

[54] INSTRUMENT FOR MEASURING THICKNESS OF THIN FILM

[75] Inventors: Asao Watanabe; Tadayoshi Kasahara, both of Tokyo; Noboru Sugahara, Yokohama, all of Japan

[73] Assignee: Canon Kabushiki Kaisha, Tokyo, Japan

[22] Filed: June 22, 1973

[21] Appl. No.: 372,694

[30] Foreign Application Priority Data

June 29, 1972 Japan..... 47-65359
Dec. 18, 1972 Japan..... 47-127424

[52] U.S. Cl..... 356/161, 356/108, 250/560

[51] Int. Cl. G01b 11/00

[58] Field of Search 356/161, 108; 250/560

[56] References Cited

UNITED STATES PATENTS

2,936,732 5/1960 Ring et al. 356/108 X
3,017,512 1/1962 Wolbert..... 356/161 X
3,439,175 4/1969 Kammüller et al. 356/161 X

3,737,237 6/1973 Zurasky 356/161
3,744,916 7/1973 Bey et al..... 250/560 X

Primary Examiner—Ronald L. Wibert

Assistant Examiner—Paul K. Godwin

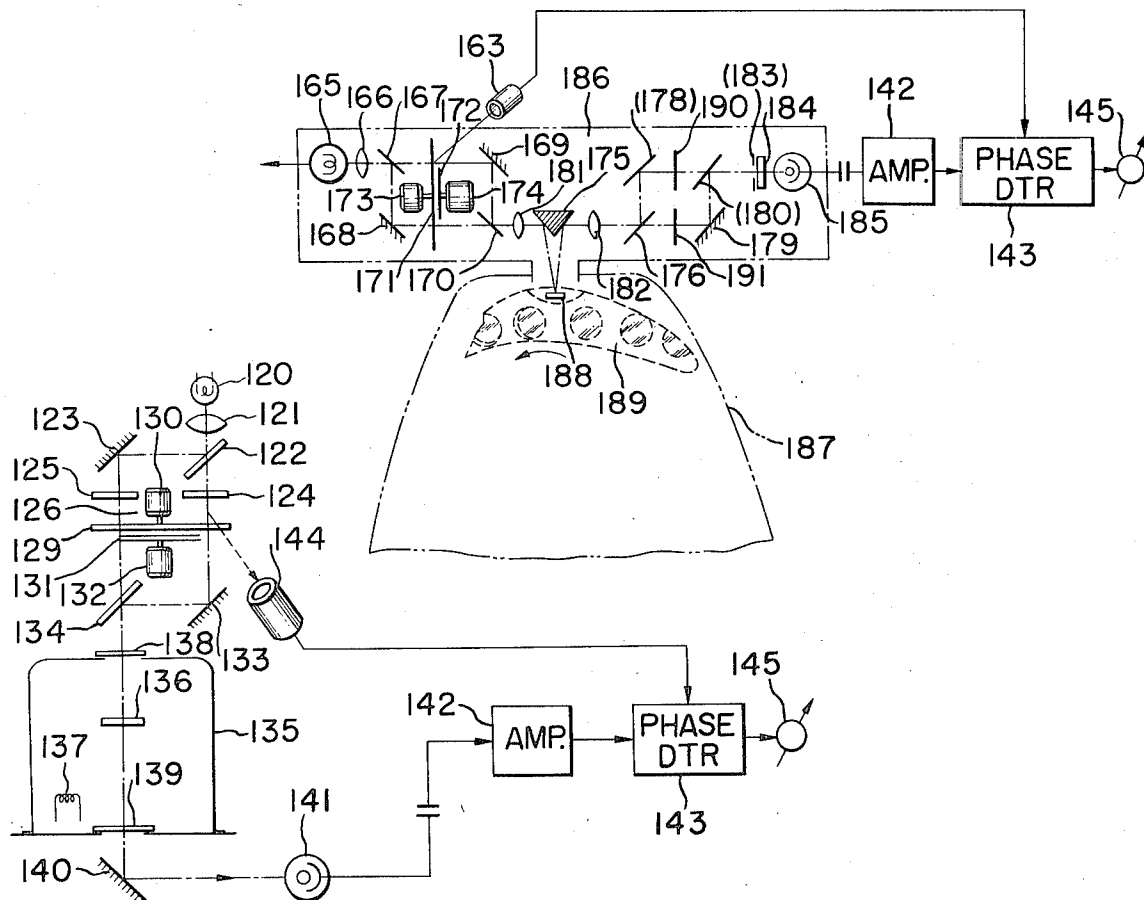
Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] ABSTRACT

A light emitted from a light source is split into a plurality of light beams of different wavelengths. The plurality of light beams are alternately transmitted to a substrate upon which is deposited a thin film whose thickness is to be measured. The light from the substrate is converted into an electrical signal when the plurality of light beams of different wavelengths are transmitted to the substrate.

A detector is provided which detects a minimum difference between the converted electrical signals, and when the minimum difference is detected by the detector, the evaporation is stopped so that a thin film with a desired thickness is deposited upon the substrate.

10 Claims, 24 Drawing Figures



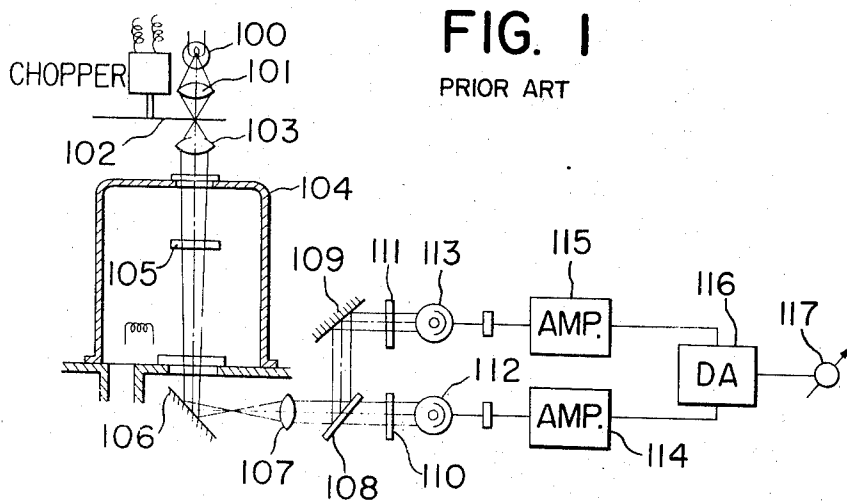


FIG. 2
PRIOR ART

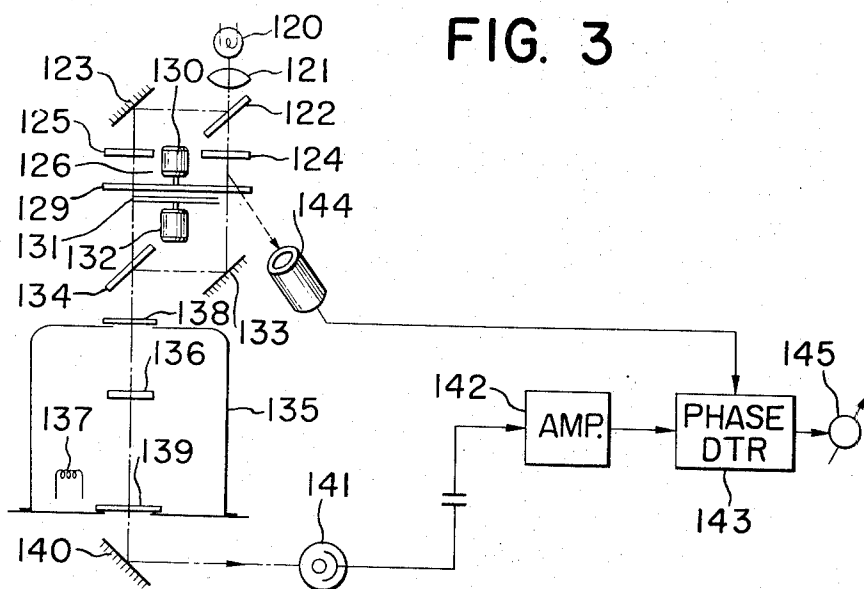
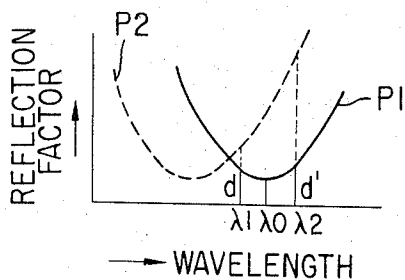


