Designation: E 2244 – 02

Standard Test Method for In-Plane Length Measurements of Thin, Reflecting Films Using an Optical Interferometer[1]

This standard is issued under the fixed designation E 2244; 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.

1. Scope

1.1 This test method covers a procedure for measuring in-plane lengths (including deflections) of patterned thin films. It applies only to films, such as found in microelectromechanical systems (MEMS) materials, which can be imaged using an interferometer.

1.2 There are other ways to determine in-plane lengths. Using the design dimensions typically provides more precise in-plane length values than using measurements taken with an optical interferometer. (Interferometric measurements are typically more precise than measurements taken with an optical microscope.) This test method is intended for use when interferometric measurements are preferred over using the design dimensions (for example, when measuring in-plane deflections and when measuring lengths in an unproven fabrication process).

1.3 This test method uses a non-contact optical interferometer with the capability of obtaining topographical 3-D data sets. It is performed in the laboratory.

1.4 The maximum in-plane length measured is determined by the maximum field of view of the interferometer at the lowest magnification. The minimum deflection measured is determined by the interferometer's pixel-to-pixel spacing at the highest magnification.

1.5 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 2245 Test Method for Residual Strain Measurements of Thin, Reflecting Films Using an Optical Interferometer[2]

E 2246 Test Method for Strain Gradient Measurements of Thin, Reflecting Films Using an Optical Interferometer[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *2-D data trace*, *n*—a two-dimensional data trace that is extracted from a topographical 3-D data set and that is parallel to the *xz*- or *yz*-plane of the interferometer.

3.1.1.1 *Discussion*—The height of the sample is measured along the *z*-axis of the interferometer. The interferometer's *x*-axis (as shown in Figs. 1 and 2) is typically aligned parallel or perpendicular to the transitional edges to be measured.

3.1.2 *3-D data set*, *n*—a three-dimensional data set with a topographical *z*-data value for each (*x*, *y*) pixel location within the interferometer's field of view.

3.1.3 *anchor*, *n*—in a surface-micromachining process, the portion of the test structure where the mechanical layer makes contact with the underlying layer (see Fig. 2).

3.1.4 *anchor lip*, *n*—in a surface-micromachining process, the extension of the mechanical layer around the edges of the anchor (see Fig. 2).

3.1.5 *bulk micromachining*, *adj*—a MEMS fabrication process where the substrate is removed at specified locations, which can create structures suspended in air.

3.1.6 *cantilever*, *n*—a test structure that consists of a beam suspended in air and anchored or supported at one end.

3.1.7 *fixed-fixed beam*, *n*—a test structure that consists of a beam suspended in air and anchored or supported at both ends (see Figs. 1 and 2, and Fig. X1.1).

3.1.8 *in-plane length measurement*, *n*—a length (or deflection) measurement made parallel to the underlying layer (or the *xy*-plane).

3.1.9 *interferometer*, *n*—a non-contact optical instrument (such as shown in Fig. 3) used to obtain topographical 3-D data sets.

3.1.10 *mechanical layer*, *n*—in a surface-micromachining process, the patterned layer (as shown in Fig. 2) that is anchored to the underlying layer where cuts are designed in the sacrificial layer and that is suspended in air where no cuts are designed in the sacrificial layer.

3.1.11 *MEMS*, *adj*—microelectromechanical systems.

3.1.12 *sacrificial layer*, *n*—in a surface-micromachining process, the layer fabricated between the mechanical layer and the underlying layer. This layer is removed after fabrication. If

[1] This test method is under the jurisdiction of ASTM Committee E08 on Fatigue and Fracture and is the direct responsibility of Subcommittee E08.05 on Cyclic Deformation and Fatigue Crack Formation.

