8. ibid.


22. Lander, Morrison and Unterwald, op. cit.


25. Cosslett, op. cit., p. 43.


27. Septier, op. cit., p. 293.


30. ibid.

32. Personal communication with Mr. R. E. Matthias, Research Microscopist, Whirlpool Corporation, Benton Harbor, Michigan.