FIG. 4

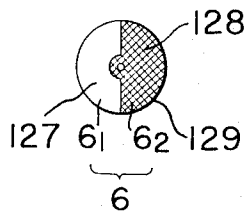


FIG. 5

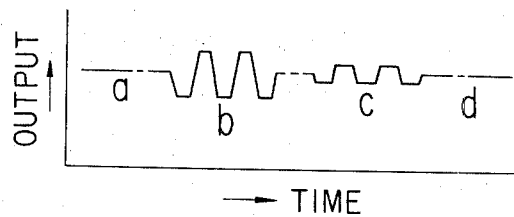


FIG. 6

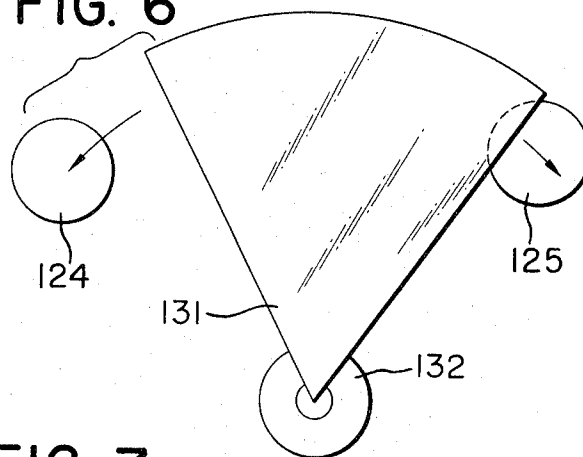


FIG. 7

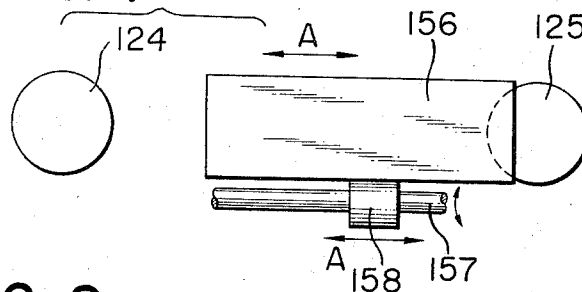


FIG. 8

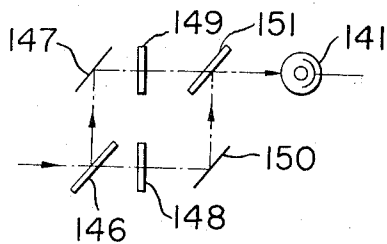


FIG. 9

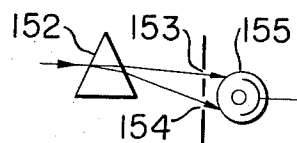


FIG. 10

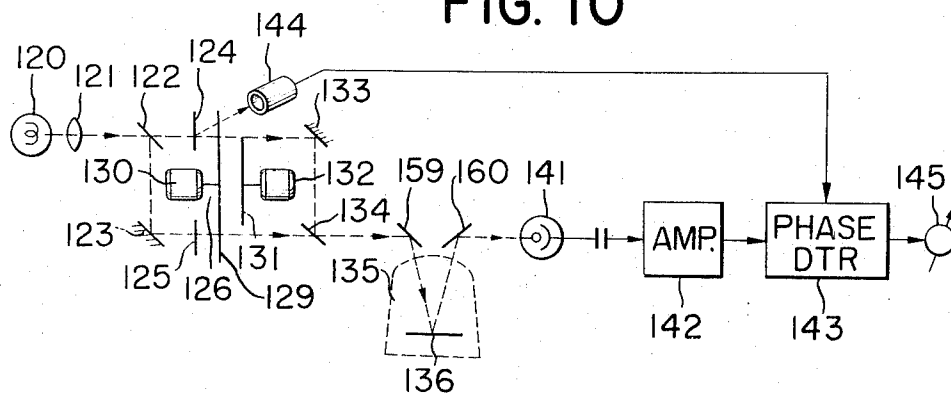


FIG. 11

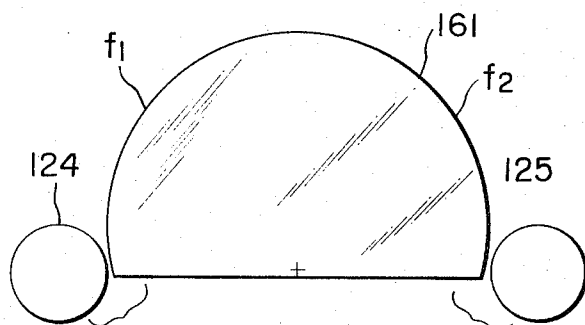


FIG. 14

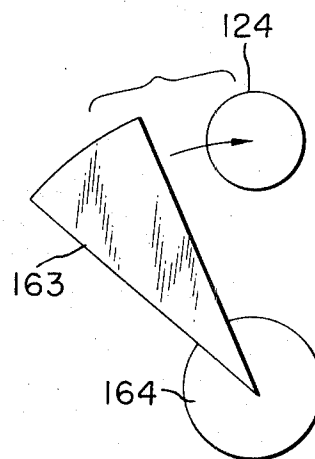


FIG. 12

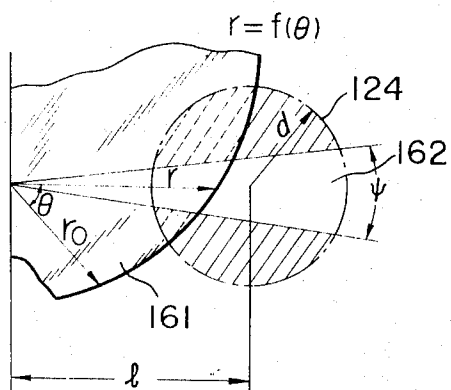


