

SEMI MS2-0307

TEST METHOD FOR STEP-HEIGHT MEASUREMENTS OF THIN, REFLECTING FILMS USING AN OPTICAL INTERFEROMETER

This standard was technically approved by the global MEMS Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on November 21, 2006. It was available at www.semi.org in February 2007 and on CD-ROM in March 2007.

1 Purpose

1.1 This test method enables the determination of step-height measurements of thin films. Step-height measurements can be used to determine thin-film thickness values. Thickness measurements¹ are an aid in the design and fabrication of MEMS devices and can be used to obtain thin film material parameters, such as Young's modulus.

2 Scope

2.1 This test method presents a procedure for measuring step-heights of thin, reflecting films using step-height test structures. It applies only to films, such as those found in microelectromechanical system (MEMS) materials, which can be imaged using an optical interferometer.

2.2 A non-contact optical interferometer is used with the capability of obtaining topographical 3-D data sets.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 All platforms involved in step-height measurements must be reflective.

NOTE 1: If in doubt as to whether or not the platforms are reflective, the chip is typically covered with approximately 8 nm of chromium followed by approximately 150 nm of gold. The chromium helps the gold adhere to the chip while the gold coverage provides a smooth, reflective surface enabling accurate interferometric measurements. This post-processing is considered outside the scope of this standard.

4 Referenced Standards and Documents

4.1 ASTM Standards²

E 2244 — Standard Test Method for In-Plane Length Measurements of Thin, Reflecting Films Using an Optical Interferometer

E 2245 — Standard Test Method for Residual Strain Measurements of Thin, Reflecting Films Using an Optical Interferometer

E 2246 — Standard Test Method for Strain Gradient Measurements of Thin, Reflecting Films Using an Optical Interferometer

E 2444 — Standard Terminology Relating to Measurements Taken on Thin, Reflecting Films. Referenced definitions reprinted, with permission, from the Annual Book of ASTM Standards, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

1 Gupta, R. K., Osterberg, P. M., and Senturia, S. D., "Material Property Measurements of Micromechanical Polysilicon Beams," *Micro lithography and Metrology in Micromachining II*, SPIE, Vol 2880, October 14-15, 1996, pp. 39-45.

Jensen, B. D., de Boer, M. P., Masters, N. D., Bitsie, F., and LaVan, D. A., "Interferometry of Actuated Microcantilevers to Determine Material Properties and Test Structure Nonidealities in MEMS," *Journal of Microelectromechanical Systems*, Vol 10, September 2001, pp. 336-346.

Marshall, J. C., "New Optomechanical Technique for Measuring Layer Thickness in MEMS Processes," *Journal of Microelectromechanical Systems*, Vol 10, March 2001, pp. 153-157.

2 ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, USA; Telephone: 610-832-9585; Fax: 610-832-9555; Website: <http://www.astm.org>

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *CMOS* — Complementary Metal Oxide Semiconductor

5.1.2 *MEMS* — Micro Electro-Mechanical System

5.2 Definitions

5.2.1 *2-D data trace* — 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 [ASTM E 2444].

5.2.2 *3-D data set* — a three-dimensional group of points with a topographical *z*-value for each (*x*, *y*) pixel location within the interferometer's field of view [ASTM E 2444].

5.2.3 *bulk micromachining* — a MEMS fabrication process where the substrate is removed at specified locations [ASTM E 2444].

5.2.4 *interferometer* — a non-contact optical instrument used to obtain topographical 3-D data sets [ASTM E 2444].

NOTE 2: 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.

5.2.5 *microelectromechanical systems* — in general, this term is used to describe micron-scale structures, sensors, and actuators or the technologies used for their manufacture (such as, silicon process technologies), or both [ASTM E 2444].

5.2.6 *platform height* — the distance in the *z*-direction that a flat, processed surface of interest is from a designated flat, processed reference surface.

5.2.7 *reference platform* — the flat, processed surface that is used to level and zero the interferometric measurements in the *z*-direction.

5.2.8 *sacrificial layer* — 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 [ASTM E 2444].