Current edition approved Oct. 10, 2002. Published November 2002.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

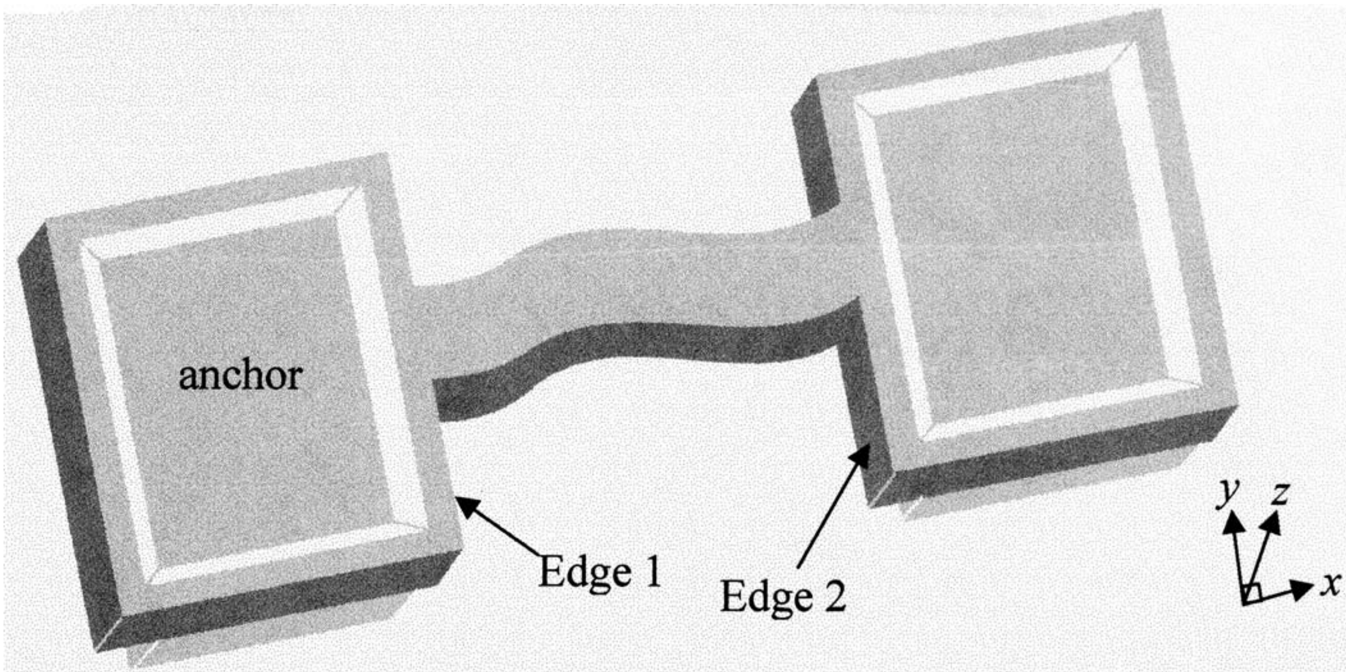
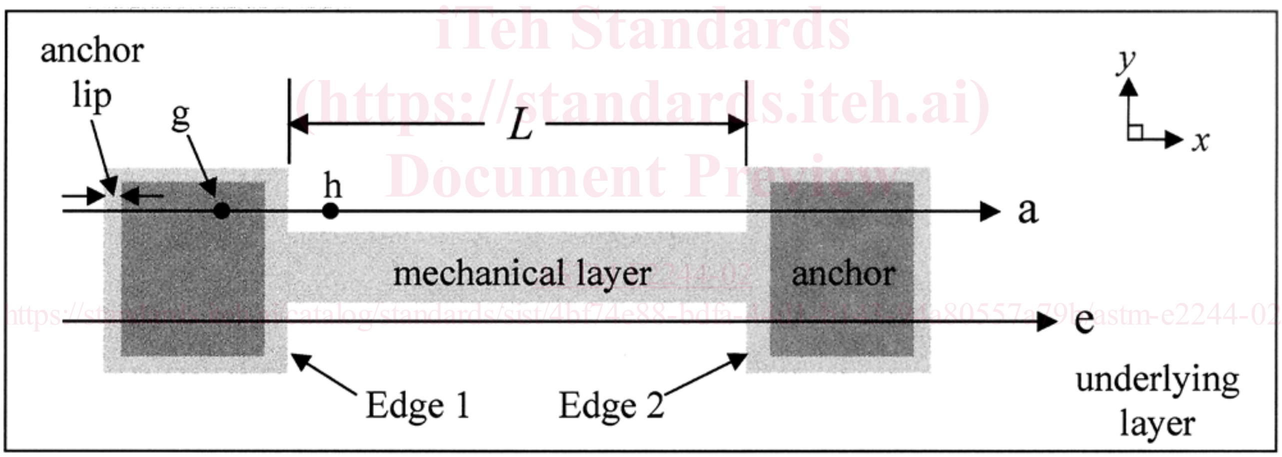


FIG. 1 Three-Dimensional View of Surface-Micromachined Fixed-Fixed Beam



NOTE 1—The underlying layer is beneath this test structure.

