MEMS/MST Model Verification and Materials Parameter Extraction using MEMSPEC™-2000

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ABSTRACT

We describe the current status of the MEMSPEC-2000 MEMS/MST characterization system. This system has been designed to provide automated multi-domain measurements of a wide range of MEMS/MST devices. The system is capable of high resolution surface profiling across the whole surface of a wafer. It can also be used to study motion of micro devices, both in-plane and out-of-plane. The system uses non-contact laser probing and automated navigation across a wafer. The system is at present fully functional and being benchmarked against a wide variety of test devices.

INTRODUCTION

Unlike electron devices and integrated circuits in which only lumped electrical parameters are needed for circuit and device level modeling, MEMS/MST devices require the precise and simultaneous measurement of multi-domain parameters, often of widely dissimilar nature. In the case of purely mechanical microsystems, the parameters describing static and dynamic mechanical characteristics must be determined non-intrusively by using externally applied electrical stimulus. Other micromechanical devices, such as micro-opto-electromechanical systems require the simultaneous measurement of signals related to light emission or reflection. Likewise, fluidic devices require measurement of parameters describing hydrodynamic, hydrostatic and thermodynamic characteristics. In the case of Micro-Total-Analysis-Systems and Lab-on-a-Chip technologies, parameters describing chemical reaction kinetics and diffusion processes must also be measured.

Overall the complexity involved in the experimental study of MEMS/MST devices is far greater than that of solid state electronics in which multi-point electrical probing coupled to external electrical measurements are most of the time sufficient for determining the basic lumped and distributed surface parameters of a device. In the microelectrical domain, probe stations, waveform generators and current-voltage measurement equipment are all instruments used to implement a well established testing and modeling methodology based on lumped circuit models and on device simulators. Unlike the case of electron devices, at present there are not yet available well-established characterization methodologies for MEMS/MST devices. Since the availability of wafer and device level metrology and characterization techniques is paramount to the establishment of robust modeling methodologies, there is a pressing need for developing both equipment and methods for characterizing MEMS/MST devices in a systematic manner.

The intrinsic multi-domain and multi-parameter nature of MEMS/MST devices makes it convenient to have access to a new type of probing method for monitoring the behavior of microstructures that while providing sufficient measurement resolution in multiple domains, do not significantly disturb the measurands. Metrology of non-electrical parameters must be performed using non-contact techniques since the mechanical structures must be probed in a non-intrusive manner. Optical techniques are the first methodologies that qualify for probing microsystems. Optical microscopy coupled to interferometry is one of the techniques most readily available. Other techniques that use focused laser probes either operating as interferometers or in triangulation mode are also available. Among the most cost-effective techniques, optical triangulation stands out as capable of high throughput at adequate resolutions.

