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Standard Practice for Preparing An Optical Microscope for Dimensional Measurements[1]

This standard is issued under the fixed designation F 728; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Editorial changes were made throughout in December l997.

1. Scope

1.1 This practice covers the preparation of an optical microscope for dimensional measurements. It is intended for preparing an optical microscope to measure the width of lines, in the range from 0.5 to 12 µm, inclusive, on hardsurface photomasks and processed silicon wafers.

1.2 This practice is applicable for a microscope equipped with a micrometer attachment, such as an optical filar, video filar, optical image-shearing with optical or video display, optical image-scanning, or video image-scanning micrometer. Adjustment and calibration of the micrometer attachment is not included in this practice.

1.3 This practice is intended for observing optically transparent specimens in bright-field transmitted illumination or optically opaque specimens in bright-field reflected illumination. It is not intended for dark-field illumination.

1.4 This practice is limited to an optical microscope with an illumination system that is an integral part of the microscope body and includes a condenser lens.

1.5 No useful figure capable of showing the arrangement of components for all microscope designs is available; therefore, this practice does not contain illustrations and procedures which would suggest a specific microscope.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For more specific hazard statements, see Note 7, Note 8, and Note 17.

2. Referenced Documents

2.1 *ASTM Standards:*

E 175 Terminology of Microscopy[2]

F 127 Definitions of Terms Relating to Photomasking Technology for Microelectronics[3]

3. Terminology

3.1 *Definitions:*

3.1.1 Other terms used in this practice are defined in Terminology E 175 and Definitions F 127.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coherence—in optics*, a measure of the ability of light to interfere.

3.2.1.1 *Discussion*—Coherence arising from the finite extent of the light source is spatial coherence. Coherence arising from the finite spectral width of the light source is temporal coherence.

3.2.2 *coherence parameter—in microscopy*, the ratio of the condenser numerical aperture to the objective numerical aperture for wide-field, bright-field, Kohler illumination.

3.2.3 *condenser aperture diaphragm—in microscopy*, a fixed or variable opening that controls the light passing through the condenser and determines the value of the condenser numerical aperture.

3.2.4 *condenser lens or substage condenser—in microscopy*, a lens that collects light for the purpose of illuminating the specimen.

3.2.5 *condenser numerical aperture—in microscopy*, the product of the index of refraction in object space multiplied by the sine of half the angular aperture of the condenser.

3.2.6 *condenser system—in microscopy*, lenses and mirrors that collect light for the purpose of illuminating the specimen.

3.2.6.1 *Discussion*—A condenser system usually consists of mirrors, a lamp collector, relay lenses, and a condenser lens.

3.2.7 *contrast—in microscopy*, the ratio of the transmittance or reflectance of two different areas on the specimen.

3.2.8 *cover glass—in microscopy*, a thin glass plate that is placed over the specimen.

3.2.8.1 *Discussion*—Some microscope objectives are designed for use with a cover glass of a specified thickness, and use of these objectives without a cover glass or with a cover glass of a different thickness from the specified thickness introduces spherical aberration in the observed image.

3.2.9 *epi-objective—in microscopy*, an objective with an annular mirror that acts as a lens to illuminate the specimen.

3.2.9.1 *Discussion*—An epi-objective is commonly used in dark-field reflected illumination, but it is also useful in bright-field illumination.

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[1] This practice is under the jurisdiction of ASTM Committee F-1 on Electronics and is the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] Discontinued; see *1992 Annual Book of ASTM Standards*, Vol 10.05.

3.2.10 *field diaphragm—in optics*, a usually variable opening that controls the field of view.

3.2.11 *field of view—in microscopy*, the area or solid angle viewed through the microscope.

3.2.11.1 *Discussion*—Field of view is often expressed as the diameter of the largest image which the eyepiece can cover.

3.2.12 *filar micrometer, optical*—for the purposes of this practice, a micrometer equipped with a movable fiducial line imaged in the eyepiece.

3.2.13 *filar micrometer, video*—for the purposes of this practice, a micrometer equipped with movable, electronically generated fiducial lines that appear, along with an image of the specimen, on a television monitor.

