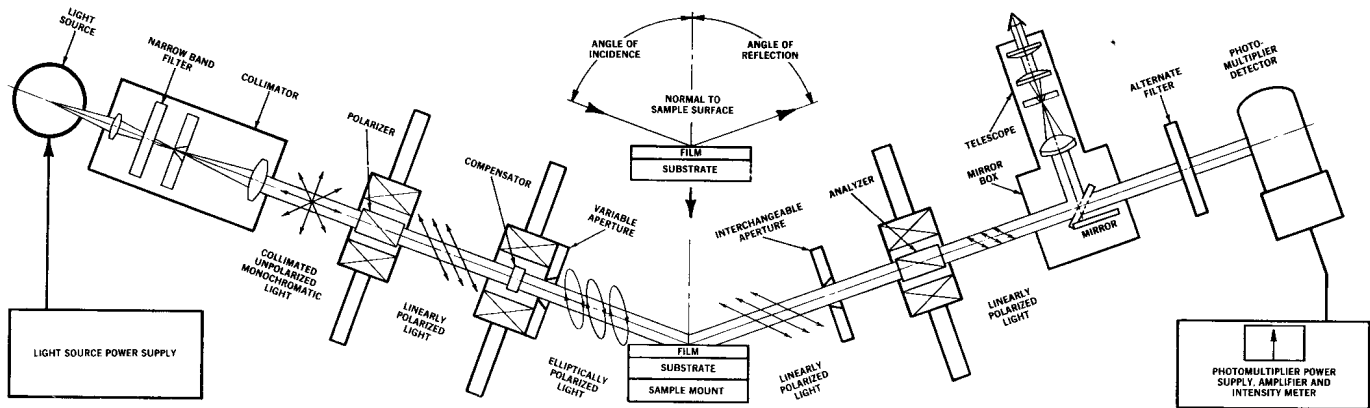


RUDOLPH RESEARCH

Type 436 and Type 437 Manual Photoelectric Research Ellipsometers



These ellipsometers are precision optical instruments which measure changes in the state of polarized light reflected from the surfaces of samples. Such measurements permit determination of the optical constants of sample surfaces, and the thickness and refractive index of thin films on those surfaces. The measurements are basically simple, involving rotation of a polarizer and an analyzer to cause extinction of a beam of polarized light reflected from the surface of the sample. Measurements can be made at any desired angle of incidence by adjusting the angle between the incidence and reflection axes. Both axes are formed by optical benches on which all components are mounted. The components can be removed and replaced, translated along the axes, and interchanged between axes, without affecting alignment. This great flexibility permits rapid alteration of the instrument configuration for other modes of measurement.

The following description of a typical method of operation is based on the ellipsometer diagram above. A collimated beam of unpolarized monochromatic light is transmitted through a polarizer and quarter-wave compensator to the surface of the sample, which it strikes at an angle of incidence set by the operator. The beam is reflected through an analyzer to a photomultiplier detector or (if the 45° mirror is inserted in the beam) to the operator's eye.

If the light source is a tungsten, tungsten-halogen, or ionized gas lamp, a collimating lens system and a narrowband filter will be required as shown. If the light source is a laser, the output will be quite parallel, and the center wavelength will be extremely monochromatic. Thus the need for a collimator will be eliminated, but a narrowband filter may still be required to suppress other wavelengths or background output. The high output intensity of lasers is useful in energy-limited measurements such as on low-reflectance samples.

The polarizer converts the collimated beam of unpolarized monochromatic light into a linearly-polarized beam. The polarization axis of the beam is determined by the orientation of the polarizer.