NOTE 2—The mechanical layer is included in both the light and dark gray areas.

NOTE 3—The dark gray areas (the anchors) are the designed cuts in the sacrificial layer. This is where the mechanical layer contacts the underlying layer.

NOTE 4—The light gray area is suspended in air after fabrication.

NOTE 5—The 2-D data traces (“a” and “e”) are used to ensure alignment.

NOTE 6—A 2-D data trace (“a” or “e”) is used to determine *L*.

FIG. 2 Top View of Fixed-Fixed Beam in Fig. 1

cuts are designed in this sacrificial layer (as shown in Fig. 2), an anchor is created allowing the mechanical layer to contact the underlying layer in that region.

3.1.13 *substrate*, *n*—the thick, starting material in a MEMS fabrication process.

3.1.14 *support region*, *n*—in a bulk-micromachining process, the region that marks the end of the suspended structure. This region is suspended in air, attached to the substrate, or both.

3.1.15 *surface micromachining*, *adj*—a MEMS fabrication process where thin, sacrificial layers are removed, which can create structures suspended in air.

3.1.16 *test structure*, *n*—a structure (such as, a fixed-fixed beam or cantilever) that is used to extract information (such as, the residual strain or the strain gradient of a layer) about a fabrication process.

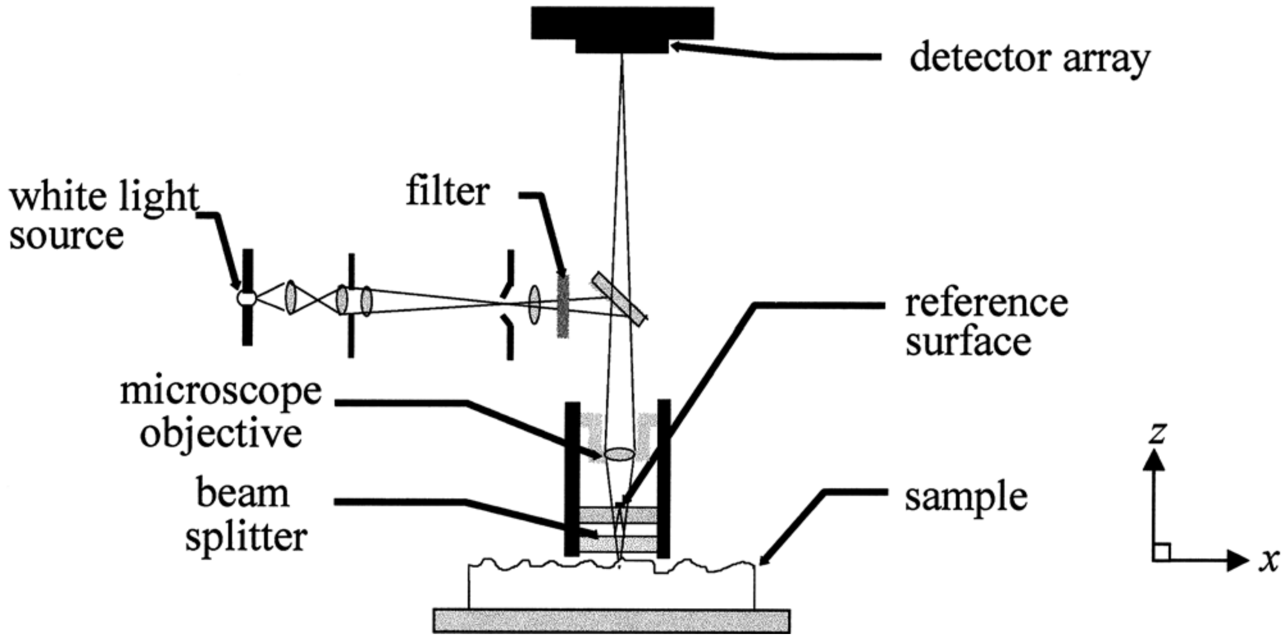


FIG. 3 Sketch of Optical Interferometer

3.1.17 *transitional edge*, *n*—an edge of a MEMS structure (such as Edge "1" in Fig. 2) that is characterized by a distinctive out-of-plane vertical displacement (as shown in Fig. 4).