3.2.14 *illumination, bright-field—in microscopy*, a method of illumination in which the image appears against a bright background generally produced by uniformly illuminating a circular and unobstructed condenser aperture diaphragm.

3.2.15 *illumination, dark-field—in microscopy*, a method of illumination in which the image appears as self-luminous against a dark background generally produced by illuminating the specimen with an annular cone of light so that only scattered light enters the objective.

3.2.15.1 *Discussion*—In dark-field transmitted illumination, the condenser has an opaque center stop. In dark-field reflected illumination, the objective has a reflective annular surface that surrounds the lenses and serves as a condenser.

3.2.16 *illumination, Kohler—in microscopy*, a method of illumination in which an image of the light source is focused on the condenser aperture diaphragm located at or near the back focal plane of the condenser lens and an image of the lamp collector is focused on the specimen plane.

3.2.17 *image-scanning micrometer, optical*—for the purposes of this practice, a micrometer that uses a phototube and scanning slit to generate an optical image profile from which the specimen dimension is determined by means of an optical threshold.

3.2.18 *image-scanning micrometer, video*—for the purposes of this practice, a micrometer that uses a television camera to generate an electronic image profile from which the specimen dimension is determined by means of an electronic threshold.

3.2.18.1 *Discussion*—In semiautomatic image-scanning micrometers, the operator sets an electronic window in the vicinity of the boundaries of the specimen image, and the edge locations are determined automatically by electronic thresholding techniques.

3.2.19 *image-shearing micrometer, optical*—for the purposes of this practice, a micrometer that optically shears, or splits, the image of the specimen into two identical images whose separation can be continuously adjusted while being viewed in the eyepiece.

3.2.20 *image-shearing micrometer, video*—for the purposes of this practice, a micrometer that optically shears, or splits, the image of the specimen into two identical images whose separation can be continuously adjusted while being viewed on a television monitor.

3.2.21 *lamp collector or lamp condenser—in microscopy*, a lens that collects light from the lamp and usually focuses the light either on the specimen or on the condenser aperture diaphragm.

3.2.22 *lamp diffuser—in microscopy*, a ground-glass plate or other light-diffusing material used to improve the uniformity of the illumination.

3.2.23 *mechanical tube length—in microscopy*, the distance between the shoulder or flange of the objective and the eyepiece seating face.

3.2.24 *micrometer attachment*—for the purposes of this practice, an instrument used with an optical microscope for measuring small distances.

3.2.25 *objective aperture—in microscopy*, a fixed opening that controls the light passing through the objective and determines the value of the objective numerical aperture.

3.2.26 *objective, flat-field—in microscopy*, an objective that is designed to show little or no field curvature over the useful field of view.

3.2.27 *objective numerical aperture—in microscopy*, the product of the index of refraction in object space multiplied by the sine of half the angular aperture of the objective.

3.2.28 *relay lens—in optics*, a lens that transfers an image from one location to another along the optical axis.

3.2.29 *vertical illuminator—in microscopy*, an illumination system used with reflected light in which the objective both illuminates and images the specimen.

3.2.29.1 *Discussion*—It usually consists of the objective (condenser), beam splitter, relay optics, field diaphragm, condenser aperture diaphragm, and filter holder.

4. Summary of Practice

4.1 An objective, eyepiece, condenser lens, and green filter are inserted into the microscope, and a representative specimen is placed on the mechanical stage.

4.2 The lamp is switched on and the image of the lamp filament or arc lamp is centered and focused on the condenser aperture diaphragm.

4.3 The microscope is adjusted to give a focused image of the representative specimen within the field of view.

4.4 For transmitted illumination, the condenser lens is adjusted to give a focused and centered image of the field diaphragm within the field of view. For reflected illumination, a relay lens and centering controls are adjusted to give a focused and centered image of the field diaphragm within the field of view.

4.5 The condenser aperture diaphragm is adjusted to give a numerical aperture that is approximately two thirds of the objective numerical aperture.