The quarter-wave compensator converts the linearly polarized light from the polarizer into elliptically-polarized light which strikes the sample. The compensator can be oriented

at any angle, but is used mostly at $\pm 45^\circ$ to the plane of incidence (or $+45^\circ$ and $+315^\circ$, since all angles are measured positive counter-clockwise from the plane of incidence when looking into the light source.). The compensator has two orthogonal axes (fast and slow) perpendicular to the direction of transmission. An entering beam which is linearly polarized parallel to any other axis, will be resolved into two components; one linearly polarized parallel to the fast axis, and the other linearly polarized parallel to the slow axis. The fast-axis component will be transmitted at a greater velocity than the slow-axis component. The quarter-wave compensator thickness is such that the slow component is retarded by 90° or one-quarter wave with respect to the fast component. When the two components emerge, they recombine, but the phase-shift between them will cause the polarization form of the output to differ from that of the input. When the axis of the linearly-polarized input is at 45° to the fast and slow axes of the compensator, the output will be circularly polarized. At other input-axis angles, the output will be elliptically polarized, with an azimuth (orientation of the major axis of the ellipse) and ellipticity (ratio of minor to major axes) determined by the orientations of the polarizer and compensator. The output of the compensator is the incident beam which strikes the sample surface.

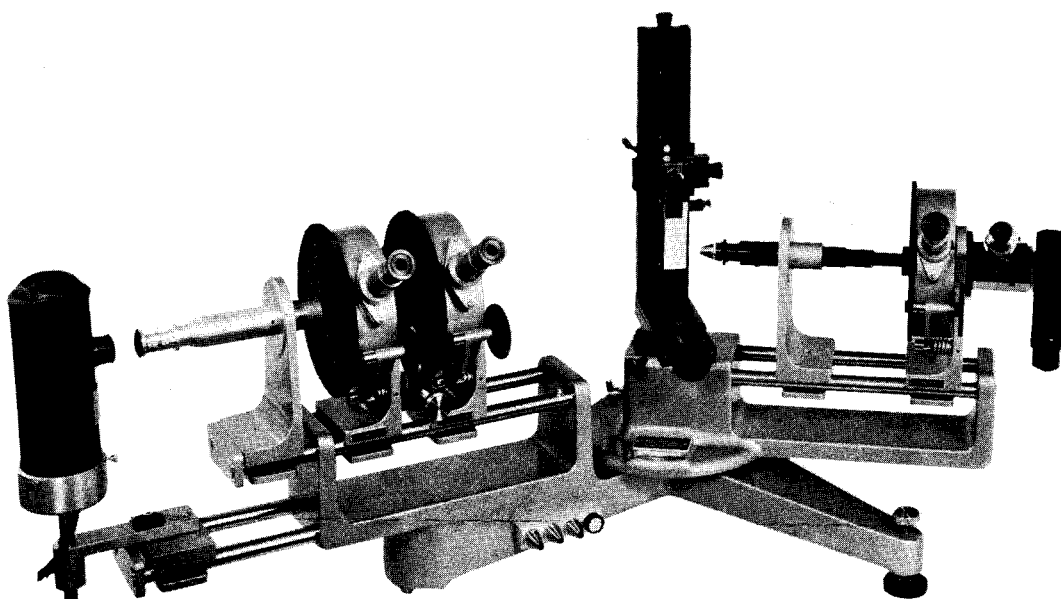
The optical properties of the sample surface cause the polarization form of the reflected beam to differ from that of the incident beam. The difference is measured as follows. The reflected beam passes through the analyzer to the photomultiplier tube, the output of which is indicated by a meter on the Electronics Unit. As the analyzer is rotated, the meter will indicate minimum intensities at two positions 180° apart. In general these minima will not correspond to true extinction, which can be achieved only if the reflected light is linearly polarized. For each sample and for each compensator setting (45° or 315°), there is some polarizer orientation at which the reflected light is linearly polarized, so that true extinction may be obtained by means of the analyzer. This orientation is found by alternately adjusting the polarizer and analyzer to deepen the minimum on the meter, until a null corresponding to true extinction is obtained. From the polarizer, analyzer and compensator orientations (designated P, A, and C) at which the null was obtained, the optical properties of the sample may be determined, as explained on Page 4.