3.1.18 *underlying layer*, *n*—in a surface-micromachining process, the layer directly beneath the mechanical layer after the sacrificial layer is removed.

3.2 *Symbols:*

3.2.1 *For Calibration*:

cal-x = the *x*-calibration factor of the interferometer for the given combination of lenses

cal-y = the *y*-calibration factor of the interferometer for the given combination of lenses

cal-z = the *z*-calibration factor of the interferometer for the given combination of lenses

cert = the certified value of the double-sided step height standard

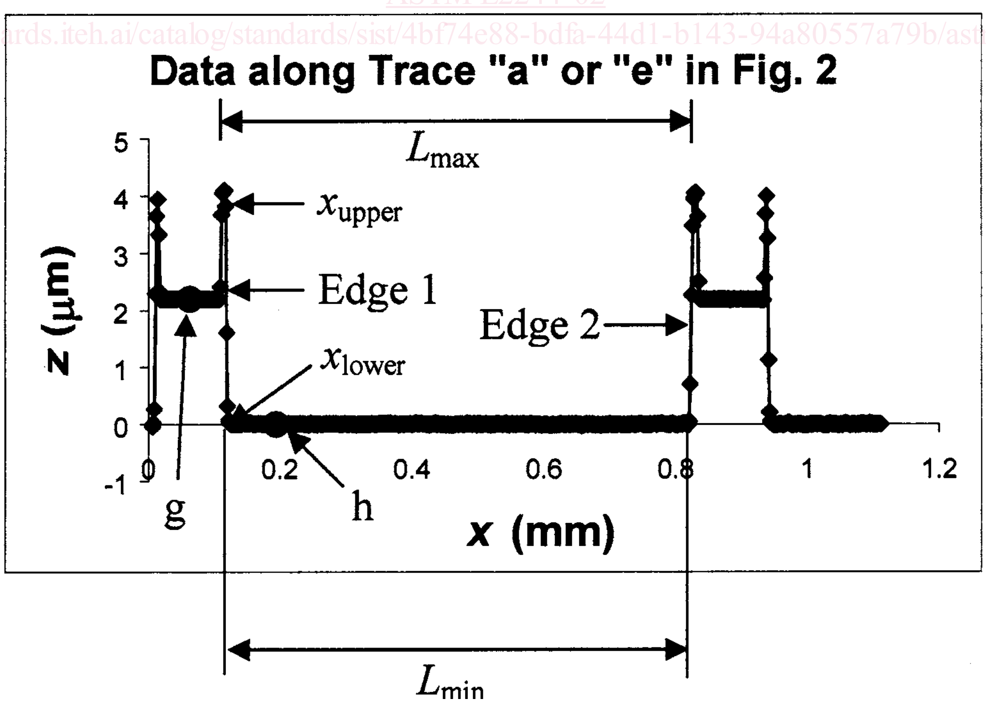


FIG. 4 2-D Data Trace Used to Find $x1_{min}$, $x1_{max}$, $x2_{min}$, and $x2_{max}$

inter-x = the interferometer's maximum field of view in the *x*-direction for the given combination of lenses

inter-y = the interferometer's maximum field of view in the *y*-direction for the given combination of lenses

mean = the mean value of the step-height measurements (on the double-sided step height standard) used to calculate *cal-z*

ruler-x = the interferometer's maximum field of view in the *x*-direction for the given combination of lenses as measured with a 10-μm grid ruler

ruler-y = the interferometer's maximum field of view in the *y*-direction for the given combination of lenses as measured with a 10-μm grid ruler

3.2.2 *For Alignment*:

$x1_{lower}$ = the *x*-data value along Edge "1" (such as shown in Fig. 4) locating the lower part of the transition

$x1_{upper}$ = the *x*-data value along Edge "1" (such as shown in Fig. 4) locating the upper part of the transition

$x2_{lower}$ = the *x*-data value along Edge "2" (such as shown in Fig. 4) locating the lower part of the transition

