



Designation: E2244 – 05

Standard Test Method for In-Plane Length Measurements of Thin, Reflecting Films Using an Optical Interferometer¹

This standard is issued under the fixed designation E2244; 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 optical 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:²

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.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E2245 Test Method for Residual Strain Measurements of Thin, Reflecting Films Using an Optical Interferometer

E2246 Test Method for Strain Gradient Measurements of Thin, Reflecting Films Using an Optical Interferometer

3. Terminology

3.1 Definitions:

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

3.1.2 *3-D data set, n*—a three-dimensional group of points with a topographical z -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 a structural layer is intentionally attached to its underlying layer.

3.1.4 *anchor lip, n*—in a surface-micromachining process, the freestanding extension of the structural layer of interest around the edges of the anchor to its underlying layer.

3.1.4.1 *Discussion*—In some processes, the width of the anchor lip may be zero.

3.1.5 *bulk micromachining, adj*—a MEMS fabrication process where the substrate is removed at specified locations.

3.1.6 *cantilever, n*—a test structure that consists of a freestanding beam that is fixed at one end.

3.1.7 *fixed-fixed beam, n*—a test structure that consists of a freestanding beam that is fixed at both ends.

3.1.8 *in-plane length (or deflection) measurement, n*—the experimental determination of the straight-line distance between two transitional edges in a MEMS device.

3.1.8.1 *Discussion*—This length (or deflection) measurement is made parallel to the underlying layer (or the xy -plane of the interferometer).

3.1.9 *interferometer, n*—a non-contact optical instrument used to obtain topographical 3-D data sets.

3.1.9.1 *Discussion*—The height of the sample is measured along the z -axis of the interferometer. The interferometer's x -axis is typically aligned parallel or perpendicular to the transitional edges to be measured.

3.1.10 *MEMS, adj*—microelectromechanical system.

3.1.11 *microelectromechanical systems, adj*—in general, this term is used to describe micron-scale structures, sensors, actuators or the technologies used for their manufacture (such as, silicon process technologies), or combinations thereof.

3.1.12 *sacrificial layer, n*—a single thickness of material that is intentionally deposited (or added) then removed (in whole or in part) during the micromachining process, to allow freestanding microstructures.

3.1.13 *structural layer, n*—a single thickness of material present in the final MEMS device.

3.1.14 *substrate, n*—the thick, starting material (often single crystal silicon or glass) in a fabrication process that can be used to build MEMS devices.

3.1.15 *support region, n*—in a bulk-micromachining process, the area that marks the end of the suspended structure.

3.1.16 *surface micromachining, adj*—a MEMS fabrication process where micron-scale components are formed on a substrate by the deposition (or addition) and removal (in whole or in part) of structural and sacrificial layers.

3.1.17 *test structure, n*—a component (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.

3.1.18 *transitional edge, n*—the side of a MEMS structure that is characterized by a distinctive out-of-plane vertical displacement as seen in an interferometric 2-D data trace.

3.1.19 *underlying layer, n*—the single thickness of material directly beneath the material of interest.

3.1.19.1 *Discussion*—This layer could be the substrate.

3.2 Symbols:

3.2.1 For Calibration:

σ_{xcal} = the standard deviation in a ruler measurement in the interferometer's x -direction for the given combination of lenses

σ_{yca} = the standard deviation in a ruler measurement in the interferometer's y -direction for the given combination of lenses

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

$inter_x$ = 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- μ m grid (or finer 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- μ m grid (or finer grid) ruler

3.2.2 For Alignment:

xI_{lower} = the x -data value along Edge "1" locating the lower part of the transitional edge

xI_{upper} = the x -data value along Edge "1" locating the upper part of the transitional edge

$x2_{lower}$ = the x -data value along Edge "2" locating the lower part of the transitional edge

$x2_{upper}$ = the x -data value along Edge "2" locating the upper part of the transitional edge

x_{lower} = the x -data value along the transitional edge of interest locating the lower part of the transition

x_{upper} = the x -data value along the transitional edge of interest locating the upper part of the transition

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 interferometric 2-D data trace of interest

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

u_L = the component in the combined standard uncertainty calculation that is due to the uncertainty in the calculated length

u_{xcal} = the component in the combined standard uncertainty calculation that is due to the uncertainty of the calibration in the x -direction

u_{xres} = the component in the combined standard uncertainty calculation that is due to the resolution of the interferometer in the x -direction

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

xI_{min} = the larger of the two x values (xI_{lower} or xI_{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}

x_{res} = the resolution of the interferometer in the x -direction

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

$z_{upper-t}$ = 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 For Round Robin Measurements:

ΔL = for the given value of L_{des} , L_{ave} minus L_{des}

ΔL_{ave} = the average value of ΔL over the given range of L_{des} values

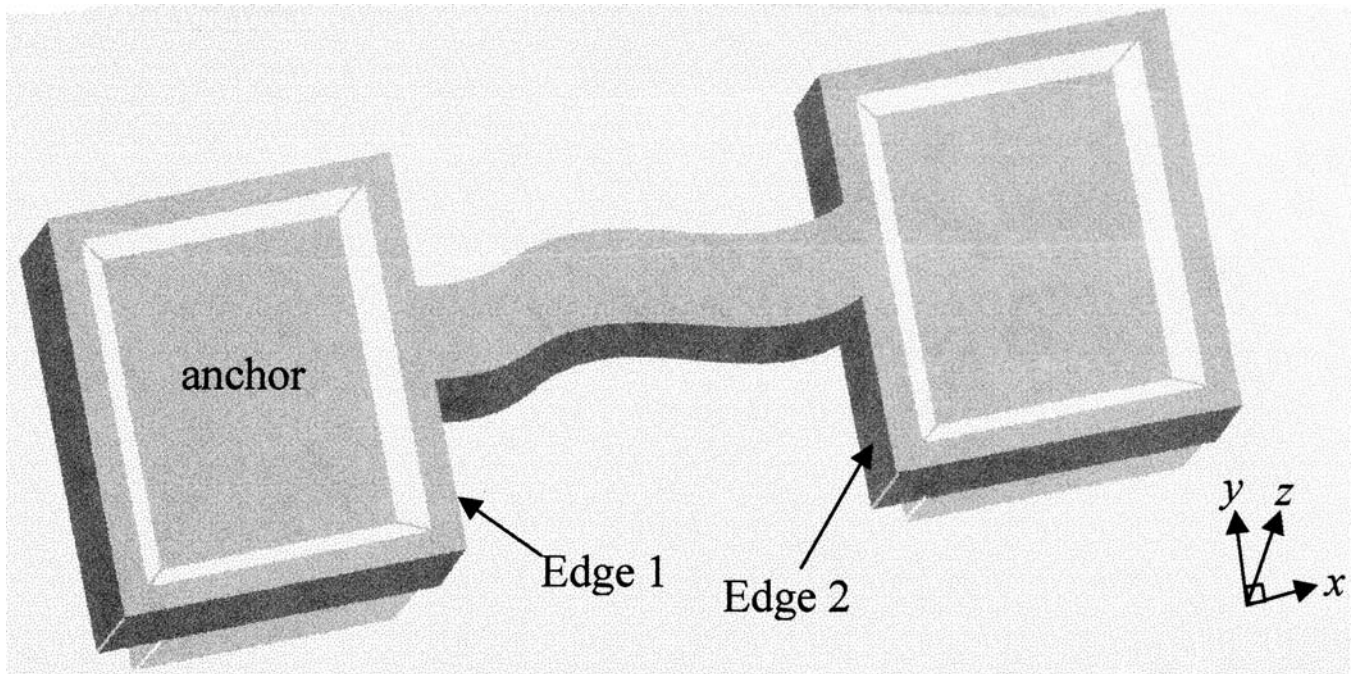
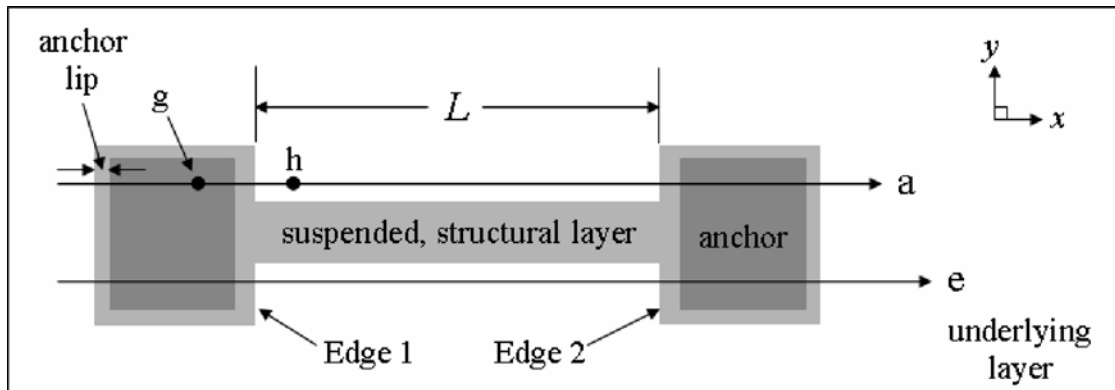


FIG. 1 Three-Dimensional View of Surface-Micromachined Fixed-Fixed Beam



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

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

NOTE 3—The light gray area is suspended in air after fabrication.

NOTE 4—The dark gray areas (the anchors) are the designed cuts in the sacrificial layer. This is where the structural layer contacts the underlying layer.