FIG. 13

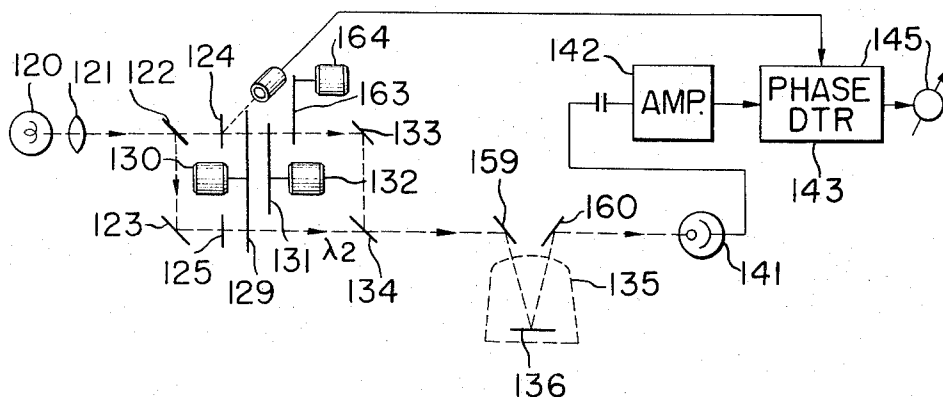


FIG. 15

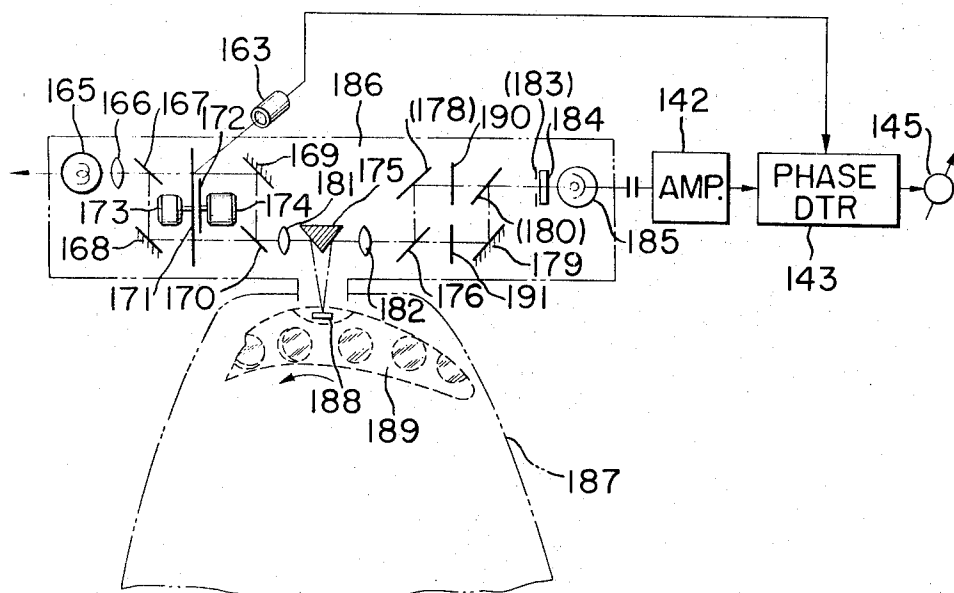


FIG. 16

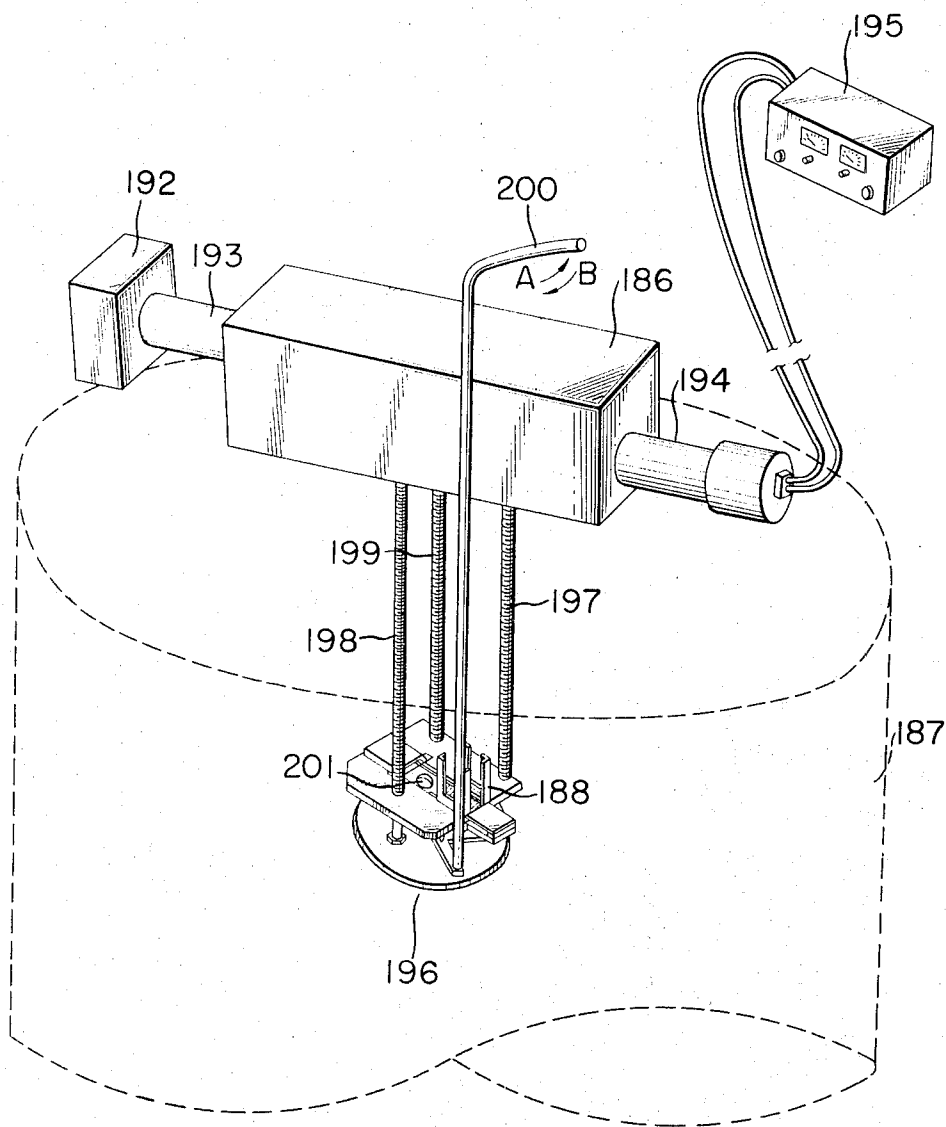


FIG. 17

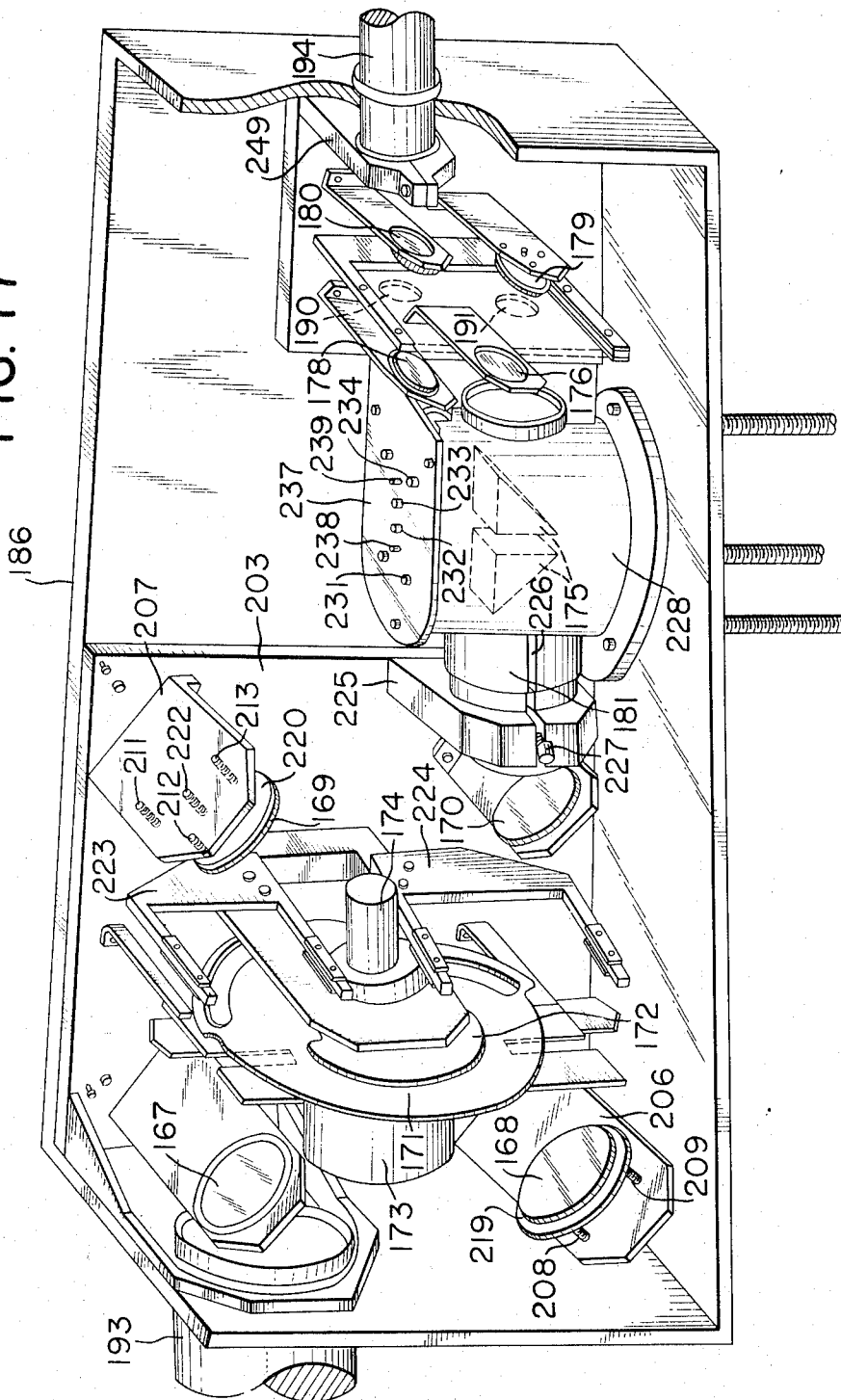


FIG. 19

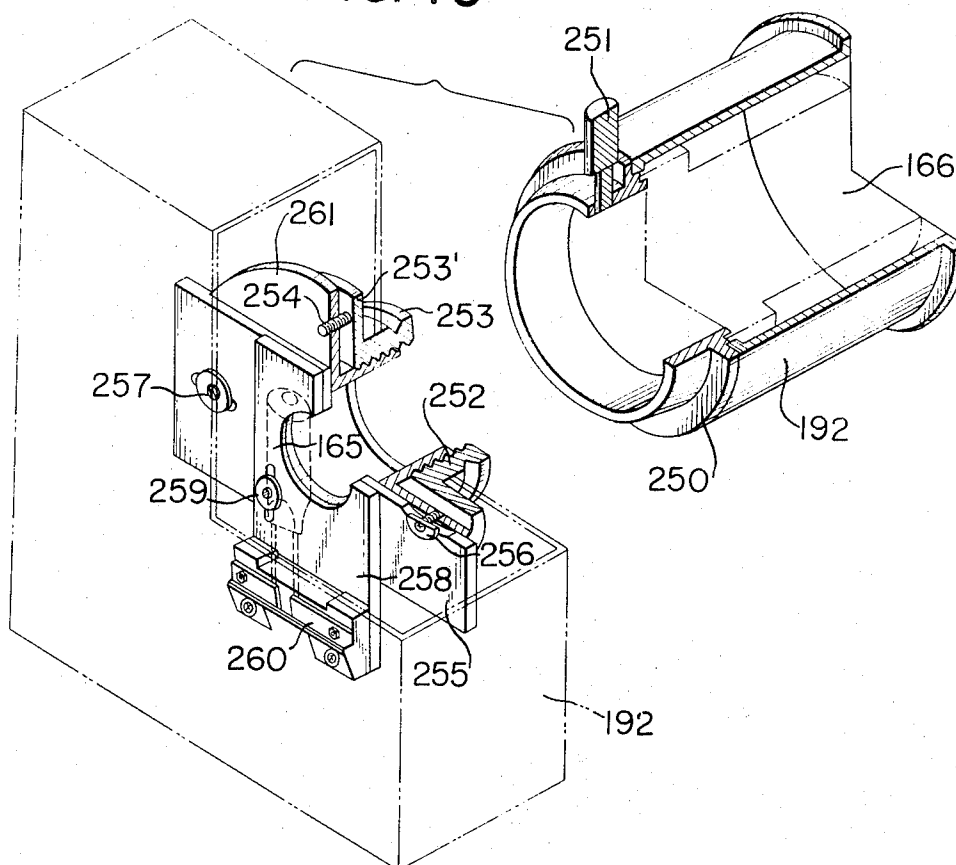


FIG. 20

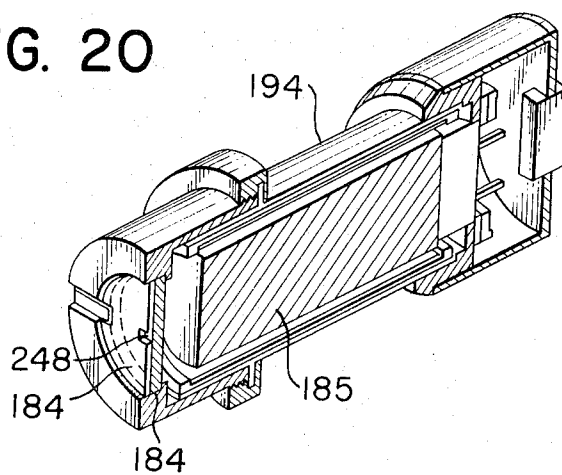


FIG. 21

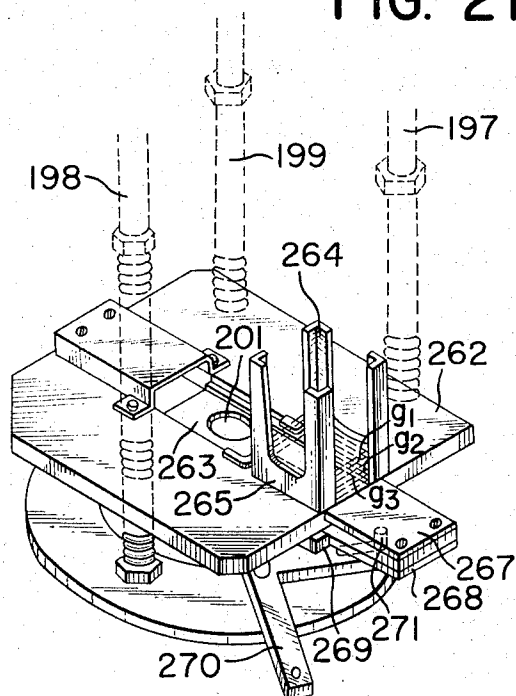


FIG. 22

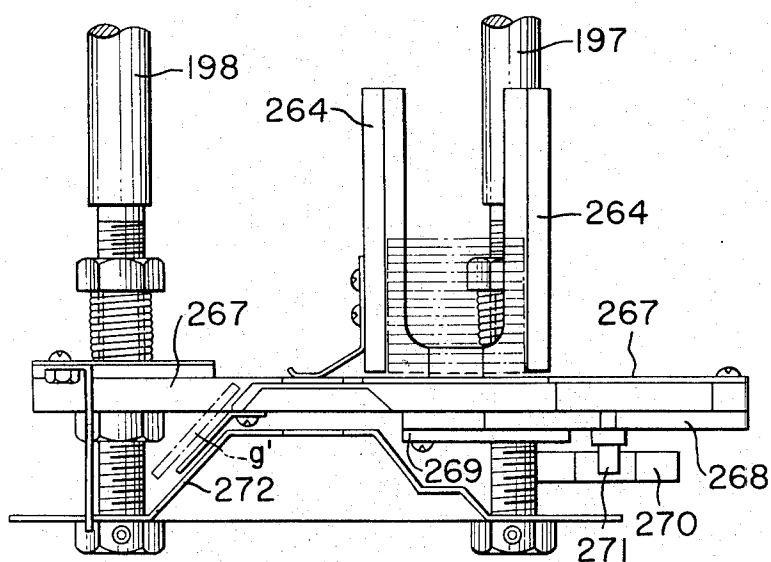


FIG. 23A

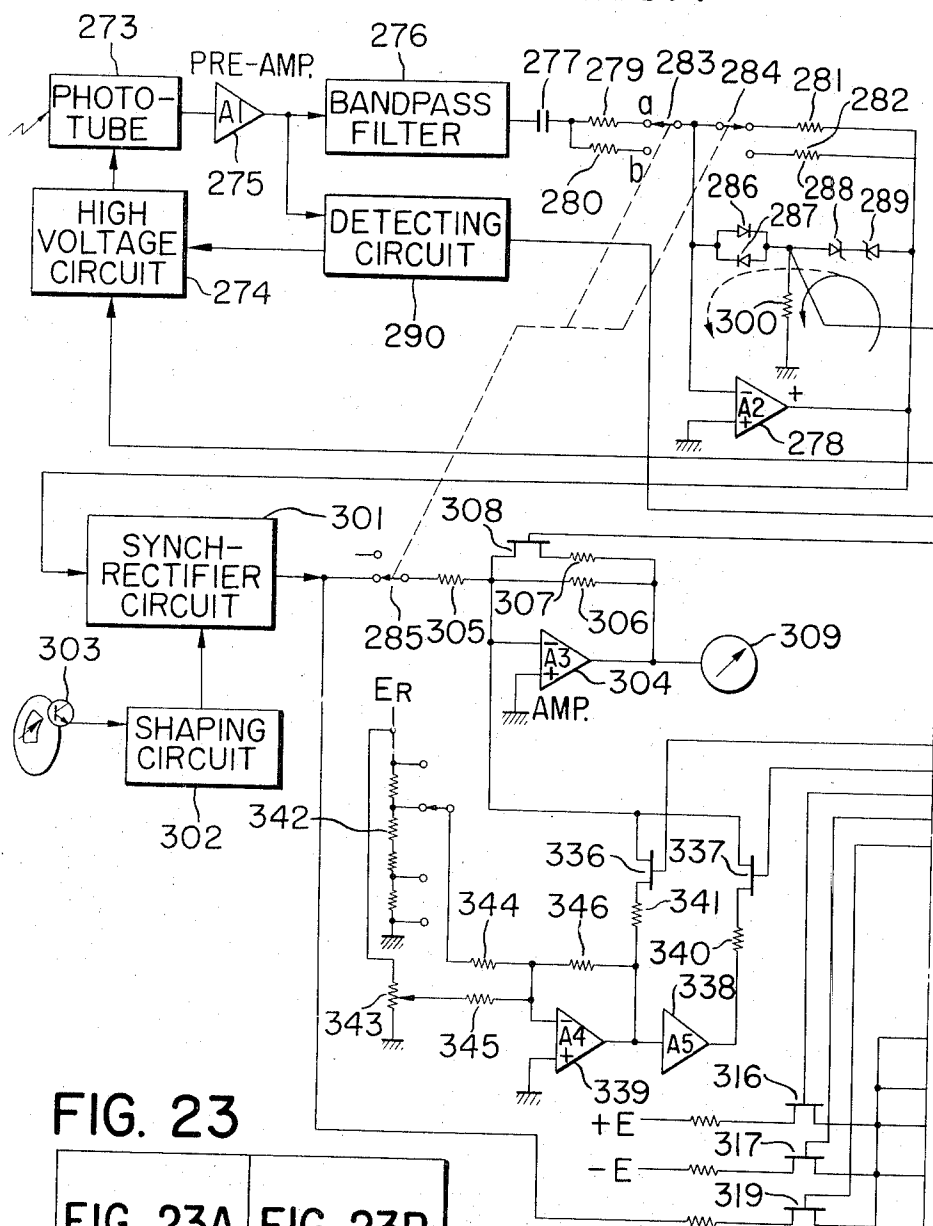
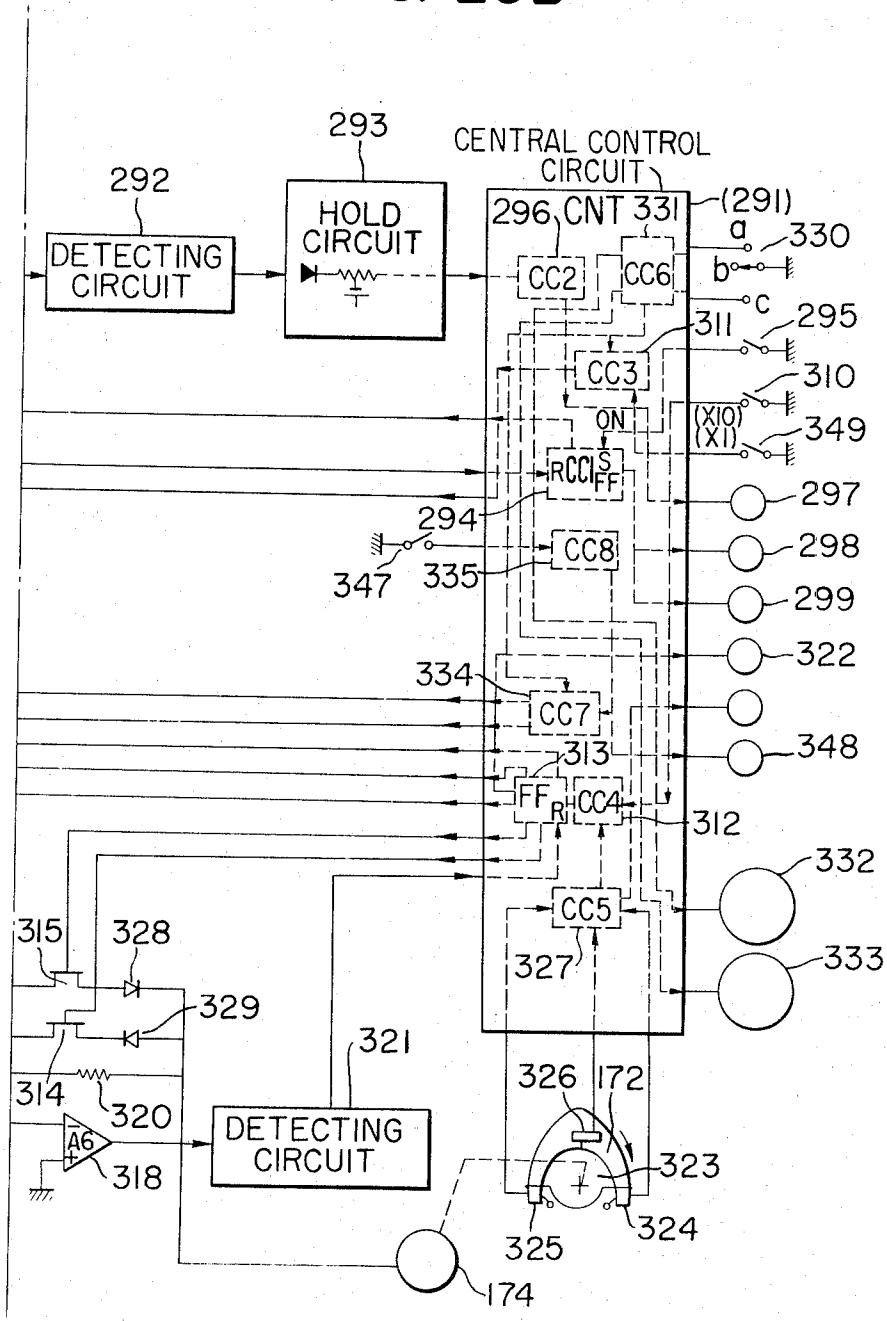