4.6 The illumination observed in the field of view is adjusted to equal the room illumination.

5. Significance and Use

5.1 Dimensional measurements made with an optical microscope are made on the optical image of the specimen and not directly on the specimen itself. The method of illuminating the specimen affects the image content, including the appearance of edges which are used in defining the size of the specimen.

5.2 This practice includes adjusting the microscope for Kohler illumination which provides uniform illumination of

the specimen, reduces stray light, and results in bright images with good contrast.

5.3 This practice provides an image with steep edge gradients by setting the ratio of condenser numerical aperture to objective numerical aperture equal to approximately two thirds. As a result, the repeatability of edge settings used in measurement eyepieces and photometer line profiles is improved.

5.4 Many different types of microscopes and micrometer attachments are used for dimensional measurements. This practice reduces the effects of image-contrast variation on measurements with these different systems.

5.5 This practice is particularly useful for preparing the microscope to measure the width of lines on hard-surface photomasks and processed silicon wafers. These linewidths are used for comparison with design values and to help determine the quality control of the processes used to fabricate the photomasks and wafers. These linewidths are useful for materials acceptance purposes or for other matters relating to the sale or purchase of materials.

5.6 This practice is intended primarily as a guide in preparing an optical microscope for dimensional measurements and is used in conjunction with the instruction manual provided by the manufacturer.

6. Interferences

6.1 Most microscopes have lenses and mirrors that are either inaccessible for adjustment or permanently fixed in position. If these components were not properly prealigned by the manufacturer, adjusting the microscope for Kohler illumination may not be possible. If the microscope cannot be adjusted for Kohler illumination, the image of the specimen may exhibit poor contrast, the field of view may be illuminated nonuniformly, and the optical resolution may be reduced. Consequently, the repeatability of edge settings used in measurement systems would be adversely affected.

6.2 A microscope objective is designed for use with a specified mechanical tube length. Using an objective with the specified mechanical tube length that is different from the actual tube length of the microscope results in a degraded image and measurement errors.

6.3 For transmitted illumination, the use of a specimen with a thickness greater than about 2 mm may make it difficult to adjust for Kohler illumination, particularly for a condenser with a numerical aperture as high as 0.6. The specimen introduces spherical aberration and defocus in the image of the diaphragm that is focused on the top surface of the specimen (speciman plane), and the sharpness of this image is reduced as the specimen thickness increases.

7. Apparatus

7.1 *Optical Microscope*, with a total magnification of 600× or greater for measuring linewidths larger than 1 µm or a total magnification of 1000× or greater for measuring linewidths 1µm or smaller, and associated instruction manual. The microscope should have the following components:

7.1.1 *Bright-Field, Dry Objective*, with a numerical aperture of 0.65 or greater for measuring linewidths larger than 1 µm or a numerical aperture of 0.85 for measuring linewidths 1 µm or smaller, and a mechanical tube length that equals the microscope tube length. The objective shall be an achromatic, flat-field objective or better and designed for use without a cover glass. If an epi-objective is used with bright-field reflected illumination, a bright-field reflector should be present in the vertical illuminator.

7.1.2 *Condenser System*, having a bright-field condenser lens, condenser aperture diaphragm, lamp collector, and field diaphragm. If the condenser aperture diaphragm is fixed and cannot be adjusted to set the condenser numerical aperture, the condenser lens should have a numerical aperture that is approximately two thirds that of the objective numerical aperture.

NOTE 1—This ratio of numerical apertures gives steep edge gradients and thereby improves the quality of dimensional measurements made on the image.

NOTE 2—For bright-field reflected illumination, the objective also serves as the condenser. In this case, the aperture diaphragm is usually positioned so that it controls only the numerical aperture of the light incident on the specimen and consequently allows the condenser numerical aperture to be adjusted without affecting the objective numerical aperture.

7.1.3 *Eyepiece*, having a magnification large enough to provide a total microscope magnification of 600× or greater for measuring linewidths larger than 1 µm or a total microscope magnification of 1000× or greater for measuring linewidths 1 µm or smaller. This eyepiece is unnecessary if the micrometer attachment (see 7.1.6) includes a built-in eyepiece. For measurement systems with a video micrometer attachment, an eyepiece is used primarily for locating and aligning the specimen rather than measuring the specimen. For such systems, it is not necessary that the eyepiece magnification be large enough to provide a total microscope magnification of 600×.