MANUAL PHOTOELECTRIC RESEARCH ELLIPSOMETERS

The Type 436 Ellipsometer (for vertical samples) and the Type 437 Ellipsometer (for horizontal samples and liquids) differ only in their bases and sample holders. All other corresponding components are identical. In both ellipsometers, the incidence and reflection arms are precision parallel-rail optical benches employing rigid pairs of precision-ground stainless-steel bars. The optical components are supported on the bench rails, in alignment with the instrument optical axes, by precision bench mounts or trusses. Each bench mount has a V-groove and a flat pad machined in its base; the V-groove rests on one rail, and the flat pad rests on the other. This point-line support is extremely precise, stable, and repeatable. Once a component is factory adjusted in its bench mount, it may be shifted along its axis, interchanged between axes, removed and

replaced, and clamped to the rails, without misalignment. Note that all components are enclosed to reduce light leakage, but, because of the overall open construction, measurements are best made in a dark room.

The basic wavelength range of the standard ellipsometer is 350 to 700 nm; it may be operated at any wavelength in that range, with proper source, filter, and compensator. Each instrument is normally equipped for operation at 546.1 nm. Components for other wavelengths are described on page 4. An extended-range model with quartz optics for operation from 210 nm to 2.5 microns can be supplied, with special sources, filters, compensators and detectors for each operating wavelength.



TYPE 436 ELLIPSOMETER

Designed for ellipsometric measurements on vertical samples, the Type 436 is recommended for most research applications. It is normally supplied, with the components described below, for operation at 546.1 nm. Alternate components and accessories are described on page 4.

D1814 Tripod Base is an extremely rigid cast-aluminum tripod, with thumbscrews on two legs for leveling. The third leg supports a stationary horizontal optical bench carrying the incidence-axis components. The reflection-axis components are carried on a swinging horizontal optical bench which pivots about a precision vertical bearing at the center of the tripod. The incidence and reflection axes intersect in the vertical axis, at which the sample holder is mounted. The angle of incidence may be set within 0.01° to any value between 25° and 90° by means of an engraved scale and vernier. A split-collar mechanism permits locking the two axes at the set angle. A transformer in the base provides 6.3 Vac for the scale-illumination lamps of the Polarizer, Compensator, and Analyzer Rotators.

A1549 Vertical Sample Mount provides five degrees of freedom for positioning the sample surface at the intersection of the incidence and reflection axes, and at equal angles to both axes. The Mount pivots about the tripod vertical axis on a large precision shaft. Dovetailed slides on the Mount permit horizontal and vertical translation of the sample in the plane of its surface, and movement in the direction normal to that plane. A block at the top of the Mount contains a fine adjustment for vertical tilt. The Mount has slots for a 1" x 3" microscope slide, but it will hold a wide range of samples, from much smaller than 1" x 3" up to 6" x 12" or even larger. The bottom plate of the Sample Mount will

also support large glass cells for liquid/solid interface studies. The Mount is easily removed from the base, leaving a normal working space of 7" diameter for alternate sample holders, chambers, cells, stirring equipment, temperature-control equipment, etc. A maximum clear space of 12" diameter is obtainable by moving components outward on the optical benches. Larger clear spaces can be supplied for special applications.

600 Mercury Light Source comprises a heavy-duty mercury lamp in a housing on a support rod, and a separate 115 Vac, 60 Hz power supply. The support rod fits into an extension of the stationary incidence-axis optical bench, which permits vertical, horizontal and rotational adjustments for aligning the lamp with the incidence axis. The output contains strong lines at 365, 405, 436, 546 and 578 nm.

C1586 Collimator/Filter Assembly is a bench-mount-supported tube containing apertures and lenses which focus the divergent light from the source into a beam of 0.002 radian half-angle divergence. A filter holder at the input end permits changing filters. A 6901 Glass Filter is normally supplied, for isolating the 546.1 nm line from the 600 Mercury Light Source; but the holder also accepts 44301 narrowband filters of any wavelength. Filters are easily removed from the holder for visual alignment of the system.

C1648 Polarizer Rotator has a precision hollow bearing which is coaxial with the incidence axis of the instrument. A Polarizer mounted inside the bearing and a large circular scale outside the bearing are rotated together by means of a handwheel. The Polarizer, a 2010 Glan-Thompson calcite polarizing prism, is oriented so that its polarization axis is within 0.02°

of zero, and is carefully centered to minimize wandering of the field with rotation. The circular scale is divided into 1440 divisions each equal to 0.25° of arc. A 25-division vernier permits reading each 0.25° interval to 0.01° . Scale illumination and a 5X magnifier eyepiece facilitate reading. The eyepiece contains a cemented doublet lens corrected to provide extreme flatness of field. The entire assembly is contained in a light-tight housing supported on a bench mount.

