THE MEMS 5-IN-1 TEST CHIPS (REFERENCE MATERIALS 8096 AND 8097)[1]

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INTRODUCTION

This paper presents an overview of the Microelectromechanical Systems (MEMS) [1] 5-in-1 Reference Material (RM), which is a single test chip with test structures from which material and dimensional properties are obtained using five documentary standard test methods (from which its name is derived). Companies can validate their use of the documentary standard test methods by comparing their in-house measurements taken on the RM with the National Institute of Standards and Technology (NIST) measurements taken on the same test structures. In addition, the MEMS 5-in-1 can be used to:

- Characterize or validate a process,
- Take local measurements of customer-designed structures,
- Compare measurements meaningfully between laboratories on similarly (or differently) processed test structures (e.g., to facilitate communications between suppliers and customers),
- Trouble-shoot a process, and
- Calibrate an instrument.

Reference values are given for an RM 8096 chip used at NIST for stability studies.

It takes a considerable amount of time to develop an RM and NIST would be willing to help customers develop their own. Alternatively, they are available for purchase from the NIST SRM Program Office [1].

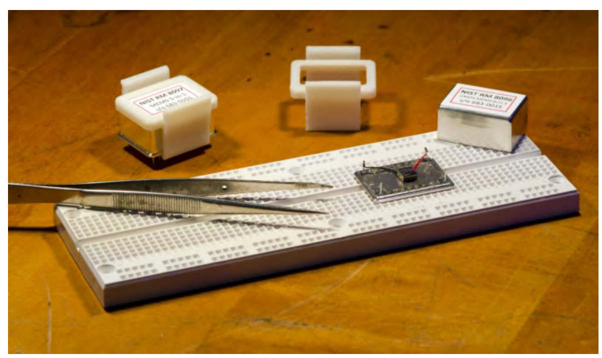

FIGURE 1. A MEMS 5-in-1 Reference Material (RM 8096).

THE MEMS 5-IN-1

The MEMS 5-in-1 is a reference device sold as a NIST Reference Material (RM) that is used to measure dimensional and material properties. There are two RM chips (8096 and 8097). RM 8096, as seen in Figures 1 and 2, was fabricated on a multi-user 1.5 µm complementary metal oxide semiconductor (CMOS)

[1] Official contributions by the National Institute of Standards and Technology (NIST) are not subject to copyright.

[1] MEMS are also referred to as microsystems technology (MST) and micromachines.

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process [2][2] followed by a bulk-micromachining etch. For this RM, the material properties of the composite oxide layer are reported on the Report of Investigation, which accompanies each unit of the RM. RM 8097, as seen in Figure 2, was fabricated using a polysilicon multi-user surface-micromachining MEMS process with a backside etch [3]. For this RM, the material properties of the first or second polysilicon layer are reported on the Report of Investigation.

The Five Standard Test Methods

Five standard test methods are used to obtain the properties of the MEMS 5-in-1 test chip. These test methods are for measuring Young's modulus [4], step height [5], residual strain [6], strain gradient [7], and in-plane length [8]. The Young's modulus and step height test methods were published by the Semiconductor Equipment and Materials International (SEMI) and the residual strain, strain gradient, and in-plane length test methods were published by the American Society for Testing and Materials (ASTM) International. Each of the five standard test methods includes round robin precision and bias data.

Eight Properties Reported

Eight properties are typically reported on the Report of Investigation. The five properties mentioned in the previous section are reported plus three more properties: residual stress, stress gradient, and beam thickness. Residual stress and stress gradient are found from calculations in the Young's modulus test method, and the beam thickness is obtained using the step height test method in an electro-physical technique [9] for RM 8096 and in an opto-mechanical technique [10] for RM 8097, as described in the NIST Special Publication SP 260-177 [11]. Therefore, five standard test methods are used to obtain eight properties.

[2] Commercial equipment, instruments, or processes may be identified. This does not imply recommendation or endorsement by the National Institute of Standards and Technology (NIST), nor does it imply that the equipment, instruments, or processes are the best available for the purpose.

Instrumentation

As specified in the respective measurement methods [4-8,11-12], the Young's modulus measurements are taken with an optical vibrometer, stroboscopic interferometer, or comparable instrument. The measurements using the other four test methods are taken with an optical interferometer and stylus profilometer, or comparable instruments.