7.1.4 *Green Filter*, having a peak wavelength between 520 and 540 nm, a peak transmittance of 60 % or greater, a half-power bandwidth of 70 nm or less, a transmittance of less than 5 % below 460 nm, and a transmittance of less than 2 % between 600 and 690 nm. For transmitted illumination, the filter should have dimensions suitable for placing it in either the filter holder or directly over the field diaphragm. For reflected illumination, the filter should have dimensions suitable for placing it in the filter holder.

NOTE 3—The requirements on the shape and size of the filter are far less restrictive if the filter can be placed directly over the field diaphragm. For microscopes operating in reflected illumination, however, the filter generally cannot be placed over the field diaphragm, and the built-in filter holder should be used.

7.1.5 *Filter Holder*, suitable for holding a filter between the light source and the condenser lens.

NOTE 4—The filter holder is usually built into either the microscope body or into the vertical illuminator.

7.1.6 *Micrometer Attachment*, suitable for making dimensional measurements. It should have a magnification large enough to provide a total microscope magnification of 600× or greater.

7.1.7 *Stage*, for supporting and positioning the specimen in the field of view with *x–y* motions. It may be manually

controlled, motor-driven, or piezo-driven.

7.1.8 *Vertical Illuminator*, for reflected illumination.

7.1.9 *White-Light Source*.

7.1.10 *White Paper*, translucent and large enough to cover the condenser aperture in transmitted illumination or large enough to cover the relay lens nearest the objective in reflected illumination.

7.2 *Specimen*, representative of those to be measured. Specimen types include hard-surface photomasks and processed silicon wafers.

NOTE 5—If a specimen used in this practice has a different thickness from the specimen to be measured, the field diaphragm may not remain in focus when the measurement specimen is refocused within the field of view (see 8.4).

8. Procedure

8.1 Read the instruction manual and become acquainted with the location of the various microscope components, including the following: objective, eyepiece, filter holder, mechanical stage, controls for positioning the stage, focus controls, light source, vertical illuminator, lamp diffuser, relay lenses, condenser lens, condenser aperture diaphragm, and controls for centering the lamp, field diaphragm, and condenser.

8.2 Set up the microscope as follows:

8.2.1 Turn on the light source.

8.2.2 For transmitted illumination, insert the objective, eyepiece or measurement eyepiece, and condenser lens into the microscope. For reflected illumination, attach the vertical illuminator to the microscope, insert the objective/condenser into the vertical illuminator, and insert the eyepiece or measurement eyepiece into the microscope.

8.2.3 Insert the green filter into the built-in filter holder.

NOTE 6—For most microscopes operating in transmitted illumination, the filter may be placed across the field diaphragm.

NOTE 7—**Caution:** Placing the filter in contact with a lens that heats up during operation of the microscope may permanently damage some gelatin-based filters and thereby alter the wavelength of the illumination reaching the specimen.

8.2.4 Place the specimen, with the surface of interest facing up, on the stage.

NOTE 8—**Caution:** Do not position the specimen area to be measured directly under the microscope objective during this step. Do not clamp the specimen against the stage.

NOTE 9—Some operators may switch back and forth between low-magnification and high-magnification objectives in an effort to facilitate finding some detail on the specimen. In such cases, the operator may inadvertently bring the objective and specimen into contact and thereby damage the specimen. Therefore, if a specimen area other than that to be measured is selected in 8.2.4, the potential for damaging the measurement area can be reduced significantly.

NOTE 10—A specimen holder or chucking arrangement may be used to control movement of the specimen provided that the holder or chuck does not clamp the specimen.