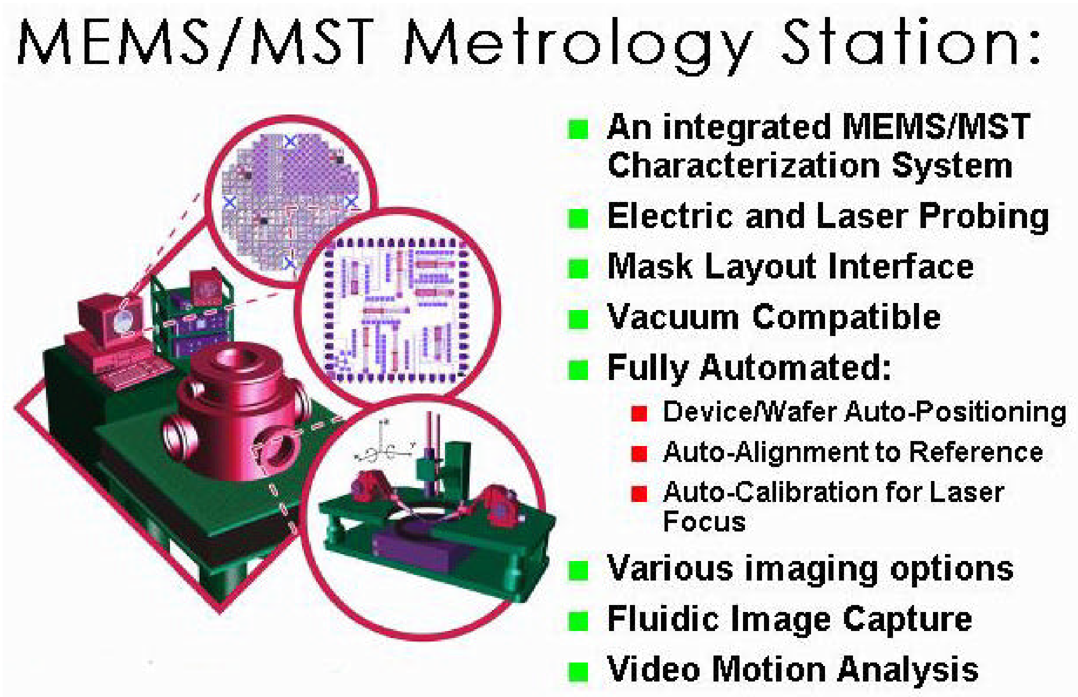

Fig. 1 MEMSPEC™-2000 automated parameter extraction tool for MEMS/MST devices.

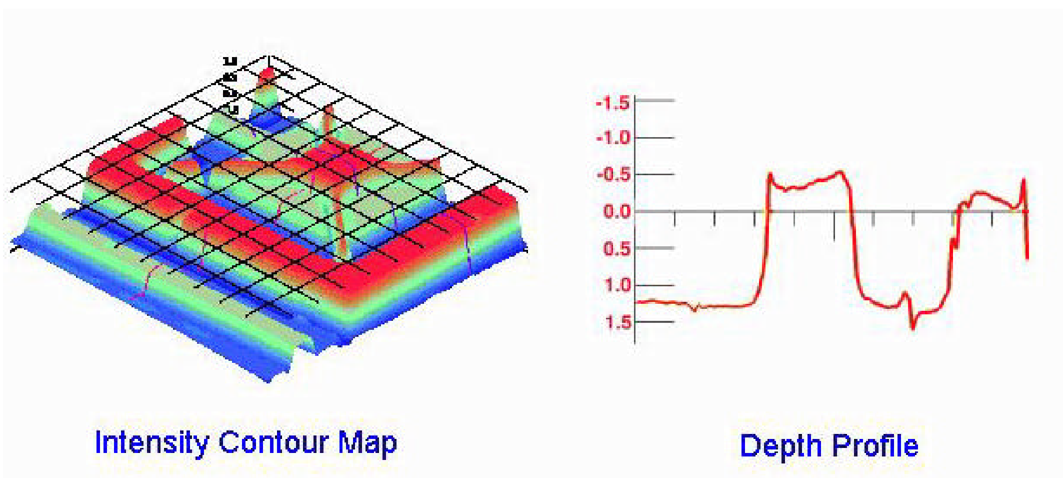

Fig. 2 Static Measurements performed on a suspended structure fabricated using MUMPS-12. The suspended mass is 20 um on the side and the support arms are 10 um. Measurements performed using MEMSPEC™-2000.

The present work analyzes requirements and describes automated model parameter extraction at wafer and device level using MEMSPEC™-2000, a recently introduced MEMS/MST metrology and characterization tool. The tool merges conventional electrical probing with non-contact optical techniques (Fig. 1). The MEMSPEC architecture implements a fully automated navigation routine having direct interface to mask layout files used to create the device, along with automatic alignment using reference marks recognition and various modes of non-contact optical probing. The tester can be directly interfaced to modeling software for performing materials parameters extraction using closed loop parameter extraction procedures. Young's Modulus can be obtained in fully automated mode across test structures present anywhere in the wafer. Resonant frequency measurements can be measured directly using the motion analysis features of the equipment. A number of examples of devices already characterized are presented below. Note the striking resemblance between the optical maps of the structures and conventional SEM pictures. (see Fig. 2)

The system is completely flexible thus allowing its utilization for a wide range of applications such as profilometry, motion analysis, various modes of image based motion analysis and high resolution intensified thermal imaging. These modes allow experimental verification of models associated to a large variety of devices ranging from purely electromechanical to fully multi-domain microfluidic devices.