5.2.9 *step height* — the distance in the *z*-direction that an initial, flat, processed surface (or platform) is to a final, flat, processed surface (or platform).

NOTE 3: It is recommended that the two platforms of interest be designed next to each other.

5.2.10 *structural layer* — a single thickness of material present in the final MEMS device [ASTM E 2444].

5.2.11 *substrate* — the thick, starting material (often single crystal silicon or glass) in a fabrication process that can be used to build MEMS devices [ASTM E 2444].

5.2.12 *surface micromachining* — 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 [ASTM E 2444].

5.2.13 *test structure* — 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 [ASTM E 2444].

5.2.14 *thickness* — the height in the *z*-direction of one or more designated thin-film layers.

5.2.15 *transitional edge* — 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 [ASTM E 2444].

5.2.16 *Young's modulus* — a material parameter indicative of how elastic (or bendable) the material is.

NOTE 4: This is also called the elastic modulus.

5.3 Symbols

5.3.1 For Calibration

5.3.1.1 σ_{cert} — the certified one sigma uncertainty of the certified step height standard.

5.3.1.2 cal_z — the *z*-calibration factor of the interferometer for the given combination of lenses.

5.3.1.3 *cert* — the certified value of the double-sided step height standard.

5.3.1.4 z_{drift} — the calibrated positive difference between the average of the six calibration measurements taken before the data session (at the same location on the step-height standard) and the average of the six calibration measurements taken after the data session (at the same location on the step-height standard).

5.3.1.5 z_{perc} — the percent quoted by the interferometer manufacturer (typically less than 3%) for the maximum deviation from linearity of the data scan over the total scan range divided by 1% such that it is unitless.

5.3.1.6 z_{repeat} — the maximum of two calibrated values; one of which is the positive calibrated difference between the minimum and maximum values of the six calibration measurements taken before the data session (at the same location on the step height standard) and the other is the positive calibrated difference between the minimum and maximum values of the six calibration measurements taken after the data session (at the same location on the step height standard).

5.3.1.7 $\bar{z}$ — the calibrated average of the twelve calibration measurements taken before and after the data session at the same location on the step height standard.

5.3.1.8 $\bar{z}_6$ — the calibrated average of the six calibration measurements from which z_{repeat} is found.

5.3.1.9 $\bar{z}_{same}$ — the uncalibrated average of the twelve calibration measurements, taken before and after the data session at the same location on the step height standard, used to calculate cal_z .

5.3.2 For Step-height Measurements and Calculations

5.3.2.1 $platNrD$ — the average of the calibrated reference platform height measurements taken from multiple data traces in one 3-D data set, where N is the test structure number (“1,” “2,” “3,” etc.), r indicates it is from a reference platform, and D directionally indicates which reference platform (using the compass indicators “N,” “S,” “E,” or “W” where “N” refers to the reference platform designed closest to the top of the chip).

5.3.2.2 $platNrDt$ — a calibrated reference platform height measurement from one data trace, where N is the test structure number (“1,” “2,” “3,” etc.), r indicates it is from a reference platform, D directionally indicates which reference platform (using the compass indicators “N,” “S,” “E,” or “W” where “N” refers to the reference platform designed closest to the top of the chip), and t is the data trace (“a,” “b,” “c,” etc.) being examined.

5.3.2.3 $platNX$ — the calibrated platform height measurement, where N is the test structure number (“1,” “2,” “3,” etc.) and X is the capital letter (or “r” is used if it is the reference platform) associated with the platform (“A,” “B,” “C,” etc.) as lettered starting with “A” for the platform closest to $platNrW$ or $platNrS$.

5.3.2.4 $platNXt$ — a calibrated platform height measurement from one data trace, where N is the test structure number (“1,” “2,” “3,” etc.), X is the capital letter associated with the platform (“A,” “B,” “C,” etc.) as lettered starting with “A” for the platform closest to $platNrW$ or $platNrS$, and t is the data trace (“a,” “b,” “c,” etc.) being examined.

5.3.2.5 $stepN_XM_Y$ — the calibrated step height measurement taken from two 3-D data sets, which is equal to the final platform height minus the initial platform height, where the step is from the initial platform to the final platform and where X is the capital letter associated with the initial platform from test structure number N , and Y is the capital letter associated with the final platform from test structure number M .