8.3 Center and focus the filament (incandescent lamp) or the bright spot (arc lamp) as follows:

8.3.1 Remove the lamp diffuser from its position in front of the lamp.

8.3.2 Close down the field diaphragm as far as possible.

8.3.3 For transmitted illumination, place a piece of thin white paper over the entrance side of the condenser lens (that is, the side facing the lamp). Some microscope manufacturers supply a cross hair on a diffusing disk which may be used in place of the white paper. If this disk is available, remove the condenser lens and insert the diffusing disk in its place. For reflected illumination, place the piece of white paper over the entrance side of the relay lens that is located nearest the objective. If the white paper cannot be placed over this relay lens, remove the eyepiece, open the condenser aperture diaphragm as wide as possible, open the field diaphragm slightly, and look down the microscope tube at the circle of light on the back side of the objective.

8.3.4 Look for an image of the lamp filament or arc on either the white paper, the diffusing disk, or the back side of the objective, depending on which is used in 8.3.3. If necessary adjust the lamp voltage until a clear image of the filament or arc can be seen.

8.3.5 Adjust the lamp-focusing control to produce a sharp image of the lamp filament or arc on either the white paper, the diffusing disk, or the back side of the objective, depending on which is used in 8.3.3.

8.3.6 Adjust the lamp-centering controls to center the image of the lamp filament or arc with respect to either the outline of the condenser aperture on the white paper, the cross hair on the diffusing disk, or the boundaries of the circle of light on the back side of the objective, depending on which is used in 8.3.3.

NOTE 11—In the case of a filament lamp, exact centering is not necessary. It is more important to choose an area of the filament that is relatively uniform in brightness and large enough to completely fill the condenser aperture diaphragm after this diaphragm has been adjusted, so that its diameter is approximately two thirds of the diameter of the objective aperture (see 8.5.6).

8.3.7 If two images of the lamp filament or arc are visible on the white paper, the diffusing disk, or the back side of the objective, adjust the controls on the reflector located behind the lamp to superimpose these two images.

8.3.8 If the white paper is used in 8.3.3 through 8.3.7, remove this piece of paper.

8.3.9 If the diffusing disk is used in 8.3.3 through 8.3.7 , remove this disk and replace it with the condenser.

8.3.10 If the eyepiece is removed in 8.3.3, replace it.

8.3.11 Replace the lamp diffuser.

8.4 Center and focus the field diaphragm on the specimen as follows:

8.4.1 Open the field diaphragm as wide as possible.

8.4.2 Observe the specimen through the eyepiece and move the stage until some detail on the specimen that is not in the area to be measured is within the field of view (see Note 8).

8.4.3 Focus the microscope to give a sharp image of the specimen.

8.4.4 Move the stage until a clear area of the specimen is within the field of view. Do not refocus.

8.4.5 Close down the field diaphragm until the edges of the diaphragm are within the field of view.

8.4.6 For transmitted illumination, use the control which moves the condenser vertically to focus the condenser lens to give a sharp image of the field diaphragm within the field of view. For reflected illumination, most microscopes should have

a relay lens in the vertical illuminator that can be moved horizontally along the axis of the illuminator. Adjust this lens to give a sharp image of the field diaphragm. After adjusting this lens, check to see that the image of the lamp filament or arc is still in focus as done in 8.3.5.

8.4.7 For transmitted illumination, use the controls which move the condenser horizontally to center the field diaphragm within the field of view. For reflected illumination, some vertical illuminators have separate controls for centering the field diaphragm. Use these controls to center the field diaphragm within the field of view if the condenser-lens centering controls are not adequate.

NOTE 12—The observer should basically see two circles of which one is the boundary of the field diaphragm and the other is the boundary of the field of view. In centering the field diaphragm, it is desirable to have the circular field diaphragm concentric with the circular field of view.

8.4.8 Open the field diaphragm until its diameter is equal to, or just slightly greater than, the field of view.

NOTE 13—Opening the field diaphragm larger than necessary may increase flare or stray light, and consequently degrade the image quality. The field diaphragm primarily controls the size of the illuminated field of view and affects the flare level, but it should have no effect on image brightness in a microscope that is properly adjusted for Kohler illumination. If a change in the image brightness is noted while opening the field diaphragm in 8.4.8, the microscope has not been adjusted for Kohler illumination.