C1649-5461-1° Compensator Rotator is mechanically identical to the Polarizer Rotator, but has a means of locking the scale at any setting. The Compensator mounted within the Rotator is a mica quarter-wave plate which provides $90^\circ \pm 1^\circ$ retardation at 546.1 nm. The Compensator is oriented so that its fast axis is within 0.02° of zero.

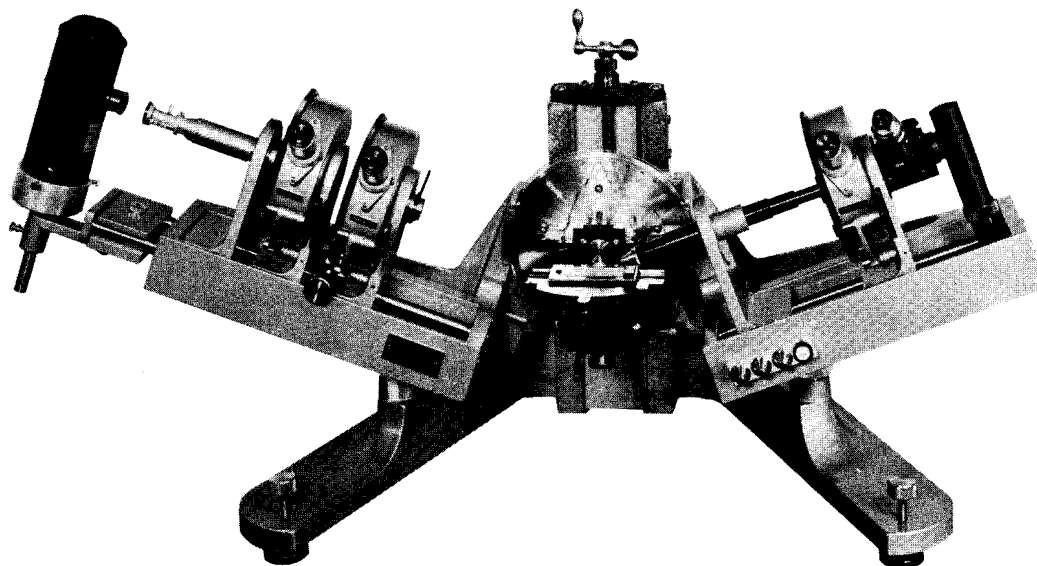
PP1643 Variable Aperture is an iris diaphragm which permits varying the diameter of the incident beam between 1 and 5 mm. It is generally mounted on the component immediately preceding the Sample Mount.

B1650 Interchangeable Aperture Assembly is supplied with four interchangeable apertures (1, 2, 3 and 5 mm diameter), permitting selection of the diameter of the central portion of the illuminated sample area on which measurements are to be made. (This diameter should be no larger than that of the illuminated area.) Apertures of intermediate or smaller diameters (down to 0.2 mm) are available on special order.

C1647 Analyzer Rotator is mechanically identical to the C1648 Polarizer Rotator. It contains a 2008 Glan-Thompson calcite polarizing prism, carefully centered to minimize wandering of the field with rotation, and oriented so that its axis is within 0.02° of zero.

D1675 Mirror Box permits selection of visual or photoelectric operation. The Mirror Box is fastened to the output side of the bench mount which supports the Analyzer Rotator, and the photomultiplier tube housing is in turn fastened to the output side of the Mirror Box. A B203 Telescope is fastened to the Box at 90° to the reflection axis. A pivoted mirror within the Box may be interposed in the light beam at an angle of 45° by means of a knob, deflecting the beam 90° through the telescope to the operator's eye. This permits observation and alignment of the sample, as well as preliminary visual nulling of Polarizer and Analyzer. Moving the mirror out of the beam permits photoelectric adjustment for precise extinction.