5.3.2.6 $stepN_{XY}$ — the average of the calibrated step height measurements taken from multiple data traces in one 3-D data set, where N is the number associated with the test structure, X is the capital letter associated with the initial platform (or “r” is used if it is the reference platform), Y is the capital letter associated with the final platform (or “r” is used if it is the reference platform), and the step is from the initial platform to the final platform.

5.3.2.7 $stepN_{XYt}$ — a calibrated step height measurement from one data trace in one 3-D data set, where N is the number associated with the test structure, X is the capital letter associated with the initial platform (or “r” is used if it is the reference platform), Y is the capital letter associated with the final platform (or “r” is used if it is the reference platform), t is the data trace (“a,” “b,” “c,” etc.) being examined, and the step is from the initial platform to the final platform.

5.3.3 For Combined Standard Uncertainty Calculations

5.3.3.1 u_c — the combined standard uncertainty value (i.e., the estimated standard deviation of the result).

5.3.3.2 u_{cert} — the component in the combined standard uncertainty calculation that is due to the uncertainty of the value of the step-height standard.

5.3.3.3 u_{drift} — the uncertainty of a measurement due to the amount of drift during the data session.

5.3.3.4 u_{linear} — the uncertainty of a measurement due to the deviation from linearity of the data scan.

5.3.3.5 u_{platNX} — the component in the combined standard uncertainty calculation for step-height measurements obtained from two 3-D data sets that is due to the uncertainty of the platform height measurement for $platNX$.

5.3.3.6 u_{repeat} — the uncertainty of a measurement due to the repeatability of a measurement.

5.3.3.7 $u_{W_{platNX}}$ — the component in the combined standard uncertainty calculation for platform-height measurements that is due to the measurement uncertainty across the width of $platNX$.

5.3.3.8 $u_{W_{step}}$ — the component in the combined standard uncertainty calculation for step-height measurements that is due to the measurement uncertainty of the step height across the width of the step.

6 Summary of Method

6.1 This test method can be used to obtain step height measurements ($stepN_{XY}$ or $stepN_XM_Y$) and their combined standard uncertainty values, u_c , using step-height test structures (such as shown in Figures 1–4). An optical interferometer (a schematic of which is shown in Figure 5) is used to obtain one or two topographical 3-D data sets. Two-D data traces along the top of the test structure(s) (such as shown in Figure 6) are extracted from the 3-D data set(s). Data averages from the 2-D data traces along the pertinent platforms, including the reference platform(s), are recorded.

6.2 *With One 3-D Data Set (recommended due to the lower values for u_c)* — For each 2-D data trace, the difference in the platform heights involved in the step are calculated. The step height, $stepN_{XY}$, is the average of these values from the different 2-D data traces. The value for u_c for this measurement is determined as given in Appendix 1.

6.3 *With Two 3-D Data Sets* — For each 3-D data set the reference platform height is calculated as the average of the reference platform height measurements taken from the 2-D data traces. For each 3-D data set, a platform height measurement is the average of the platform measurements from the 2-D data traces minus the just calculated reference platform height from that 3-D data set. The step height, $stepN_XM_Y$, is the difference in height between the two platforms measured in the separate 3-D data sets. (This assumes that the reference platform in each 3-D data set is comprised of the same design layers.) The equations used to determine u_c for this measurement are given in Appendix 1.

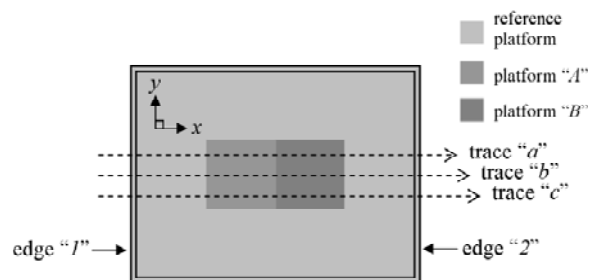


Figure 1
An Ideal Step-Height Test Structure Indicating the Location of Some 2-D Data Traces