EXPERIMENTAL MEASUREMENTS

A number of surface micromachined devices have been scanned to illustrate the flexibility of the MEMSPEC-2000 system. The system provides two simultaneous imaging modes, intensity and depth. The intensity data provides information on the surface reflectivity of the material and allows direct recognition of features. The depth surface scan data allows precise topographic maps of the device under test. Figure 3a shows the result of a topographic scan of an area of 100 μm square. The unidimensional color gradient observed in Fig 3a results from a minor tilt in the device positioning. Figure 3b shows a cross-section formed by taking a horizontal cut along a main axis.

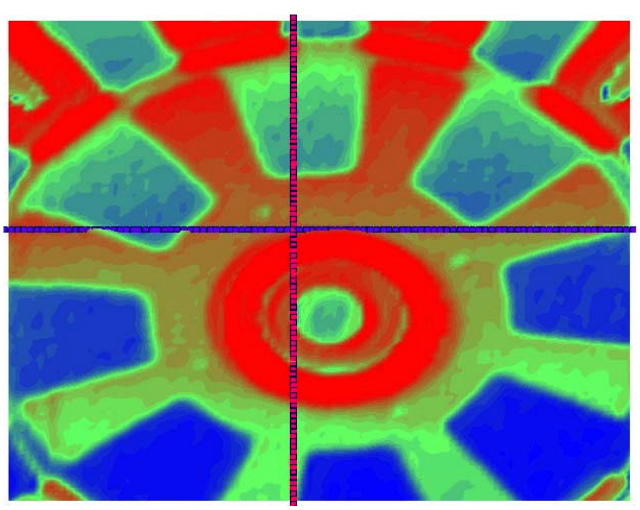

Fig. 3a Scanned optical X-Y surface depth profile of a 100 um by 100 um electrostatic motor,

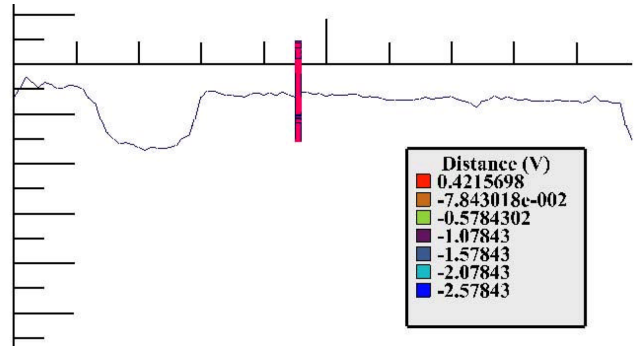

Fig. 3b depth profile of a horizontal cut section as shown.

Figures 4a and 4b show the result of s scan of a 100 μm x 250 μm ultra-wide cantilever beam (UWCB). Underneath the beam is a low resistivity polysilicon electrode. In figure 4a the scan indicates the regions of different materials via the intensity levels. Blue regions correspond to a gold layer having high reflectivity at the wavelength of the laser used, green corresponds to medium reflectivity conductive polysilicon, while red corresponds to a surface coated a thin low reflectivity nitride layer. In figure 4b, the result of the topographical scan of the beam is shown. It is clear from this scan that a relatively large (1μm) depression exists in the center of the beam suggesting incomplete release, partial stiction along with warping due to stress gradient.

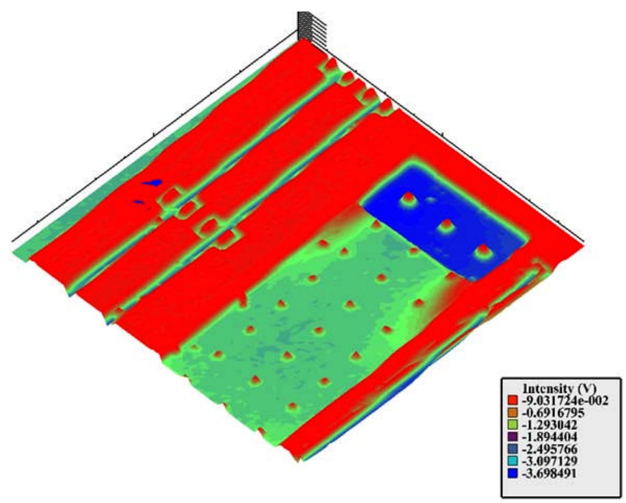

Figure 4a. Intensity map of the ultra-wide (100μm by 250μm) cantilever beam.