A6339 Photoelectric Detection System comprises a B6337 Photomultiplier Unit and a separate D6338 Electronics Unit. The Photomultiplier Unit is an electrostatically and magnetically shielded housing containing a IP21 photomultiplier. The IP21 is selected for high sensitivity and low dark current, and is carefully aligned within the housing to give maximum response. The Electronics Unit contains a photomultiplier power supply, a high-gain amplifier, and a light-intensity meter. A switch permits selection of four decades of sensitivity.



TYPE 437 ELLIPSOMETER

This instrument is designed to make ellipsometric measurements on horizontal samples and liquids. It is normally supplied with the components described below, for operation at 546.1 nm. Alternate components and accessories are described on Page 4.

D1849 Wing Base has two arms which swing simultaneously in a vertical plane of incidence, maintaining equal angles of incidence and reflection with respect to a horizontal sample surface. The two angles are simultaneously adjustable from 50° to 90° by means of a precision threaded spindle and dovetail movement. A ball-bearing support with a threaded sleeve provides an individual fine adjustment for each axis. A scale with verniers permits setting to within 0.01° of the desired angles. The wing base is supported on three feet, two of which have leveling screws to assure that the incidence and reflection axes swing in a vertical plane. A transformer built into the base provides 6.3 Vac for the scale-illumination lamps of the Polarizer, Compensator, and Analyzer Rotators.

C6213 Horizontal Sample Mount provides five degrees of freedom for positioning the sample surface at the intersection of the incidence and reflection axes. It is mounted on a horizontal pivot at the intersection of the axes. In addition to rotation about this pivot, there are horizontal, vertical and transverse movements employing hand-lapped dovetailed slides. The fifth adjustment permits tilting in the horizontal plane. All adjustments are calibrated. The Sample Mount may be removed from the base, leaving sufficient space for accommodation of a 5" diameter cell or chamber.

The following components of the Type 437 Ellipsometer are identical to those which have been described for the Type 436: **600 Mercury Light Source; C1586 Collimator/Filter Assembly; C1648 Polarizer Rotator; C-1649-5461-1 Compensator Rotator; PP1643 Variable Aperture; B1650 Interchangeable-Aperture Assembly; C1647 Analyzer Rotator; D1675 Mirror Box with B203 Telescope; and the A6339 Photoelectric Detection System.**

CONVERSION OF MEASUREMENTS TO PHYSICAL QUANTITIES

The conversion of ellipsometric data (i.e., the settings P, A and C of the polarizer, analyzer and compensator) into the optical constants of the sample surface, or into the thickness and refractive index of a film on that surface, may be accomplished empirically or by computation. The empirical approach is to calibrate the instrument by measuring P, A, and C for a group of similar samples with known optical constants, thickness and refractive index, and preparing a table or graph of P, A and C versus these quantities. If a large enough number of samples covering a wide enough range of properties is used, extremely accurate results can be obtained on unknown samples; and all computation (except for interpolation, if tables are used) is eliminated.

Although the equations expressing the relationships between the ellipsometric measurements (P, A and C) and the physical

quantities (optical constants of surfaces, and the thickness and refractive indices of films on those surfaces) have been known for more than 80 years, no simple, rapid method of manual computation has been developed. However, the computation can be handled easily by a digital computer. Upon request, a generalized Fortran IV computer program will be supplied without charge to each ellipsometer customer.

Rudolph Research also offers an ellipsometric data computation service which provides tables and/or graphs relating P, A and C to the desired physical quantities, with intervals and ranges and for film/substrate systems specified by the customer. Such pre-computed data requires no theoretical understanding on the part of the user, and permits accurate conversion of measurements to physical quantities with minimum time and effort. This service is discussed in Tech. Bull. 360.

OPTIONAL COMPONENTS AND ACCESSORIES FOR ELLIPSOMETERS

Rudolph Research has supplied ellipsometers for many different applications and has developed a large number of alternate components and accessories. These permit use of the instrument not only in a variety of ellipsometric measurements, but in entirely different optical applications. The following is only a partial listing of optional components and accessories which are compatible with the basic instruments. We will be pleased to quote on these or other components for your special application, as well as on complete optical instruments employing combinations of such components.