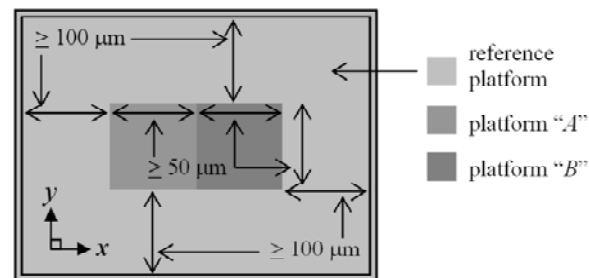


Figure 2
Dimensional Considerations for the Ideal Step-Height Test Structure in Figure 1

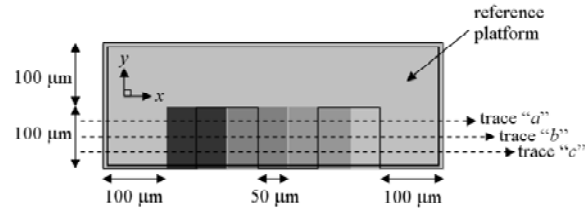


Figure 3

A Step-Height Test Structure with Multiple Steps Indicating the Location of Some 2-D Data Traces

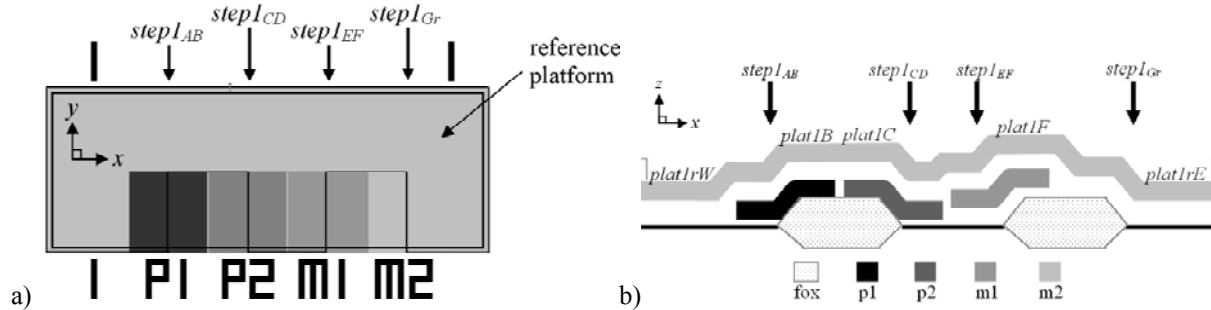


Figure 4

For Step-Height Test Structure 1 in Figure 3 a) a Design Rendition and b) a Cross Section

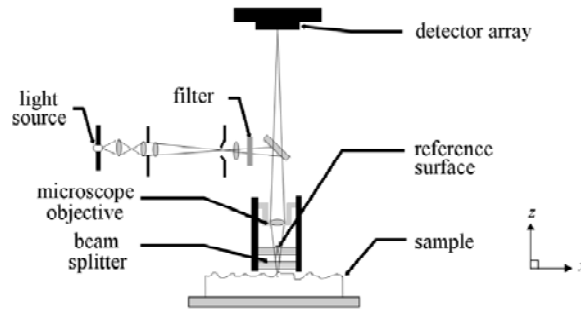


Figure 5

Schematic of an Optical Interferometer

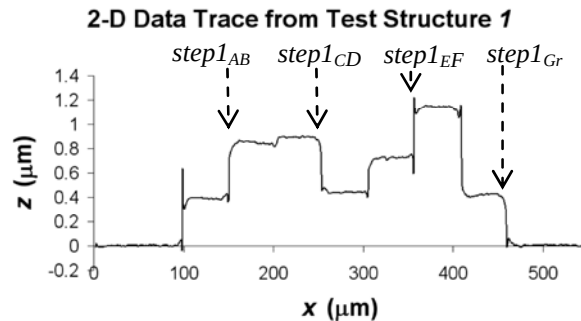


Figure 6

Sample 2-D Data Trace along the Top of the Step-Height Test Structure in Figure 3 and Figure 4