The MEMS Calculator

The MEMS Calculator website (Standard Reference Database 166) [13] contains data analysis sheets for calculating the MEMS properties. This website is accessible via the NIST Data Gateway (http://srdata.nist.gov/gateway/) with the keyword "MEMS Calculator." Initially, the measurements are input on the pertinent data analysis sheet; then the "Calculate and Verify" button is clicked to obtain the results. A verification section is at the bottom of each data analysis sheet. If all the pertinent boxes in this section say "ok," then the data are verified. Otherwise, the specific issue is addressed by modifying the inputs and recalculating.

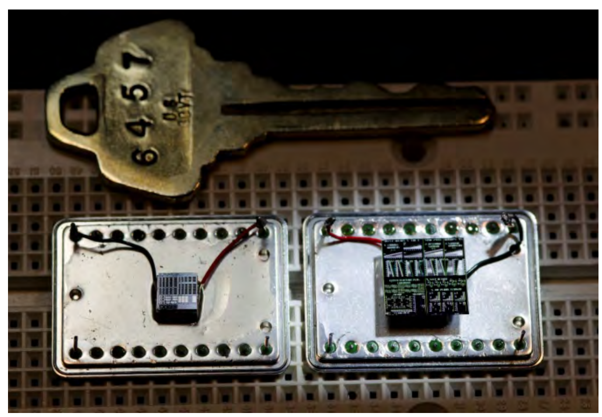

FIGURE 2. RM 8096 (left) and RM 8097 (right).

Accompanying Material

Each MEMS 5-in-1 is accompanied by a Report of Investigation, the pertinent data analysis sheets [13], the five standard test methods [4-8], and the NIST SP 260-177 [11]. The data analysis sheets that accompany the MEMS 5-in-1 identify the specific test structures for measurement and include the raw data used at NIST to obtain the measurements on the Report of Investigation. The SP 260 is a comprehensive user's guide for the MEMS 5-in-1. It specifies that the applicable SEMI or ASTM standard test methods be used to take the measurements on the same test structures that the NIST measurements were taken. It also recommends a method by which the user's measurements can be compared with the NIST-measured values on the Report of Investigation in order to validate their use of the documentary standard test methods.

THE REPORT OF INVESTIGATION

The RM Report of Investigation provides a NIST reference value for each property. A NIST reference value is a best estimate of the true value provided on a NIST Certificate/Certificate of Analysis/Report of Investigation where all known or suspected sources of bias have not been fully investigated by NIST [14]. Table 1 includes example NIST reference values for an RM 8096 monitor chip used at NIST for stability studies. An effective value is reported when there are deviations from the ideal geometry or composition of the measured test structure(s) [11].

TABLE 1. Example NIST Reference Values for RM 8096.

Measurement[a]	**NIST Reference Value ± Expanded Uncertainty (for k=2 for ≈95 % confidence)**
1. Effective Young's modulus, E	56.6 GPa ± 17.8 GPa
2. Effective residual strain, ε_r	$-2.83\times10^{-3} \pm 0.71\times10^{-3}$
3. Effective strain gradient, s_g	1101 m^{-1} ± 167 m^{-1}
4. Step height,[b] $step1_{AB}$	0.499 µm ± 0.108 µm
5. In-plane length,[c] L (at 25×)	202.2 µm ± 3.0 µm
6. Effective residual stress, σ_r	−160 MPa ± 67 MPa
7. Effective stress gradient, σ_g	62.3 TPa/m ± 18.9 TPa/m
8. Thickness, t_{SiO2}	2.65 µm ± 0.20 µm

[a] These measurements, except where noted, are for a composite oxide layer.

[b] This is a metal2-over-poly1 step from active area to field oxide. Other physical step height standards are available with lower uncertainty values and are recommended for calibrating instruments.

[c] The in-plane length measurement is taken between two metal2 lines.

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2. The RM 8096 chips were fabricated through MOSIS on the 1.5 µm On Semiconductor (formerly AMIS) CMOS process. The URL for the MOSIS website is http://www.mosis.com.

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13. The data analysis sheets, SP 260-177, and MEMS 5-in-1 details can be found at the MEMS Calculator website (Standard Reference Database 166) accessible via the NIST Data Gateway (http://srdta.nist.gov/gateway/) with the keyword "MEMS Calculator."
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Keywords

MEMS 5-in-1, MEMS Calculator, Reference Material, RM 8096, RM 8097, test chip