8.5 Adjust the ratio of the condenser numerical aperture to objective numerical aperture as follows:

8.5.1 If the condenser system has a numerical aperture that is approximately two thirds of the objective numerical aperture (see 7.1.2), no adjustment is necessary.

8.5.2 Remove the eyepiece.

8.5.3 Look down the microscope tube at the back lens of the objective which is visible as a bright circle. If necessary, adjust the lamp voltage until the intensity of the bright circle is comfortable for viewing. Several circular apertures outside of the bright circle may also be visible.

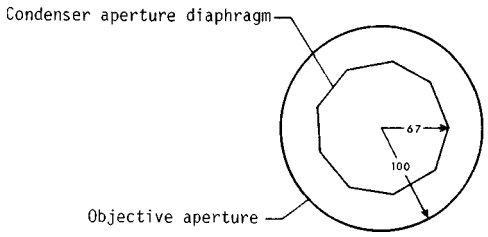
8.5.4 Close down the condenser aperture diaphragm as far as possible and identify which of the apertures corresponds to the condenser aperture diaphragm by noting its movement.

8.5.5 Slowly open the condenser aperture diaphragm and identify the first, or innermost, circular aperture that defines the bright circle of light and does not become larger as the condenser aperture diaphragm is opened further. This aperture is the objective aperture.

NOTE 14—Identification of the condenser aperture diaphragm and the objective aperture may be difficult. Using a condenser lens with a fixed, known numerical aperture that satisfies the requirement for the ratio of condenser numerical aperture to objective numerical aperture given in 7.1.2 eliminates this difficulty.

8.5.6 Set the condenser aperture diaphragm so that its diameter is approximately two thirds of the diameter of the objective aperture (see Fig. 1).

NOTE 15—The condenser aperture diaphragm should *not* be used to adjust image brightness. Although adjustment of the condenser aperture diaphragm affects image brightness, its primary effect is control of the spatial coherence at the specimen. A coherence parameter of two thirds gives steep edge gradients while maintaining image brightness.



NOTE 1—The values shown for the radius of the condenser aperture diaphragm and the radius of the objective aperture are dimensionless. These values are given only to show the two-third ratio of the radii.

FIG. 1 Schematic Showing the Ratio of Condenser Numerical Aperture to Objective Numerical Aperture (Set Equal to Approximately Two Thirds)

NOTE 16—Some microscopes have numbered settings marked on the edge of the aperture diaphragm to denote the numerical aperture of the condenser lens. The operator should not rely initially on these settings. Compare the visual setting obtained in 8.5.6 with the numbered setting. If the settings agree, then the numbered setting may be used to set the ratio of numerical apertures.

8.5.7 If the condenser aperture diaphragm does not open wide enough or close down far enough to set the ratio of condenser numerical aperture to objective numerical aperture equal to approximately two thirds in 8.5.6, replace the condenser with one that does meet the required ratio and repeat 8.4.1 through 8.5.6.

8.5.8 Replace the eyepiece.

8.6 Adjust the light level in the field of view as follows:

8.6.1 Observe the specimen through the eyepiece and move the mechanical stage until some specimen detail in the area to be measured is within the field of view. If necessary, refocus the microscope to give a sharp image of the specimen.

NOTE 17—**Caution:** The refocusing should be performed very slowly and carefully to avoid bringing the specimen and objective into contact and thereby damaging the specimen.

8.6.2 Remove any bright, discrete light sources from the immediate surround of the microscope so that the operator experiences relatively uniform illumination before looking into the microscope.

8.6.3 Use the lamp-voltage control to adjust the brightness of the lamp until the illumination level of the specimen as viewed through the eyepiece is nearly equal to the room illumination in the immediate surround of the microscope. For photometric and video systems, adjust the lamp brightness to give a minimum signal-to-noise ratio of 100.

NOTE 18—If the specimen illumination is much brighter than the ambient room level, the pupil of the eye closes down abruptly when the operator looks into the microscope and thereby reduces the resolving power of the eye.

9. Keywords

9.1 bright-field; dark-field; dimensional; microscope; optical microscope

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