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New approach offers precision 3-D imaging and analysis of MEMS interiors

By Russell Kerschmann

Editor's note: The following article describes a kind of CAT scan for MEMS that uses a blade instead of an electromagnetic beam to slice subsections. Removal of these subsections reveal strengths and weaknesses of the inner material of a sample device. Images of each subsection are combined by computer to present a comprehensive image that can be examined from any angle and at any depth.

While MEMS device fabrication technologies are rapidly evolving and MEMS systems are becoming mainstream for a variety of applications, precision measurement methods of MEMS components for research and manufacturing quality control are not proceeding apace.

Since MEMS devices are built as 3-D structures, often with complex architectures, digital microimaging has traditionally been used as one means for providing metrics on the quality of MEMS fabrication. Scanning electron microscopy (SEM), confocal microscopy, and other microscopy modalities have some 3-D measurement capacity of MEMS devices, but they also suffer from profound limitations.

For example, SEM can provide highly detailed images, but only of the surfaces of devices. Important internal details, such as manufacturing defects that might weaken or otherwise interfere with the function of the device, cannot be detected with SEM. Understanding hidden component interactions in fully-assembled MEMS machines is, in general, beyond the capabilities of SEM.

Likewise, while confocal microscopy has been used less in MEMS research and manufacturing, it can generate digital, 3-D spatial data; but because this technology requires laser light penetration of the sample, the volume of material that can be imaged is repeatedly insufficient.

In the face of some spectacular successes in fabricating MEMS devices, the community is left without an industry-standard method for measuring its products for research and manufacturing quality control. The ideal technique would generate accurate digital replicas of entire MEMS parts and assemblages, address large volumes of MEMS material in a single data set, and allow easy access and analysis of internal structure at micron-range resolution.

***Fig. 1. MEMS LIGA part imaged by DVI technology. Image is an accurate digital replica of all internal and external structures and can be subjected to a variety of visualization and quantitative analysis methods.* Source: Dr. Douglas Chinn, Sandia National Laboratories, Livermore, CA.**

Generating virtual MEMS

We describe an entirely new approach to quantitative microanalysis of millimeter-scale MEMS systems that depend on the generation of exceptionally high-resolution, high fidelity digital volume replicates of MEMS and other types of material samples. These replicates form the basis for a new spectrum of visualization and analysis tools for the development of MEMS metrics.

Resolution gives MEMS researchers the advantage of an integrated, micron-level analysis of surface and interior structure of unprecedented amounts of material (hundreds of cubic millimeters/sample), including entire MEMS parts and even assembled micromachines, something long sought after by the MEMS community.

Digital volumetric imaging (DVI) works by embedding the MEMS part in a polymer matrix with tightly controlled optical properties. The polymer is extremely opaque to light, with extinction near 100% over distances of just a few microns. Once solidified, the resulting solid block containing the part is mechanically sectioned on a diamond knife at thicknesses as small as 0.25 µm. After each cut, the thin section is removed from the area of the block by a vacuum system and discarded.

Instead of imaging the sections, the freshly cut surface of the block is illuminated and a high-resolution 2-D digital image of the reflected light emitted from the cut face is captured through epi-illumination microscope optics onto a 2000 x 2000 pixel CCD camera. The polymer acts as a solid support for the MEMS part and prevents any reflected light from deep in the block reaching the camera. A high-contrast image is generated because the part has a much higher specular reflectance than the embedding polymer.

Precision MEMS metrics in 3-D digital space

DVI evolved into a MEMS metrics tool from its beginnings as a microanalysis technology for biological tissues and other types of manufactured materials.

In addition to serving MEMS researchers, DVI is currently used by pharmaceutical research laboratories for imaging of vertebrate embryos, experimental animal lung, bone samples, and other tissues, as well as in the consumer products industry for microanalysis of polymer-based products, such as Velcro and non-woven textiles. Imaging composite constructs of MEMS devices and biological and non-biological materials is thus possible using DVI.

With DVI, MEMS researchers can generate and interactively manage complete 3-D replicas of their materials (Fig. 1, page 1). Once such accurate 3-D data is available, a whole host of manipulations and measurements are possible, such as determining the surface area of a complex fabrication, part volume, point-to-point distances, and a variety of other important metrics with micron-range accuracy. In addition, surface point-cloud data generated by DVI can be used to back-generate accurate CAD data from the actual part, allowing for direct comparison to design CAD data, thereby providing a new quality control method.

Currently, DVI is used for imaging LIGA and other metal MEMS devices; however, methods for imaging silicon parts are under active development in conjunction with the MEMS community. In order to attain the level of detail in relatively large objects, DVI imaging requires a destructive analysis. In many cases, this is not of consequence, and there is no other 3-D microimaging technology we know of that is capable of giving MEMS researchers highly accurate metrics of hidden component interactions in MEMS devices.

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