LIGHT SOURCES AND ACCESSORIES

C6334 Laser is a Spectra-Physics Model 133 Helium-Neon Laser with separate power supply. Has 1 mW output at 632.8 nm. Furnished with ultra-stable A6336 Laser Mount for attachment to Rudolph ellipsometers. Mount has adjustments for aligning laser beam with ellipsometer incidence axis.

B6335 Ground-Glass Eye Protector mounts on telescope eyepiece for operator safety when laser source is employed.

A6336 Laser Mount for attachment of customer's Spectra-Physics Model 133 Laser to input arm of ellipsometer bench. Has adjustments for aligning laser beam with incidence axis. Similar mounts available for other lasers.

C6332 Tungsten-Iodine Ultra-Stable Light Source comprises a 28 Vac regulated power supply and a 75 Watt lamp in a housing which attaches to the ellipsometer input arm. Housing has adjustments for aligning lamp with incidence axis. Lamp color temperature of 3000°K is maintained very closely by 0.05% regulation of power supply.

FILTERS AND ACCESSORIES

C6333 Variable-Wavelength Interference Filter is adjustable to any center wavelength from 400 to 700 nm. Bandwidth varies with beam diameter, from 12.6 nm at 2 mm to 14.5 nm at 4mm. Attaches to front of Mirror Box in place of Analyzer, which is then separately mounted.

44201 Filter Holder, for 44301 Interference Filters, mounts between Mirror Box and Photomultiplier Unit, eliminating all stray light except at measuring wavelengths.

44301 Interference Filters are available for any center wavelength between 350 and 700 nm. Standard bandwidth 10 nm; narrower bandwidths available. The filters fit Model 44201 Filter Holder or filter holder in Collimator/Filter Assembly.

POLARIZING COMPONENTS AND ACCESSORIES

C1649/35701 Babinet-Soleil Compensator/Rotator is a C1649E Compensator Rotator containing a 35701 Babinet-Soleil Compensator. The Compensator Rotator has a scale and vernier which can be read to 0.01°, and a scale lock to hold Compensator at any desired setting. The Babinet-Soleil Compensator adjusts to provide quarter-wave compensation at any wavelength between 210 nm and 2 microns.

C1649-X-Y Compensator/Rotator is a C1649E Compensator Rotator containing a 2600-X-Y fixed mica plate which provides 90°±Y° compensation at X nm wavelength. Specify X (546.1 or 632.8 nm) and Y (1° or 2°).

Digital-Readout Rotators are designed for direct replacement of the vernier-scale Polarizer, Compensator and Analyzer Rotators described in this bulletin. These rotators can be used for rapid nulling with subsequent readout of angular position, or for rapid setting to desired angles. The output angle is digitally displayed by mechanical counters. There is zero backlash between the output position and the angle displayed on the counter. Special long-life subminiature lamps illuminate the counters without causing internal stray light which might affect instrument operation. These rotators can be supplied as replacements for the vernier-scale rotators in existing Type 436 and 437 Ellipsometers, or as part of complete new digital-readout Ellipsometers. Information available on request.

MISCELLANEOUS COMPONENTS AND ACCESSORIES

C6330 Collimator/Filter Assembly is similar to the C1586 Assembly normally supplied, but has less collimation. For a given source this collimator assembly provides more incident beam energy, so that it is useful for measurements on low-reflectance surfaces and for other energy-limited applications. Available with 3 or 10 milliradian half-angle collimation, providing orders of magnitude more energy than the standard collimator.

A6331 Optical Bench for building into vacuum systems, or for combining ellipsometers with other instruments.

A6043 Vertical Sample Mount for Type 436 Ellipsometer. Provides five degrees of freedom for sample alignment, with calibrated adjustments for motions in the plane of the surface.

44801 Vacuum Chuck fits on A1549 and A6043 Vertical Sample Mounts. Permits rapid mounting of silicon wafers and other flat samples, small or large. Operates from any convenient source such as water aspirator or vacuum line.