FIG. 23

FIG. 23A FIG. 23B

FIG. 23B



INSTRUMENT FOR MEASURING THICKNESS OF THIN FILM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a thin film thickness measuring instrument and more particularly an instrument for measuring, by use of two light beams of different wavelength, the thickness of a thin film being deposited by vacuum evaporation.

2. Description of the Prior Art

In the measurement of a thin film being deposited upon a base such as a lens by vacuum evaporation, the optical properties of the thin film are continuously measured, and a desired thickness is considered to be attained when the optical properties satisfy predetermined conditions. There are two methods for measuring the optical properties. One method is called a monochromatic method, which measures the transmissivity or reflectivity by using a single light beam of a predetermined wavelength incident upon the thin film being deposited, thereby measuring the thickness thereof. The other is called a dichromatic method which uses two light beams of different wavelength that measure the thickness of the thin film with a greater degree of accuracy than the method using only one light beam as will be described in detail hereinafter.

The spectral characteristic curve of a light beam incident at a right angle to a thin transparent film (with an index of refraction of n and a physical thickness of d becomes a periodic curve having extreme values at the wavelength λ when it satisfies the condition of $nd = m\lambda/4$ ($m = 0, 1, 2, \dots$). As is well known in the art when plotted against $1/\lambda$, the characteristic curve is symmetrical about the wavelength of an extreme value. When a thin film is being deposited by vacuum evaporation, a white light beam is made incident upon the thin film and the reflectivities (or transmissivities) of two light rays λ_1 and λ_2 which are displaced in wavelength from a predetermined wavelength λ_0 by the same wavelength on both sides of λ_0 within a range of $\lambda_0/4$, are measured. The reflectivities are varied as the thickness of a thin film is increased, and become equal to each other when the following condition is satisfied:

$$nd = m\lambda_0/4 \quad (m = 0, 1, 2, \dots)$$

It is so defined that when the reflectivities of the two light beams of different wavelengths equal each other, the thin film, whose optical properties are measured by the center wavelength λ_0 , has attained a desired thickness.

The above mentioned principle of the instrument for measuring thickness of a thin film will be discussed hereinafter in detail in conjunction with the accompanying drawings.

In such an instrument for measuring the thickness of a thin film according to the prior art, the amplifiers, phototubes and other components required considerable stability and thus there arose many problems especially when the thickness of the thin film was measured with the desired degree of accuracy.

SUMMARY OF THE INVENTION

One of the objects of the present invention is therefore to provide an instrument for measuring the thickness of a thin film which is simple in construction and adjustment and is capable of measuring the thickness with a high degree of accuracy.

Another object of the present invention is to provide an instrument for measuring the thickness of a thin film by the use of two light beams or rays of different wavelengths.

Another object of the present invention is to provide an instrument for measuring the thickness of a thin film which does not require the use of photoelectric transducers of the same characteristics and the adjustment of the variation in the characteristics obtained from a plurality of photoelectric transducers due to their product variation.

Another object of the present invention is to provide an instrument for measuring the thickness of a thin film which is provided with only one amplifier so that the adjustment of the variation in characteristics of a plurality of amplifiers can be eliminated.

Another object of the present invention is to provide a method and an instrument for measuring the thickness of a thin film by selectively using the light ray or beam of a predetermined wavelength or two light rays or beams of different wavelengths.

Another object of the present invention is to provide an instrument for especially measuring the thickness of a thin film being deposited by vacuum evaporation.

Another object of the present invention is to provide an instrument for measuring the thickness of a thin film which may be mounted on an apparatus for deposition of a thin film by vacuum evaporation in a simple manner.

Another object of the present invention is to provide an instrument for measuring the thickness of a thin film in which the error caused by the interference of light beams other than the light beam or beams used for the measurement can be completely eliminated.

Another object of the present invention is to provide an instrument for measuring the thickness of a thin film which is capable of measuring the overall thickness of a plurality of thin films of different substances which are successively deposited one upon another.

The above and other objects, features and advantages of the present invention will become more apparent from the following description of preferred embodiments thereof taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view illustrating a conventional instrument for measuring the thickness of a thin film by using two light beams of different wavelength;

FIG. 2 is a graph used for the explanation of the instrument shown in FIG. 1;

FIG. 3 is a view illustrating the underlying principle of an instrument for measuring the thickness of a thin film in accordance with the present invention;

FIG. 4 is a front view of an optical chopper used in the instrument shown in FIG. 3;

FIG. 5 is a view used for the explanation of the mode of operation of the instrument shown in FIG. 1;

FIG. 6 is a view of a stop plate used in the instrument shown in FIG. 3;

FIG. 7 is a view illustrating a modification of the present invention;

FIG. 8 is a view illustrating another modification thereof;

FIG. 9 is a view illustrating a further modification thereof;

FIG. 10 is a view illustrating a second embodiment of the present invention;

FIG. 11 is a view illustrating a stop plate used in the instrument shown in FIG. 10;

FIG. 12 is a view used for the explanation of the stop plate shown in FIG. 11;

FIG. 13 is a view illustrating a variation thereof;

FIG. 14 is a view illustrating a shutter used in the instrument shown in FIG. 13;

FIG. 15 is a view illustrating a third embodiment of the present invention;

FIG. 16 is a perspective view illustrating the instrument of the second embodiment of the present invention whose underlying principle is illustrated in FIG. 15;

FIG. 17 is a perspective view illustrating the principle component parts thereof;

FIG. 18 is a top view thereof;

FIG. 19 is a perspective exploded view of a light source thereof;

FIG. 20 is a perspective view, in cross section, of a phototube thereof;

FIGS. 21 and 22 are perspective and sectional views of a specimen holder thereof; and

FIGS. 23 A + 23B are circuit diagrams of the instruments shown in FIGS. 3, 10 and 13.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1 and 2, the light beam emanated from a light source 100 is collected by a lens 101, suitably modulated by an optical chopper 102, transmitted into a vacuum chamber 104 through a lens 103 to transmit through a substrate 105, upon which is to be deposited a thin film by vacuum evaporation, redirected by a reflecting mirror 106, made into parallel rays by a lens 107, split by a semi-transparent mirror 108 and reflecting mirror 109 and intercepted, through filters 110 and 111, by photoelectric transducers 112 and 113, such as phototubes, for example.

The outputs of the phototubes 112 and 113 are amplified by amplifiers 114 and 115, respectively, and applied to a differential amplifier 116, the output of which is indicated by an indicator 117.

It is assumed that when a thin film deposited upon the substrate 105 attains a predetermined thickness, the characteristic curve P1 (See FIG. 2) will be obtained. The center wavelengths of light transmitted through the optical filters 110 and 111 are λ_1 and λ_2 which are displaced from the center wavelength λ_0 by the same wavelength on both sides thereof. The light beam emanated from the light source 100 is emitted to the substrate 105 upon which a thin film is to be deposited by vacuum evaporation, and the gains of amplifiers 114 and 115 are so controlled that the pointer of the indicator 117 indicates zero. The characteristic curve P2 (See FIG. 2) is obtained when the deposition by vacuum evaporation is started and the thickness of a thin film deposited upon the substrate 105 is still thin. The outputs of the amplifiers 114 and 115 are not equal to each other. When a desired characteristic curve P1 is

obtained as the deposition proceeds, the difference in output of the amplifiers 114 and 115 becomes zero so that the reading of the indicator 117 is zero. The deposition is therefore stopped so that a thin film with a desired thickness is deposited upon the substrate 105.

The final signal from which the thickness of the thin film deposited upon the substrate is to be determined is the difference in output between the two amplifiers 114 and 115, which corresponds to the difference between the line segments d and d' shown in FIG. 2. The line segments d and d' represent an intensity of the order of 5 percent in the case of reflection and of the order of 95 percent in the case of transmission. The difference between the line segments d and d' is theoretically of the order of 0.01 - 0.05 percent so that the amplifiers, phototubes and other components must have a stability of the order of 1/10,000 and there arise many problems when the thickness of a thin film is measured with a desired degree of accuracy.

First Embodiment, FIGS. 1-9

Referring to FIG. 3, a first embodiment of the present invention will be described. Reference numeral 120 denotes a light source; 121, a condenser lens; 122, a semi-transparent mirror; 123, a reflecting mirror; 124 and 125, filters which permit the light beams of wavelengths λ_1 and λ_2 to pass therethrough; 126, an optical chopper comprising a chopper plate 129 consisting of a semi-circular light transmissive section 127 and a semi-circular light shielding section 128 and a motor 130 for rotating the chopper plate 129, the light beams transmitted through the optical filters 124 and 125 being alternately chopped by the rotating chopper plate 129; 131, an aperture blade for controlling the light intensity; and 132, a motor for driving the aperture blade 131.

As shown in FIG. 6, the aperture blade 131 comprises a segment plate which is swung through a predetermined angle by the motor 132 which in turn is controlled in response to the control signals transmitted from a motor control circuit, thereby controlling or shielding the light beams emerging from the optical filters 124 and 125 so as to control the intensities of the two light beams.