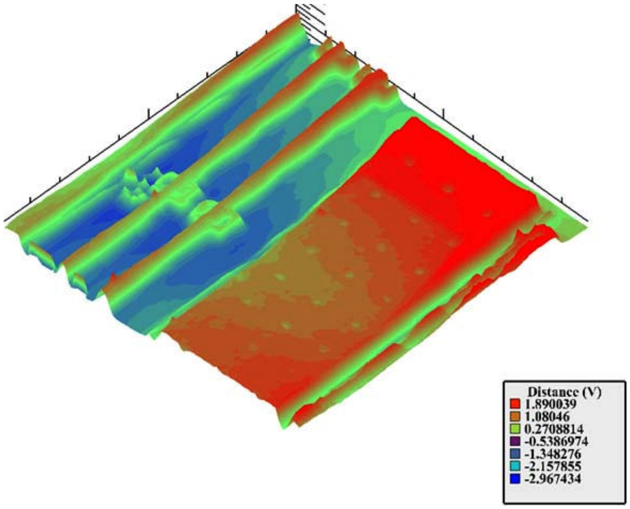

Figure 4b. Topographical map of the ultra-wide cantilever beam.

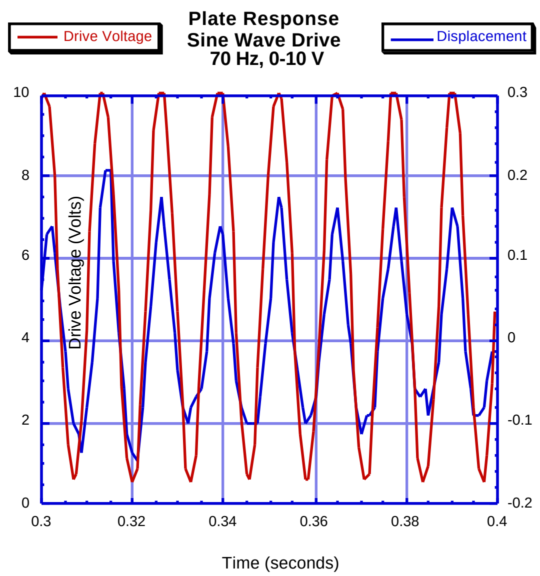

Figure 5: Time response of point on ultrawide cantilever beam to 0-10 v sine wave excitation

The time response of a single point on the UWCB is plotted in figure 5. In this case, the vertical motion of a point near the center of the beam was monitored while a 0 to 10 V excitation voltage was applied to the electrode. The measurement shows a deflection of +/- 0.15 um, indicating a possible problem with the operation of the device, as the expected deflection is on the order of 1 um.

CONCLUSIONS

The MEMSPEC-2000 system incorporates several automated modes of operation that are useful for extracting information on a wide range of MEMS/MST devices under test. Surface profiles can be easily performed with vertical resolutions of 0.1 um or better. The minimum lateral resolution is 1 micron at lower vertical depth range and slowly degrades for larger vertical feature structures. The temporal response of moving structures can also be measured at discrete points with response times on the order of 10 microseconds.

In the intensity map mode, the changes in the imaging pattern allow discrimination of deposited materials on the surface of the device under test. In the depth profile map mode, topographic features can be measured throughout the surface of a die. These capabilities allow the user to easily inspect dies for quality control purposes at various levels of resolution. Detailed localized studies of structures are possible for failure mode detection and investigation. Mechanical parameters such as Young's modulus, Poisson's ratio and residual stresses can be estimated using suitably chosen test structures. These capabilities allow validation of analytical models for micromechanical structures and for benchmarking finite element simulation codes .

The most appealing characteristic of the MEMSPEC™-2000 system is its high testing throughput resulting from automated operation and from parallel batch measurements. This significantly reduces the time required for device characterization. Furthermore, the fact that the data is stored in digital format allows to the user to extract quantitative information at any point in the future.