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

L_{ave} = the average in-plane length value for the reproducibility or repeatability measurements. It is equal to the sum of the L values divided by n

L_{des} = the design length

mag = the magnification used for the measurement

n = the number of reproducibility or repeatability measurements

u_{cave} = the average combined standard uncertainty value for the reproducibility or repeatability measurements. It is equal to the sum of the u_c values divided by n

3.2.5 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. Consider the surface-micromachined fixed-fixed beam shown in Figs. 1 and 2. An optical interferometer (such as shown in Fig. 3) is used to obtain a topographical 3-D data set. A 2-D data trace (such as

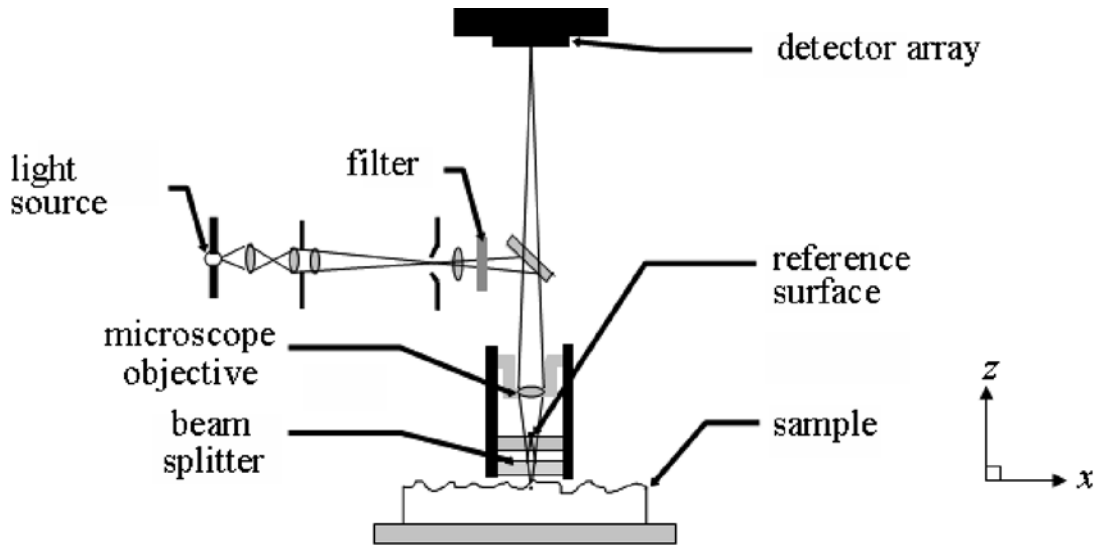


FIG. 3 Schematic of an Optical Interferometer

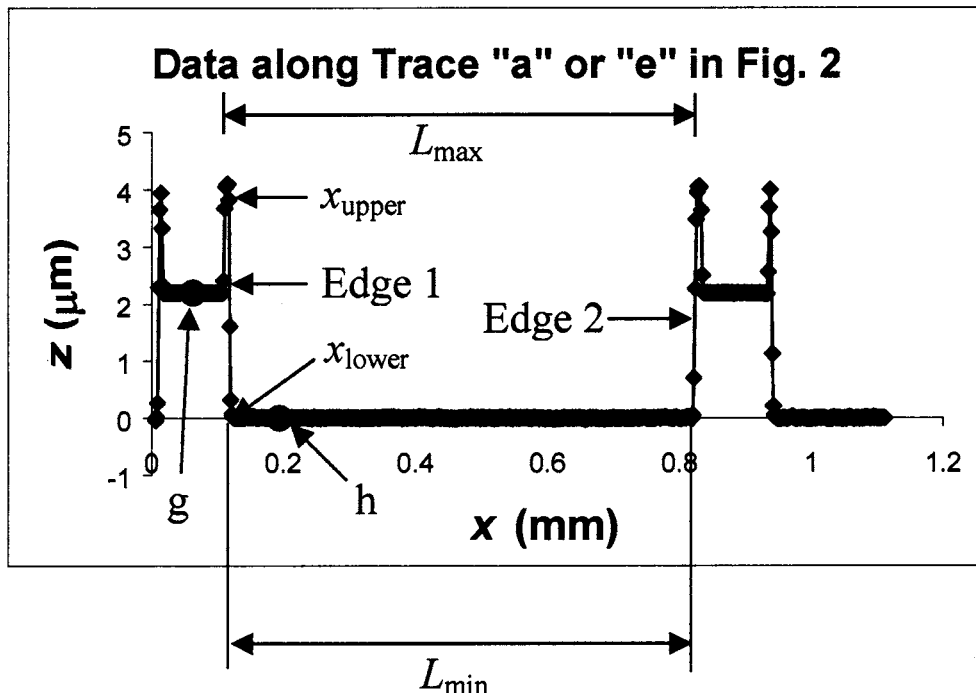


FIG. 4 2-D Data Trace Used to Find $x1_{min}$, $x1_{max}$, $x2_{min}$, and $x2_{max}$

TABLE 1 Interferometer Pixel-to-Pixel Spacing Requirements

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

shown in Fig. 4) is extracted from this 3-D data set for the analysis of the transitional edges of interest.

4.2 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 or a surface-micromachined structure with transitional edges greater than 8 μm in height.)

4.3 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} .

4.4 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 $x2_{upper}$).