Referring back to FIG. 3, reference numeral 133 denotes a reflecting mirror; 134, a semi-transparent mirror for superimposing the light beams of wavelength λ_1 and λ_2 from the optical filters 124 and 125 one upon another; 135, a Bell jar; 136, a substrate to be treated; 137, an evaporation source; 138 and 139, windows made of a transparent material; 140, a reflecting mirror; 141, a phototube; 142, an amplifier; 143, a phase detector which is adapted to detect the phase of the input signal with reference to the output of a phototube 144 which intercepts the light beam from the optical chopper 126; and 145, an indicator. The amplifier 142, the phase detector 143 and the indicator 145 constitute detecting means.

The evaporant material is evaporated by heating and deposited upon the substrate (136). Instead of the phototube 141, a phototransistor or the like may be employed.

When no thin film is formed upon the substrate, that is when the thickness of the thin film is zero, there is no difference in the transmissivity of the light beams of wavelengths λ_1 and λ_2 incident upon the substrate so that the output of the phototube 141 becomes a constant DC level as shown in FIG. 5a. As a result the read-

ing of the indicator 145 would be zero. However the output of the phototube 141 includes a pulsating component, as shown in FIG. 5, because of the radiation characteristic of the lamp 120, the sensitivity of the phototube 141, and the optical characteristics of the filters 124 and 125 and the half mirrors 132 and 134. Therefore the indicator 145 indicates as if a thin film with a certain thickness has already been deposited upon the substrate.

The motor 132 is driven to displace the aperture blade 131 as shown in FIG. 6 so as to partly shield the optical filters 124 and 125. This is done in order to eliminate the pulsating component of the output of the phototube 141. Thereafter the evaporant material 137 is vaporized by heating and deposited upon the substrate 136. Two light beams of wavelength λ_1 and λ_2 are alternately incident upon the substrate by the chopper plate 129, and the output of the phototube 141 is amplified by the amplifier 142 and detected by the phase detector 143 so that the signal which is correlated in phase with the rotation of the chopper plate 129 is derived and applied to the indicator 145 for reading. Until a thin film deposited upon the substrate attains a predetermined thickness, the output waveforms indicated by *b* and *c* in FIG. 5 are applied to the indicator 145. When a desired thickness is attained, there is no difference between the outputs of the phototube in response to the light beams of wavelength λ_1 and λ_2 so that the reading of the indicator 145 becomes constant. Therefore one can see that the thin film deposited upon the substrate 136 has attained a desired thickness. Then the evaporation is stopped so that the thin film with a desired thickness is deposited upon the substrate 136.

Variation, FIG. 8

When the phototube is sensitive over a wide range of wavelengths, in order to intercept two light beams of different wavelengths, the operating point of the phototube deviates considerably by the so-called stray light beam emanated from the light source so that a noise is generated. This problem can be overcome by the arrangement shown in FIG. 8. The light beam emerging from the Bell jar through the window 139 is split by a semitransparent mirror 146 and a reflecting mirror 147, and optical filters 148 and 149, which transmit the light beams of wavelength λ_1 and λ_2 , respectively, are inserted into the two split optical paths, respectively. The split light beams are superposed one upon another by a semi-transparent mirror 151 and a reflecting mirror 150 so as to be intercepted by the phototube 141.

Variation, FIG. 9

Alternatively, as shown in FIG. 9, a prism or refraction grating 152 is located in front of the phototube 141 in such a manner that the refracted light rays of wavelength λ_1 and λ_2 may be incident upon the phototube 141 through windows 153 and 154 of a shield plate 155.

As described hereinbefore according to the present invention the thickness measuring instrument may be made extremely simple in construction even though two light beams of different wavelength are used because only one photoelectric transducer as well as an amplifier are used. Therefore, the variation in gain may be made negligible, and a measurement with a higher degree of accuracy may be stabilized. Furthermore, the preadjustment by the aperture blade 131 serves to provide a constant level output, containing no pulsating component, when a thin film is deposited to a desired

thickness, so that measurement with a higher degree of accuracy is possible.

Variation, FIG. 7

In the first embodiment and its variations described hereinbefore, the ratio of intensity between the two light beams λ_1 and λ_2 is so great that it is not necessary to use the blade 131, which is symmetrical as shown in FIG. 6, but the use of a symmetrical aperture blade is preferable because, in one case the light beam of wavelength λ_1 is shielded, and in the other case the light beam of wavelength λ_2 is shielded, depending upon the wavelengths λ_1 and λ_2 . In the variation shown in FIG. 7, a rectangular blade 156 is used, which is reciprocated in the directions indicated by the double-pointed arrow A by a threaded rod 157, which is in mesh with an internally threaded gear 158 that is rotated by a motor (not shown), whereby either of the light beams of wavelengths λ_1 or λ_2 may be selectively shielded as needed.

Second Embodiment, FIGS. 10-14

The second embodiment is described in detail hereinafter with particular reference to FIG. 10. This embodiment is different from the first embodiment described hereinbefore with reference to FIG. 3 in that instead of measuring the light beams transmitted through the thin film and the substrate, the light beams reflected therefrom are intercepted by a photoelectric tube. The same reference numerals are used in FIGS. 3 and 10 to designate similar component parts.

The light beam from the half mirror 134 is redirected by a mirror 159 to make it incident upon the substrate 136, and the light beam reflected by the substrate 136 is redirected by a mirror 160 to make it incident upon the phototube 141. The reflectivities of the light beams of wavelengths λ_1 and λ_2 are also varied as shown in FIG. 2 so that the thickness of a thin film deposited upon the substrate 136 may be measured in a manner substantially similar to that of the first embodiment.

In the second embodiment, in order to improve the accuracy in measurement, an aperture or stop plate 161 of the type shown in FIGS. 11 and 12 is used. When the aperture blade of the type shown in FIG. 6 or FIG. 7 is used, the intensity of the light beam emerging from the optical filter 124 or 125 is linearly varied. That is, the variation or increase or decrease in the intensity of the light beam, controlled by the aperture blade, is in proportion to the angle of rotation of the motor. Therefore, the variation in intensity of the light beam per unit of angle of rotation (that is, the variation in intensity of light beam when the aperture blade is angularly displaced by $\Delta\theta$ /the intensity of the light beam from the optical filter 124 or 125 which is not shielded by the aperture blade at all), when the optical filter 124 or 125 is substantially shielded, is considerably higher than when the optical filter 124 or 125 is shielded only over a small area. That is, the variation in intensity of light beam with respect to the light displacement of the aperture blade is not constant so that the light intensity adjustment cannot be attained smoothly. In order that the ratio of the variation in light intensity dx when the aperture blade is rotated through a unit angle of rotation $d\theta$ to the intensity of light transmitted through the optical filter, which is shielded, must satisfy the following equation:

$$-dx/x = k d\theta$$

where $K = \text{a constant}$.

An approximate solution of Eq. (1) may be obtained in the following manner. Assume that the radius from the center 0 to the periphery $f-1$ and $f-2$ of the aperture blade is r and that when $f-1$ is tangent to the filter 124 when $\theta = 0$, the radius is r_0 . Furthermore, assume that when $\theta \rightarrow cs$, $f-1$ completely shields the filter 124 and the radius is r_{max} and that the radius is $r-1$ at a predetermined angle θ_1 (which is the critical angle at which the light beam can be beam shielded by the aperture blade). Then the radius r , from the center 0 to $f-1$ when the angle of rotation is θ , is given by

$$r = r_{max} - (r_{max} - r_0) e^{-\alpha\theta} \quad (2)$$

where

$$\alpha = (1/\theta) \ln (r_{max} - r_0/r_{max} - r_1).$$

A configuration defined by Eq. (2) is a segment with an angle ϕ , as shown in FIG. 11.

Eq. (2) gives the solution when the light beam transmitted through a segment 162 with a subtended angle ϕ is shielded by the shielding plate 161, but does not give the solution when the light beam transmitted through the circular opening O of the filter 124 or 125 is shielded. However Eq. (2) may be applied to the latter case in practice.

In the preadjustment effected by the aperture blade 161 whose configuration is defined by Eq. (2), the variation in light intensity per unit of angle of rotation is constant so that a preadjustment with a higher degree of accuracy may be accomplished in a simple manner when the aperture blade is rotated by a servomotor, as shown in FIG. 10.

Variation, FIGS. 13 and 14

FIG. 13 illustrates a variation of the second embodiment shown in FIG. 10, with the same reference numerals being used to designate similar component parts as shown in FIG. 10. In the variation shown in FIG. 13, a shutter 163, which is driven by a motor 164 (See FIG. 14), is inserted in the optical path of the filter 124 in order to use the thickness measuring instrument shown in FIG. 10 to measure the thickness of a thin film by using only one light beam. When the motor 164 is driven so that the shutter 163 is displaced so as to shield the whole surface of the filter 124, only the light beam of wavelength λ_2 is incident upon the substrate from the light source 120. The absolute reflectivity of the thin film is measured in terms of the deflection of the pointer of the indicator.

In general, the thickness of a thin film can be measured more accurately when two light beams are used rather than when only one light beam is used, but it may be preferable to use only one beam in the measurement, depending upon the characteristics and formation of the thin film. Furthermore, when two light beams are used, they must be suitably balanced and the sensitivity in the measurement must be suitably determined. In this case the sensitivity may be determined in a simple manner when the thickness measuring instrument is switched to the mode using only one light beam after the two light beams are balanced by the aperture blade.

Third Embodiment, FIGS. 15-22

In FIG. 15 illustrating a third embodiment of the present invention, reference numeral 165 denotes a

white light source; 166, a collimator lens; 167, a dichroic mirror in order to permit the transmission thereof of the light beam of wavelength λ_1 and to reflect the light beam of wavelength λ_2 ; 168 and 169, reflecting mirrors; 170, a dichroic mirror complementary to the dichroic mirror 167; 171, an optical chopper; 172, a stop blade; 173 and 174, motors for driving the optical chopper 171 and the stop blade 172, respectively; 175, a reflecting mirror; 176, a dichroic mirror for transmitting the light beam of wavelength λ_1 but reflecting the light beam of wavelength λ_2 ; 178 and 179, reflecting mirrors; 180, a dichroic mirror complementary to the dichroic mirror 176; 183, a slit disposed in a focal plane of focusing lenses 181 and 182; 184, a diffusion plate located behind the slit 183; and 185, a phototube.

The light source 165 and the phototube 184 are housed within a casing 186, which in turn is disposed on top of a Bell jar 187 in such a manner that the light ray reflected by the reflecting mirror 175 may be incident upon a specimen 188 held within the Bell jar 187. Within the Bell jar, which is evacuated, is disposed a rotary table 189 upon which are bonded lenses L_1-L_n upon which are deposited the thin films. The rotary table 189 is rotated in order to ensure a uniform deposition of the thin films upon the lenses. The specimen 188, comprising a glass plate, is placed in the lower portion of a through bore formed at the center of the rotary table 189.

The white light emanated from the light source 165 is split by the dichroic mirror 167 into light beams of wavelengths λ_1 and λ_2 , which are alternately chopped by the optical chopper 171 in order to be incident upon the dichroic mirror 170, so as to be combined into one beam. Therefore, the light beam combined by the dichroic mirror 170 is divided in time into the light beam of wavelength λ_1 and the light beam of wavelength λ_2 . The light from the mirror 170 is redirected by the mirror 175 to be incident upon the specimen 188 within the Bell jar 187. The light reflected by the specimen 188 is incident upon the dichroic mirror 176 through the mirror 175 and the lens 182.

A thin film is deposited upon each of the lenses L_1-L_n placed upon the rotary table 189 in the Bell jar 187. In this case, a thin film is also deposited upon the specimen 188 so that the thickness of the thin film deposited upon each lens may be measured by measuring the thickness of the film deposited upon the specimen 188 in a manner substantially similar to that described hereinbefore.