$x2_{upper}$ = the *x*-data value along Edge "2" (such as shown in Fig. 4) locating the upper part of the transition

x_{lower} = the *x*-data value along the transitional edge of interest locating the lower part of the transition (see Fig. 4)

x_{upper} = the *x*-data value along the transitional edge of interest locating the upper part of the transition (see Fig. 4)

3.2.3 *For In-plane Length Measurement*:

L = the in-plane length measurement

L_{max} = the maximum in-plane length measurement

L_{min} = the minimum in-plane length measurement

sep = the average calibrated separation between two interferometric pixels (in either the *x*- or *y*-direction) as applies to a given measurement or $sep = (sep_1 + sep_2) / 2$

sep_1 = the average calibrated separation between two interferometric pixels at one end of the in-plane length measurement

sep_2 = the average calibrated separation between two interferometric pixels at the other end of the in-plane length measurement

$t_{support}$ = in a bulk-micromachining process, the thickness of the support region where it is intersected by the 2-D data trace of interest (such as, Trace "a" or "e" in Fig. X1.1, as shown in Fig. X1.2)

u_c = the combined standard uncertainty value (that is, the estimated standard deviation of the result)[3]

$x1_{max}$ = the smaller of the two *x* values ($x1_{lower}$ or $x1_{upper}$) used to calculate L_{max}

$x1_{min}$ = the larger of the two *x* values ($x1_{lower}$ or $x1_{upper}$) used to calculate L_{min}

$x2_{max}$ = the larger of the two *x* values ($x2_{lower}$ or $x2_{upper}$) used to calculate L_{max}

$x2_{min}$ = the smaller of the two *x* values ($x2_{lower}$ or $x2_{upper}$) used to calculate L_{min}

z_{upper} = the *z*-data value associated with x_{upper}

$z_{upper\text{-}t}$ = in a bulk-micromachining process, the value for *z* when the thickness of the support region, $t_{support}$, is subtracted from z_{upper}

3.2.4 *Discussion*—The symbols above are used throughout this test method. However, the letter "*D*" can replace the letter "*L*" in the symbols above when referring to in-plane deflection measurements. Also, when referring to *y* values, the letter "*y*" can replace the first letter in the symbols above that start with the letter "*x*."

4. Summary of Test Method

4.1 Any in-plane length measurement can be made if each end is defined by a transitional edge. To obtain the endpoints of the in-plane length measurement for a surface-micromachined structure, four steps are taken: (*1*) select four transitional edges, (*2*) obtain a 3-D data set, (*3*) ensure alignment, and (*4*) determine the endpoints. (This procedure is presented in Appendix X1 for a bulk-micromachined structure.)

4.2 At the transitional edges defining L, the endpoints are $x1_{min}$, $x1_{max}$, $x2_{min}$, and $x2_{max}$. L_{min} and L_{max} are calculated from these values. L is the average of L_{min} and L_{max}.

4.3 Alternatively for a surface-micromachining process, if the transitional edges that define L face the same way (for example, two right-hand edges) and have similar slopes and magnitudes, a different approach can be taken. Here, L is the positive difference between the endpoints $x1_{lower}$ and $x2_{lower}$ (or $x1_{upper}$ and $x2_{upper}$).

5. Significance and Use

5.1 In-plane length measurements are used in calculations of parameters, such as residual strain and Young's modulus.

5.2 In-plane deflection measurements are required for specific test structures. Parameters, including residual strain, are calculated given these in-plane deflection measurements.

6. Apparatus [4]

6.1 *Non-contact Optical Interferometer*, capable of obtaining a topographical 3-D data set and has software that can export a 2-D data trace. Fig. 3 is a sketch of a suitable non-contact optical interferometer. However, any non-contact optical interferometer that has pixel-to-pixel spacings as specified in Table 1 and that is capable of performing the test procedure with a vertical resolution less than 1 nm is permitted. The interferometer must be capable of measuring step heights from 0.1 nm to at least 10 μm higher than the step height to be measured.

TABLE 1 Interferometer Pixel-to-Pixel Spacing Requirements

Magnification, ×	Pixel-to-pixel spacing, μm
5	< 1.57
10	< 0.83
20	< 0.39
40	< 0.21
80	< 0.11

[3] Taylor, B. N. and Kuyatt, C. E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," *NIST Technical Note 1297*, National Institute of Standards and Technology, September 1994.

[4] The same apparatus is used as in Test Method E 2245 and Test Method E 2246.