The light beam is split into two light beams by the mirror 179. The light beam of wavelength λ_1 is redirected and transmitted through the optical filter 190, which transmits only the light beam of wavelength λ_1 , to be incident upon the dichroic mirror 180. The light beam of λ_2 is transmitted through the optical filter 191 which transmits only the light beam of λ_2 and redirected by the reflecting mirror 179 to be incident upon the dichroic mirror 180 where the two light beams of wavelengths λ_1 and λ_2 are combined into one light beam which is incident upon the slit plate 183. The light beam focused upon the slit plate 183 is diffused by the diffusion plate 184 and converted into an electrical signal by the phototube 185.

When the thickness of the thin film deposited upon the specimen 188 reaches $\lambda_0/4$, the outputs of the phototube in response to the light beams of λ_1 and λ_2 be-

come equal to each other so that the thin films deposited upon the lenses are detected to have reached $\lambda_0/4$.

Since the dichroic mirrors 167 and 170 are used for the time-division of the light beam to be incident upon the specimen 188, the luminous fluxes L_{λ_1} and L_{λ_2} of the light beams of λ_1 and λ_2 are given by

$$L_{\lambda_1} = R_1 \lambda_1 \times T_2 \lambda_1 = 78.9\%$$

$$L_{\lambda_2} = R_1 \lambda_2 \times T_2 \lambda_2 = 0.5\%$$

during a time interval t_1 when the chopper 171 interrupts the optical path of the mirror 167, where

R_1 : reflectivity of mirror 167

T_2 : transmissivity of mirror 170.

In the next time interval t_2 ,

$$L_{\lambda_1} = T_1 \lambda_1 \times R_2 \lambda_1 = 0.5\%$$

$$L_{\lambda_2} = T_1 \lambda_2 \times R_2 \lambda_2 = 84.5\%$$

Therefore the luminous fluxes intercepted by the phototube 185 are given by

$$Q_{\lambda_1} = (R_1 \lambda_1 \cdot T_2 \lambda_1)^2 = 62\%$$

$$Q_{\lambda_2} = (T_1 \lambda_2 \cdot R_2 \lambda_2) = 71\%$$

where Q_{λ_1} and Q_{λ_2} are luminous flux efficiencies of light beams of wavelengths λ_1 and λ_2 , respectively.

In the second embodiment where the half mirrors are used (see FIG. 13), the luminous flux efficiencies are

$$Q'_{\lambda_1} = R_1 \lambda_1 \cdot T_2 \lambda_2 = 10\% \text{ and}$$

$$Q'_{\lambda_2} = T_1 \lambda_2 \cdot R_2 \lambda_1 = 13\%.$$

Then, it is seen that in the third embodiment the luminous flux efficiency may be increased by about six times.

Since the evaporant material is heated within the Bell jar, stray light is generated and is incident upon the mirror 175 to be redirected so as to be incident upon the phototube 185. To overcome this problem, slit plate 183 is interposed. Furthermore, the brightness distribution upon the surface of the light source 165 may be made uniform by locating the diffusion plate 184 behind the slit plate 183 and in spaced apart relation with the phototube 185, whereby the adverse effect caused by the nonuniform density of the filament of the light source 165 may be eliminated. Furthermore, the above arrangement makes it possible to compensate for the variation in sensitivity of the light receiving surface of the phototube so that the deviation of the optical path will not cause variation in the sensitivity.

Referring to FIG. 16, which illustrates a perspective view of the thickness measuring instrument described hereinabove with reference to FIG. 15, the optical system generally indicated by reference numeral 186 is mounted on top of an apparatus 187 for deposition by vacuum evaporation. Reference numeral 192 denotes a lamp house in which is disposed the light source 165; 193, a lens barrel housing the collimator lens 166; 194, a casing housing a photoelectric electron multiplier tube corresponding to the phototube 185 shown in FIG. 15; 195, an electronic circuit unit to which is applied the output of the phototube; and 199, a specimen holder suspended into the Bell jar 187 from the under-surface of the optical system 186 by means of three threaded rods 197-199. The specimen holder 196 has a lever 188 extending out of the Bell jar.

The housing of the optical system 186 has a cylinder which is disposed upon the bottom so as to form an airtight fit over the upper opening of the Bell jar. The specimen holder 196 is located at the center of the Bell jar 187, and a plurality of specimens 188 mounted upon the specimen holder 196 is moved one by one to a center opening 201 of the specimen holder when the lever 200 is reciprocated in the directions indicated by the arrows A and B.

The evaporant material is deposited upon the specimen 188 placed in the opening 201 of the specimen holder 196, and the light beams of wavelengths λ_1 and λ_2 are incident upon the specimen so that the reflected light beams are intercepted by the phototube 194, the output of which is applied to the electronic unit 195 in the manner described hereinbefore.

As shown in FIG. 15, within the Bell jar is disposed the rotary table upon which is placed the lenses. When the thin film with a desired thickness has been deposited upon the lens, the specimen upon which was deposited the evaporant material, is displaced to the light so as to be dropped onto the bottom of the Bell jar. When the lever 200 is returned in the direction indicated by arrow B, a new specimen 188 is placed into the opening 201 for the next deposition.

Referring to FIGS. 17 and 18, the dichroic mirrors 167 and 170, the reflecting mirrors 168 and 169, and the motors 173 and 174 for driving the chopper and the stop blade are mounted upon a mount 203 which, in turn, is fixed to the side wall of the casing 186 in such a manner that it may be vertically moved by tightening or loosening adjusting screws 204 and 205 screwed into internally threaded holes formed in the side wall of the casing 186, as best shown in FIG. 18.

Each of the reflecting mirrors 168 and 169 is fixed to a mirror holder 219, or 220, which is normally so biased as to move forward by springs 214 and 215 or 216 and 218 fitted over guide pins 208-210 (210 being not shown) or 211-213 fixed to an upright mirror holder 206 or 207 fixed to the mount 203. The mirror holders 219 and 220 are provided with adjusting screws 221 and 222 which are rotatably fixed to the mirror holders 219 and 220 and screwed into the internally threaded holes formed through the mirror stands 206 and 207, so that the position of the mirrors 168 and 169 may be adjusted. More particularly, the coarse adjustment of the mirrors 167 and 170 may be made by tightening or loosening the adjusting screws 204 and 205, respectively, and then the fine adjustment is made by tightening or loosening the adjusting screws 221 and 222.

Optical filter holders 223 and 224 are also mounted upon the mount 203 so that the optical filters may be inserted when the balancing between the light beams of wavelengths λ_1 and λ_2 is impossible. The balance between the two light beams may be attained by the optical filters and the stop blade 172.

A focusing lens 181 barrel holder 225 is also mounted upon the mount 203, and a pin 227, extending from the focusing lens barrel, is fitted into a groove 226 formed in the holder 225 so that the focusing lens 181 may be displaced in the optical direction thereof.

A cylinder 228, in which is housed the reflecting mirror 175, and which has an extension fitted over the focusing lens barrel as best shown in FIG. 18, is fitted into the top of the Bell jar and fixed thereto with screws (not shown). The cylinder 228 is provided with a transparent sealing member 229 for maintaining the vacuum

in the Bell jar and with a dust-proof glass 230. Mirror holders 235 and 236 are suspended by guide pins 231-234 from a top cover 237 of the cylinder 228, and adjusting screws 238 and 239, which are rotatably fixed to the mirror holders 235 and 236, respectively, are screwed into internally threaded holes drilled through the top cover 237 so that the reflecting mirrors 175 may be displaced in the vertical direction, independently of each other by tightening or loosening the adjusting screws 238 and 239, respectively, thereby adjusting the optical length.

The reflecting mirrors 178 and 179 are mounted in a manner substantially similar to that of the reflecting mirrors 168 and 169, and are displaced in parallel with each other along the guide pins 240, 241, 242 and 243 by tightening or loosening the adjusting screws 244 and 245, respectively, whereby the optical length may also be adjusted. The optical filters 190 and 191 and the focusing lens 182 are mounted on the same mounting as the reflecting mirrors 178 and 179.

The casing 194 housing the phototube is best shown in FIG. 20. The diffusion plate 184 is interposed between the phototube 185 and the slit plate 183 having a slit 248 formed at the center thereof. The light receiving surface of the phototube 185 is spaced apart from the diffusion plate by 10 millimeters. The housing 194 has one end fixed to a holder 249 (See FIG. 17) in such a manner that the focal plane of the focusing lens 182 coincides with the slit 248 of the slit plate 183.

As best shown in FIG. 19, at one end of the lens barrel 192 is fitted a mount 250 to which is screwed a screw 251. The lamp house 192 is provided with a sleeve 252 for engagement with the mount 250 of the lens barrel 192, and when the sleeve 252 and the mount 250 are engaged with each other the screw 251 is tightened, whereby the lens casing 194 may be securely fixed to the lamp house 192. A projection or flange 253 is formed around the periphery of the sleeve 252 so that it may cooperate with the screw 251 to prevent the mount 250 from falling off the sleeve 252. Reference numeral 254 denotes a light source base body which forms the outer helicoid for engagement with the inner helicoid of the sleeve 252; 255, an intermediate member is provided with slots into which are fitted two guide pins 256 and 257 extending from the base body 254; and 258, a lamp holder is provided with slots which are at right angles with respect to the slots of the intermediate member 255 and fixed electrodes 260 are provided for engagement with the light source or lamp 165.

When the lamp house 192 is mounted upon the mount 250, the distance between the filament of the lamp and the mount must be maintained at a predetermined distance and the center of the filament must be made to coincide with that of the mount 250 by using the some jigs.

After the light source 165 such as an iodine lamp is mounted, the guide screws or pins 256, 257 and 259 are loosened so that the intermediate member 255 and the holder 258 may be displaced in the X- and Y-directions in order to coincide the center of the filament with that of the mount. Thereafter the guide screws are tightened to securely hold the members 255 and 258 in position, and the sleeve 253 is rotated to cause its upright end surface 253' to move in the Z-direction in order to maintain a predetermined distance between the filament and the mount 250. Thereafter,

the screws 261' of the base 254 are tightened so as to hold the sleeve 253 in a stationary position.

Thereafter, the sleeve 253 is inserted into the mount 250 and securely held in position by tightening the screw 251. Thus the lamp 165 is located at the center of the mount, that is, at the focal point of the collimator lens 166.

Next, referring to FIGS. 21 and 22, the specimen holder will be described in detail, as follows. Reference numeral 262 denotes a base fixed to the leading ends of the threaded rods 197, 198 and 199; 263, a specimen passage formed at the center of the base 262; 264 and 265, frames for storing the specimens such as glass plates g_1 , g_2 , g_3 and so on; 266, a bell crank having one end connected to the lower end of the lever 200 and its center pivoted to the base 262; 267, a pressure plate whose one end is fixed to a sliding member 268 and whose leading end is adapted to engage with the lowermost specimen g so as to cause it to move toward the center opening 201; 268, a sliding member which has its side edges slidably fitted into guides 269 and which has a pin 271 fitted into a slot formed in the lever 270; and 272, a guide located below the base 262 so that the used specimen g' may slide over the guide 272 to drop onto a predetermined position within the Bell jar.

Next, the mode of operation will be described. The housing 186 of the optical system is mounted upon the Bell jar, and then the lever 200 is actuated in the direction indicated by the arrow A so that the lever 270 (See FIG. 21) is rotated in a counterclockwise direction to cause the pressure plate 267 to push the lowermost specimen g . The lowermost specimen g is moved along the guides 263 to the opening 201. The light source 165 in the lamp house 192 is adjusted in the X-, Y- and Z-directions so that the filament is positioned at the center of the collimator lens 166. When the light source 165 is turned on and the motor 173 is driven, the light beams of wavelengths λ_1 and λ_2 are incident in a time division manner upon the specimen in the opening 201 through the optical system consisting of the mirrors 167, 170, 181 and 175. The reflected light is incident upon the slit plate 183 through the optical system consisting of the mirror 175, the focusing lens 182, and the mirrors 176, 178, 179 and 180.

However, when the mirrors 167 and 170 are not adjusted correctly or when the lamp 165 is not correctly positioned, the light reflected from the specimen will not be focused upon the slit and will be deviated in either direction.

Since many mirrors are used, it is almost impossible to adjust them independently of each other so that the reflected light may be focused upon the slit.

To overcome this problem, according to the present invention the mount 203 is displaced by tightening or loosening the adjusting screws 204 and 205, thereby adjusting the position of the mirrors 167 and 170 so as to cause the reflected light to be focused at a point adjacent to the slit plate 183. Next the fine adjustment is made by adjusting the positions of the mirrors 168, 169, 175, 178 and 179 independently of each other so that the reflected light is correctly focused upon the slit. Thereafter, the preadjustment is made by driving the stop blade 172 so that the pointer of the meter of the electronic unit 195 will indicate zero.

The deposition by vacuum evaporation is then started and a thin film is also formed upon the specimen. When the thin film is deposited to a desired thick-

ness, the pointer of the meter will indicate zero as described hereinbefore.

When a plurality of thin film layers of different materials are deposited, the deposition of one material is stopped as soon as the pointer indicates zero, and then the next evaporant material is placed in the Bell jar. The lever 200 is actuated to bring the used specimen, that is, the specimen upon which is deposited the thin film, toward the guide 272 to drop it into a predetermined position in the Bell jar. Next, the lever 200 is moved in the direction B and then in the direction A so that a new specimen g may be placed in the opening 201.

The next deposition is then started so that the next evaporant material is deposited upon the thin film which has already been formed upon the lens.

As described hereinbefore, according to the present invention the coarse and fine adjustments of the optical elements or mirrors are made so that the adjustment of the relative positions of the mirrors may be simplified. Furthermore, the light source is arranged as a unit, which is provided with a mechanism for positioning the lamp in the correct position, so that the replacement of the lamp may be facilitated. The replacement of specimens may be made only by reciprocating the operating lever so that the formation of a multilayer on a lens may be facilitated.

The stray light from the Bell jar is completely eliminated because a slip plate and a diffusion plate are used and especially because the light receiving surface or photocathode of the phototube is spaced apart from the diffusion plate. Furthermore, the variation in sensitivity over the light receiving surface or photocathode of the phototube, which is inherent thereto, may also be eliminated because the diffusion plate is spaced apart from the phototube.

Next, referring to FIG. 23, the electronic circuit which may be used with the first, second and third embodiments, described hereinbefore with reference to FIGS. 3, 10, 13 and 15, will be described. Reference numeral 273 denotes a phototube which corresponds to the phototube 141 or 185 and to which is applied a high voltage from a high voltage source 274; 275, a pre-amplifier; 276, a bandpass filter which transmits only the fundamental component which is the frequency of rotation of the chopper, but prevents the transmission of the noise; 277, a coupling capacitor; 279, 280, 281 and 282, resistors used for the adjustment of the amplification of an AC amplifier 278; 283 and 284, switches interlocked with a switch 285; 286, 287, 288 and 289, diodes and zener diodes inserted into a feedback circuit of the amplifier 278; and 290, a detector for detecting the DC component of the output of the amplifier 275 in excess of a predetermined level. As shown in FIG. 5, the output of the amplifier 275 includes a high DC component even when the differential signal ($s \lambda_1 - s \lambda_2$) is small. Therefore the DC component in the output signal of the phototube must be detected so that the pre-amplifier 275 may be prevented from being saturated or deactivated by the DC component. When the excess DC component is detected, the output of the detector is applied to a central control circuit 291 to be described hereinafter. Reference numeral 292 denotes a detector which detects its input in excess of a predetermined level; 293, a holding circuit which holds the output of the detector for a predetermined time and applies the control signal to the central control circuit

291, the holding circuit being of any conventional type comprising capacitors, resistors and a diode; and the output of the detector 290 being applied to the reset input terminal of a control circuit 294 such as a flip-flop in the central control circuit 291. The control circuit 294 is set when a high-voltage source actuating switch 295 is closed so that the signal is applied to the high-voltage source 273 which in turn supplies a high voltage to the phototube 273, but is reset in response to the output of the detector DT₁, thereby causing the high voltage source 274 to supply a low voltage to the phototube 273. The output of the holding circuit 293 is applied to the input of the control circuit 296 in the central control circuit so that an "over" indicating lamp 297 connected to the control circuit 296 is turned on. In response to the outputs from the control circuit 294 the indicating lamps 298 and 299 are turned on or off, thereby indicating whether the excess output is being derived from the amplifier 275 or not and also indicating the output voltage of the high voltage source.

When the amplifier 278 is saturated by excess AC input, the capacitor 277 is charged so that it takes a long time before the normal operation of the amplifier 278 is restored even when the excess input is removed. In this case, the feedback resistor in the amplifier 278 is short-circuited in such a manner that either resistor 279 or resistor 280 is connected in series to the capacitor 277. Since the impedance of the capacitor 277 may be negligible in the case of the AC component, the amplification factor becomes $-R_{280}/R_{279}$. Since the capacitor 277 is inserted, the amplification factor for the DC component of the amplifier 278 is zero so that there is no fear at all that the operating point of the amplifier 278 will be deviated due to the offset of the amplifier 278. When the excess input is applied to the amplifier 278, its output is increased for example in the positive (+) direction in excess of the voltage at which the diode 288 is conducted so that the input and output of the amplifier 273 is short-circuited. In this case there arises no problem since the forward voltage is applied to the zener diode 289. When the input is not in excess of a predetermined level, the diode 288 is not conductive. When the excess output of the amplifier 278 is in the negative (-) direction, the diode 289 is conductive so that the input and output of the amplifier 278 is also short-circuited.

When the amplifier 278 is operated under the normal condition i.e., no excess input is applied, a voltage drop across the resistor 300 occurs due to the small leakage current of the zener diodes 288 and 289. The value of the resistor 300 is so selected that the diodes 286 and 287 are not conductive even in the forward direction by the above voltage drop. When the diodes 288 and 289 are conductive as the excess input is applied to the amplifier 278, a sufficiently high current flows through the resistor 300 so that a sufficient forward voltage is applied to the diodes 286 and 287 by the voltage drop across the resistor 300. Therefore, the diodes 286 and 287 are conductive so that the feedback resistor 281 is short-circuited. As a result the capacitor 277 is rapidly discharged.

However, since the excess input is applied to the amplifier 278, the linearity of the amplifier 278 is lost so that there is no proportionality between the input and output.

The excess input may be detected by monitoring the voltage drop across the resistor 300 in the manner described hereinabove. When the voltage drop across the resistor 300 is rapidly increased in response to the excess input, the detector 292 detects this voltage drop and the output of the detector 292 is held for a predetermined time by the holding circuit 293. The level of the output of the holding circuit 293 is varied in a DC manner and the indicating lamp 297 is turned on in response to the output of the control circuit 296, thereby indicating that the amplifier 278 is saturated by a excess input so that the normal measurement cannot be accomplished.

As described above, when the DC component in the output of the phototube 273 is in excess of a predetermined level, the voltage supplied from the high voltage source 274 to the phototube 273 drops. When the AC component in the output of the phototube 273 is in excess of a predetermined level, the indicating lamp 297 is turned on, thereby indicating that the amplifier 273 is saturated so that the normal measurement cannot be accomplished.

Reference numeral 301 denotes a synchronous rectifier connected to the output of the amplifier; 302, a pulse signal waveform shaping circuit for shaping the sync signals generated by a photo-cell 303 disposed in the opening of the chopper 129 into the pulses, the circuit 302 being connected to the synchronous rectifier 301 in order to apply the sync signals thereto; 304, an amplifier which is connected to the output of the synchronous rectifier 301 through a switch 285 and a resistor 305; 306 and 307, resistors inserted into the feedback circuit of the amplifier 304 so as to vary the amplification factor thereof; 308, an electronic switching element comprising a FET connected in series to the resistor 307 so that the resistor 307 may be selectively connected to the feedback circuit of the amplifier 304, $R_{306} = 10 \times R_{307} // R_{306}$ (where $//$ denotes the parallel connection) so that when the electronic switching element 308 is closed the resistance is set to 1/10 of the resistance when the electronic switching element is off (that is, X 1, X10); and 309, an indicator connected to the output of the amplifier 304.

Reference numeral 310 denotes a switch for changing the scale of the indicator 209. When the switch 310 is closed, the scale is X1 whereas when the switch 310 is opened, the scale is X 10.

Reference numeral 311 denotes a control signal generator for applying the ON signal to the switching element 308; and 312, a control circuit for adjusting the stop blade 172 when the pointer of the indicator 309 will not indicate zero due to the product variation of the light source, the dichroic mirrors and the half mirrors, that is, when the deflection due to the light beam of wavelength λ_1 does not coincide with that due to the light beam of wavelength λ_2 . The control circuit 312 is connected to the switch 310 and to a control circuit 313 including a flip-flop. Reference numeral 314 denotes a FET switching element whose gate is connected to the set output terminal of the control circuit 313 including the flip-flop; 315, 314, 316, and 317, FET switching elements connected to the output of the control circuit 313 including the flip-flop; 318, an amplifier connected to the output of the synchronous rectifier 301 through a switching element 319; and 320, a feedback resistor. A detector 321 is connected to the output of the amplifier 318 so that when the output of the

amplifier 318 is less than a predetermined level, the control circuit 313 including the flip-flop is reset.

When the thickness measurement is made by the dichromatic method, the switch 310 is depressed so that the flip-flop is set in response to the output of the control circuit 312. Then the switching element 319 is turned on whereas the elements 314, 315, 316 and 317 are turned off. When the output of the synchronous rectifier 301, that is, the difference between the outputs in response to the light beams of wavelengths λ_1 and λ_2 , is derived, the motor 174 for driving the stop blade is driven in response to the output of the amplifier 318 so that the stop blade is displaced in the optical path of the beam of a wavelength λ_1 or λ_2 , thereby controlling the intensity of the light. Therefore, the output of the amplifier 318 gradually approaches zero so that the motor 174 is stopped. When the output of the amplifier 318 is less than a predetermined level, the control circuit 313, including a flip-flop, is reset through the detector 321 and the switching element 319 is turned off and the switching elements 314 and 315 are turned on whereas the elements 316 and 317 remain turned off. Since the set output of the flip-flop 313 is connected to the indicating lamp 322, when the control circuit 313 including the flip-flop is set so that the motor 174 is driven, the lamp 322 is turned on, thereby indicating that the stop adjustment is being made.

The stop blade 172 is drivingly coupled to the motor 174, and a cam 323 is secured on the shaft of the stop blade 172. Reference numerals 324 and 325 denote limit switches mounted on the ends of the cam 323; and 326, a switch for detecting the position of the stop blade 172.

Reference numeral 327 denotes a control circuit which is adapted to transmit the control signals to the control circuit 312 in response to the signals from the limit switches 324 and 325 and to reverse the state of the control circuit 313 including the flip-flop, thereby turning on only the switching elements 314 and 315.

Therefore, the stop blade is rotated only in one direction. When the detecting switch 326 is opened, either of the elements 315 or 314 is turned on depending upon whether the limit switch 324 or 325 is closed so that the feedback circuit of the amplifier 318 is short-circuited. As a result, the input to the servomotor 174 is interrupted so that the motor 174 is stopped, thereby preventing overrun of the stop blade. Since the diodes 328 and 329 are connected in back-to-back relation with respect to each other and in series to the elements 315 and 314, the polarity of the output to be applied to the motor 174 depends upon whether the switching element 315 or 314 is turned on.

Reference numeral 330 denotes a change-over switch for selecting the thickness measurement with the dichromatic method or with the monochromatic method; and 331, a driving circuit for selectively driving a rotary solenoid 332 or 333 when the switch 330 is actuated. In the case of thickness measurement with a monochromatic method, a contact *a* (wavelength λ_1) or a contact *c* (wavelength λ_2) is closed so that the rotary solenoid 332 or 333 is selectively driven. The solenoid 332 corresponds to the electromagnetic component indicated by 164 in FIG. 13, and when the solenoid 332 is energized, the light beam of wavelength λ_1 is interrupted so that the thickness measurement is made only with the light beam of wavelength λ_2 . The rotary solenoid 333 is adapted to drive a shutter (not

lower the amplification factor, thereby preventing a nonlinear error.

When the thickness measurement with the monochromatic method is made, with the contact *b* of the switch 330 closed, the control circuit 313 including the flip-flop is set and the elements 315, 314 and 319 are turned off. Either of the elements 316 or 317 is turned on depending upon whether the limit switch 324 or 325 is closed by the cam 323, and the positive or negative voltage is applied to the amplifier 318 from the power source so that the servo-motor 174 is rotated in a clockwise or counterclockwise direction. The stop blade 172 is moved to its neutral position, that is, the position where neither of the limit switches 324 and 325 are closed by the cam 323. In the case of the thickness measurement with the monochromatic method, both of the optical paths may be used with maximum efficiency, and the difference in efficiency between the two optical paths may be determined.

We claim:

1. An instrument for measuring the thickness of a thin film deposited on a substrate surface comprising: light source means for emitting light to be projected upon said substrate and film;
projection means for projecting alternately and in succession two light beams of different wavelengths λ_1 and λ_2 onto the substrate and film to be measured along the same light path, said two light beams being absorbed or reflected depending upon the thickness of the film to be measured;
a first splitting means for splitting light beams transmitted through or reflected from the film to be measured into two bundles of light;
a first filter means comprising a first filter for transmitting only the light beam of wavelength λ_1 and a second filter for transmitting only the light beam of wavelength λ_2 ;
means for condensing said two light beams of wavelengths λ_1 and λ_2 derived from said filter means;
a photo-electric converter for converting light beams condensed by said condensing means into electric signals;
means for detecting the minimum difference between a first signal and a second signal from said converter, said first signal depending on the light beam of wavelength λ_1 , said second signal depending on the light beam of wavelength λ_2 .

2. An instrument defined in claim 1 wherein said light beam projection means comprises a second splitting means for splitting into two light beams the light emitted from said light source means, a second filter means comprising a third filter for transmitting only the light beam of wavelength λ_1 of the two light beams from said second splitting means and a fourth filter for transmitting only the light beam of wavelength λ_2 of the two light beams from said second splitting means, means for alternately chopping said two light beams from said second filter means, a second condensing means for condensing said two light beams from said chopping means, and a window for transmitting said two light beams derived from said second condensing means onto the substrate and film to be measured along the

same light path.

3. An instrument defined in claim 1 wherein said first splitting means comprises a dichroic mirror.

4. An instrument defined in claim 1 wherein said photoelectric converter is provided with a slit adapted to intercept only said two light beams condensed by said condensing means.

5. An instrument defined in claim 2 wherein said second splitting means comprises a dichroic mirror.

6. An instrument defined in claim 2 wherein said light beam projecting means is provided with stop means for controlling quantity of light of at least one light beam from said second splitting means.

7. An instrument defined in claim 2 wherein said chopping means is provided with a rotary disk having a transparent area partly formed therein.

8. An instrument defined in claim 2 further comprising an additional converter means for converting one of two light beams derived from said second splitting means into an electric signal, said electric signal being applied to said detecting means for phase detection.

9. An instrument defined in claim 2 further comprising means for supporting a plurality of substrates, and means adapted to move said substrates one by one into such a position that two light beams from said light beam projection means are projected along the same light path and to remove said substrates one by one from said specified position.

10. An instrument for measuring the thickness of a thin film deposited on a substrate surface comprising: light source means for emitting light to be projected upon said substrate and film;

projection means for projecting alternately and in succession two light beams of different wavelengths λ_1 and λ_2 onto the substrate and film to be measured along the same light path, said two light beams being absorbed or reflected depending upon the thickness of the film to be measured;

a first splitting means for splitting light beams transmitted through or reflected from the film to be measured into two bundles of light;

a first filter means comprising a first filter for transmitting only the light beam of wavelength λ_1 and a second filter for transmitting only the light beam of wavelength λ_2 ;

means for condensing said two light beams of wavelengths λ_1 and λ_2 derived from said filter means;

a photoelectric converter for converting light beams condensed by said condensing means into electric signals;

means for detecting the minimum difference between a first signal and a second signal from said converter, said first signal depending on the light beam of wavelength λ_1 , said second signal depending on the light beam of wavelength λ_2 , said detecting means comprising an amplifier having a detector for detecting an excess input to prevent an error in measuring due to the excess input and a gain decreasing circuit responsive to the output of said excess input detector for decreasing the gain thereof.

* * * * *

shown) inserted in the optical path of the light beam of wavelength λ_2 . Reference numeral 334 denotes a control circuit for selectively conducting FET switching elements 336 and 337 in response to the outputs of the control circuits 331 and 335.

Reference numeral 338 denotes a circuit which amplifies and inverts the output of an amplifier 339. When the switching element 337 is turned on, the correction current flows through a resistor 340 to the amplifier 304, but when the switching element 336 is turned on, the current has a polarity opposite to that of the current flowing through resistor 341 into the amplifier 304.

Reference numeral 342 denotes a voltage divider for dividing the reference voltage ER applied to the terminal thereof into voltages of 0, 10, 20, . . . and 90 percent thereof; 343, a variable resistor for fine adjustment connected in parallel with the voltage divider 342; and 344, 345 and 346, resistors of the amplifier 339. The value of the resistor 345 is 10 times that of the resistor 344.

The circuit, comprising the amplifiers 339 and 338 and the voltage divider 342, is provided in order to improve the accuracy measurement of the indicator 309 in the case of measurement with monochromatic method.

In the case of the monochromatic method, the pointer of the indicator 309 deflects in a counterclockwise or clockwise direction depending upon whether the light beam of wavelength λ_1 or wavelength λ_2 is used. Therefore, whether the light beam wavelength λ_1 or λ_2 is used is easily detected from the deflection of the pointer of the indicator 309. In the case of thickness measurement with the monochromatic method, the thickness of a thin film is measured from the transmissivity or reflectivity of a specimen for the light beam of wavelength λ_1 or λ_2 . Therefore, the variation in thickness of the order of 4 percent of a thin film must be detected under the condition of 90 percent incident light. In this case, it is advantageous to indicate the value which is equal to the reading of the indicator minus 90 percent and to increase the sensitivity of the indicator by ten times. It is thus possible to indicate the variation only on an enlarged scale. For this purpose, the element 308 is turned off as described hereinbefore so that the sensitivity of the indicator 309 is increased by 10 times and the element 336 or 337 is turned on to apply the correction current to the amplifier 304. For example, assume that a correction current of 90 percent is subtracted from the reading of the indicator 309, then the input of the amplifier 339 is connected through a resistor 344 to a terminal of the voltage divider 342 from which the voltage equal to 90 percent of a reference voltage ER is derived. The fine adjustment of the voltage division by the voltage divider 342 may be accomplished by the variable resistor 343, but in the amplifier 339 the voltage which is amplified and inverted (the gain being dependent upon the ratio of the resistors 344, 345, and 346) is such that the elements 336 and 337 are selectively turned on when the contacts *a* and *c* of the switch 330 are closed. When the element 336 is turned on, the correction current flows into the input of the amplifier 304 through the resistor 341, whereas when the element 337 is turned on the correction current with an opposite polarity flows into the amplifier 304 through the resistor 340. That is, depending upon the light beam of wavelength λ_1 or λ_2 the addition and subtraction currents are applied so that

the 90 percent DC bias indication component may be subtracted.

In the case of the thickness measurement with the dichromatic method, the above correction is not required so that when the contact *b* of the switch 330 is closed, the "ON" signal is not transmitted from the control circuit 334 to the elements 336 and 337.

Reference numeral 347 denotes a switch which is opened when the terminal from which 0 percent divided voltage is derived is selected and opened, when the other terminals of the voltage divider 342 are selected. When the switch 347 is closed the driving circuit 335 is actuated to turn on the lamp 348 and to transmit the operation start signal to the control circuit 334.

Next the mode of thickness measurement with the dichromatic method will be described as follows. The contact *b* of the switch 330 is closed and the switches 295 and 349 are closed. Then the chopper is rotated by a circuit (not shown), and the light reflected from or transmitted through a specimen, not having a thin film thereon is intercepted by the phototube 273.

The output of the phototube 273 is applied to the amplifier 278 through the amplifier 275, the filter 276, the capacitor 277 and the resistor 279 so that the pointer of the indicator 309 is deflected through the synchronous amplifier 301 and the amplifier 304. As described hereinbefore, prior to the deposition by vacuum evaporation, switch 310 must be turned on so that the pointer of the indicator 309 indicates zero. The output signal of the synchronous rectifier 301 represents the absolute signal of the fundamental chopper component of the phototube 273 so that when the output signal is not zero, the stop blade driving motor 174 is driven by the output of the amplifier 318 so that the light beams of wavelengths λ_1 and λ_2 are partly interrupted until the reading of the indicator 309 becomes zero. As soon as the motor 174 is stopped, the flip-flop 313 is set in response to the output from the detector 321 to turn on the lamp 322, indicating that the initial stop setting is being carried out.

When the reading of the indicator 309 will not become zero even when the stop blade 172 is rotated, that is, when the reading of the indicator will not become zero even when the stop blade 172 is rotated because of a maladjustment of the optical system, the stop blade is displaced to the end of its stroke so that either of the limit switches 324 or 325 is opened. When either of the switches 324 or 325 is closed by the cam 323, a signal is applied to the element 315 or 314 through the control circuits 327, 312 and 313 so that the motor 174 is stopped. Thus, the overrun of the stop blade 174 may be prevented.

When the deposition is started after the above adjustment has been made, the output of the phototube 273 varies in response to the thickness of the thin film deposited upon the specimen, and the desired thickness is attained when the reading of the indicator 309 is zero.

When the output signal of the phototube 273 is in excess of a predetermined level, the DC component thereof is detected by the detector 290 so that the control circuit 294 controls the high-voltage circuit 274 so as to supply the low voltage to the phototube 273. The AC component of the phototube 273 is detected by the detector 292 and the lamp 297 is turned on. The feedback circuit of the amplifier 273 is short-circuited to

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,869,211 Dated March 4, 1975

Inventor(s) ASAO WATANABE, ET AL.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 10, "wavelength" should read --wavelengths--;

Column 1, line 33, "reflation" should read --refraction--;

Column 1, line 33, after "d" insert --)--;

Column 6, lines 56 and 57, "That is, the variation in intensity of light beam" should read --That is, the variation in intensity of the light beam--;

Column 6, line 57, "light displacement" should read --displacement--;

Column 7, lines 9 and 10, "at which the light beam can be beam shielded" should read --at which the light beam generally can be shielded--;

Column 8, line 1, "collimater" should read --collimator--;

Column 11, lines 55 and 56, "using the some jigs" should read --using the same jigs--;

Column 11, line 57, "idodine" should read --iodine--;

Column 13, line 29, "slip plate" should read --slit plate--;

Column 14, line 8, "high-voltage source 273" should read --high-voltage source 274--;

Column 14, line 65, "linearlity" should read --linearity--;

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,869,211 Dated March 4, 1975

Inventor(s) ASAO WATANABE, ET AL. Page 2

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 17, line 23, "accuracy measurement" should read
--measurement accuracy--;

Column 17, line 52, "from which the voltage equal to 90 percent of a reference voltage" should read
--from which a voltage equal to 90 percent of the reference voltage--;

Column 18, line 17, insert a colon after "as follows";

Column 19, line 36, "ligth" should read --light--;

Column 20, line 50, "consensed" should read --condensed--.

Signed and Sealed this

eleventh Day of November 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks