

Analysis of MEMS Structure Sidewalls for Carbon and Fluorinated Residue with SEM, EDS and TSA

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Abstract

The transition of MEMS and MOEMS devices from the laboratory to laminate-based (PCB) high-volume manufacturing is challenging. Devices now must be manufactured with low defect rates and high reliability. Micromanufacturing techniques used for deep reaction ion etching (DRIE) typically use fluorine plasma chemistries and can leave fluorinated sidewall residues that may release in the form of flakes. Sidewall residues that release as flakes can interfere with moving parts in fluidic and optical pathways, rendering the devices useless.

Analysis of fluorine and other contamination can be quantified using Scanning Electron Microscopy (SEM) equipped with Electron Dispersive Spectroscopy (EDS). New EDS techniques, using fast DSP (Digital Signal Processor) controlled systems, add additional power to conventional EDS, capturing and analyzing significantly more X-Ray CPS (counts per second) than the older systems. Digital systems controlled by software provide additional analytical capability through post-processing. Trace Element Sensitivity Analysis (TSA), a new post-processing technique for chemical mapping of surfaces, enables detection of low level contamination that formerly would have been lost in the noise. It is capable of determining individual particle chemistry with excellent accuracy and traceability.

Keywords: Scanning Electron Microscopy (SEM), MEMS, MOEMS, contamination, EDS, failure analysis

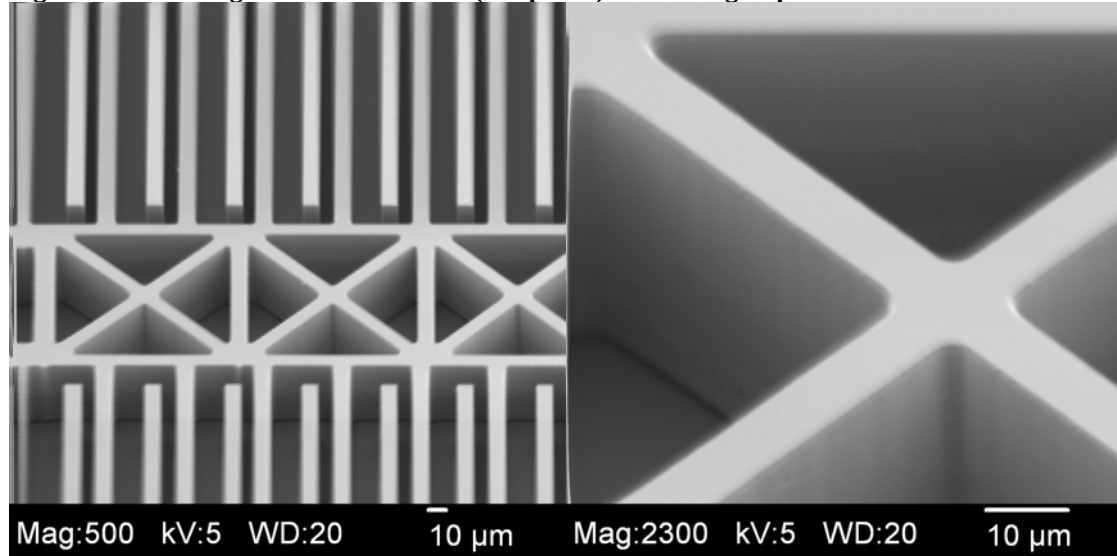
Introduction

Unlike semiconductor die, where the wafer surface remains pretty much planar after each microfabrication step, MEMS devices typically have nonplanar structures on or in the substrate at points during and even after microfabrication [1]. These nonplanar structures are often very fragile and can be easily broken during subsequent microfabrication processes or handling.

Imaging MEMS devices with SEM is commonly used because of its excellent resolution and depth of focus. Optical microscopy has a very limited depth of focus because of the wavelength of the light source and the numerical aperture (N.A.) of the lens. SEM, because the source of imaging is an electron beam, has a much longer depth that is in good focus. In addition, the SEM is capable of resolving details at much higher magnification

than optical microscopy. Figure 1 illustrates the excellent depth of focus and resolution of the SEM. The image is in good relative focus the entire depth of the sidewall. Optical microscopy cannot provide focused images down into the sidewalls of the MEMS device and also cannot achieve the magnification levels of SEM.

When an electron beam interacts with a surface both electrons and x-rays are emitted. The emitted electrons are detected based on their energy levels. Secondary electrons are most commonly used for imaging. The electron beam also interacts with the surface, to emit x-rays that carry surface chemistry information. Each electron shell of each element in the periodic table emits an x-ray signature that corresponds in energy level (keV) with that electron shell. In this study the elements that were of interest were fluorine and carbon but the EDS system is capable of detecting all of the elements with atomic number higher than that of the EDS

Figure 1. SEM Images of MEMS Device (sample #1) illustrating Depth of Focus and Resolution

system window, In this case carbon was at the low end of the instruments capability.

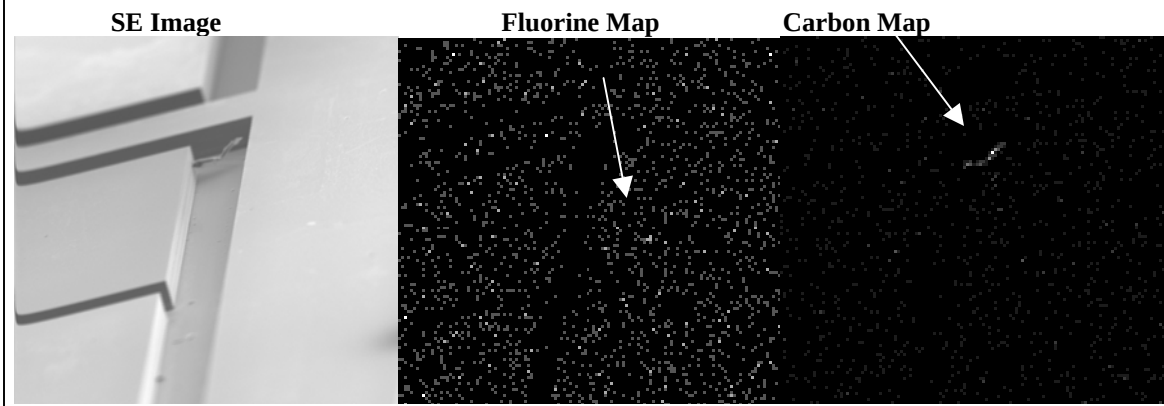
Fast DSP based systems can capture and analyze the entire x-ray spectra for each pixel in the image. With high CPS DSP-based systems, maps of the surface chemistry can be analyzed to reveal the presence of a trace level contaminant in a single pixel of data. Earlier systems would be forced to accumulate data, losing the individual pixel data in the noise of the total.

MEMS Devices Evaluated

For this study, two types of MEMS devices were investigated. The first type possessed interdigitated teeth-like structures (20 μ m wide by 620 μ m long) fabricated in the 75 μ m thick device layer of an SOI wafer. An optical photograph of some micromachined teeth fabricated with this process is presented in Fig. 2. For these die, the typical fabrication process [2] consisted of photolithography, Bosch process DRIE [3, 4] to etch the design into the device layer, dicing, cleaning, a timed HF release to undercut the movable features in the device layer by removing the underlying SiO₂ box layer and critical point drying. This set of devices was chemically and O₂ plasma cleaned after dicing to remove photoresist residue and sidewall polymerization. The second set of MEMS devices used a similar design (interdigitated teeth-like structures 10 μ m wide by 620 μ m long), except it was DRIE etched 75 μ m into an ordinary 500 μ m thick Si wafer. The second set

of devices was deliberately left “dirty” after microfabrication, where the remaining photoresist was not removed by ashing in order to yield “interesting” devices for examination with the EDS and TSA techniques.

The fabrication process utilized to fabricate these and many types of MEMS devices utilizes materials that can leave undesirable residue on the fabricated devices. Photoresist is an organic light-sensitive polymeric material utilized in photolithography to realize etching and liftoff masks on the layer of material beneath the photoresist layer [5]. After processing, any remaining photoresist residue is typically removed in a chemical bath/rinse and/or in an O₂ plasma process called ashing. Any unremoved photoresist residue on surfaces consists of carbon compounds. The Bosch process of DRIE uses a sequential alternating process of plasma/sputter etching and passivation. During the passivation step, C₄F₈ and SF₆ are chemically combined to form a thin layer of polymerized CF₂ on exposed surfaces [6]. Subsequent etching steps remove the CF₂ layer from horizontal surfaces but not from vertical surfaces, which achieves high aspect ratios in etching. It can be difficult to completely remove the CF₂ layer on vertical surfaces after etching is completed. Any unremoved passivation residue on surfaces consists of fluorine compounds. The second set of fabricated devices was purposely left “dirty” where photoresist residue and CF₂ were purposely left on the fabricated devices for inspection with these techniques. Any remaining

Figure 3. Trace Sensitivity Analysis (Sample #1) Showing Detection of Fluorine and Carbon

residue on micromachined structures, whether from photoresist or from the DRIE passivation step, can be problematic for the operation and/or reliability of MEMS devices. Since many MEMS devices have moving structures with tiny spaces in between, sometimes as small as $1\mu\text{m}$, any remaining residue can clog these tiny spaces and interfere with device operation. Therefore techniques for examining fabricated MEMS devices for residue are very useful for enhancing reliability.



Figure 2. An Optical Photograph of the Micromachined Interdigitated Teeth Structures.

Trace Sensitivity Analysis

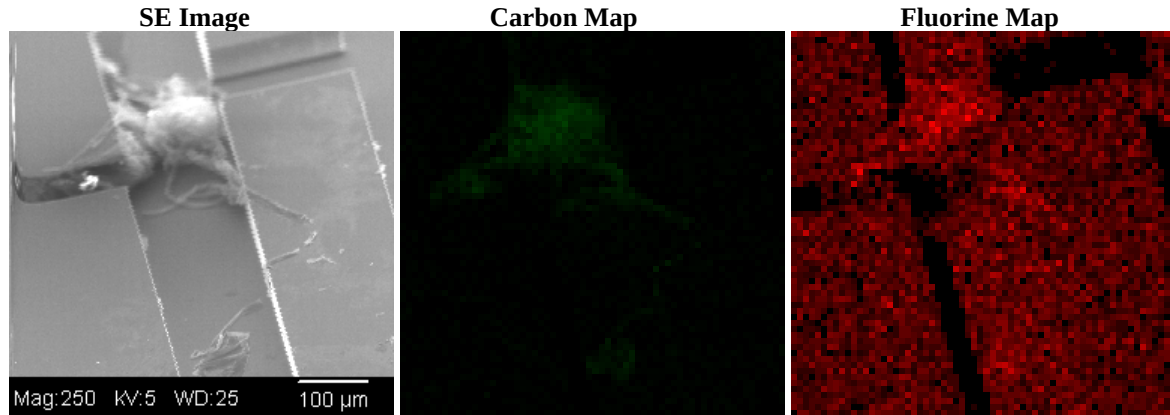
Trace Sensitivity Analysis is a post processing technique that is performed in software. New software techniques enable storage of the entire chemical spectra associated with each pixel within an image frame. A composite spectra is then generated using the maximum amplitude (x-ray counts) at any individual pixel for each energy level (keV) in the spectra. Peaks are identified (elemental identification) and Regions of Interest (ROI) are

defined. As the user moves the cursor through the spectra at each defined ROI, the image window brightness corresponds to pixels where that ROI was identified. Figure 3 shows three photomicrographs. The image on the left is the SE image of sample #1. The middle image is a Fluorine map of the same image. The bright spots are pixels where fluorine was detected. The image on the right is a carbon map of the same image. Carbon is only detected in the small particle that can be seen in the trench.

Figure 4 is a conventional EDS Map of sample #2, the one that was intentionally left dirty. There is a large particle visible in the trench at 250X. Conventional EDS mapping is capable of detecting and imaging both carbon and fluorine in and around this particle. The carbon and fluorine maps are shown. Carbon is only detected in the large particle down in the trench. Fluorine is present all over the surface.

Conclusions

As MEMS and MOEM devices move from the lab to high-volume manufacturing, all of the skill sets that our industry has developed will be required to produce and package these difficult products. The use of SEM, EDS and TSA will play an important role in meeting these challenges. The first step towards solving a problem is seeing it. The use of advanced SEM-based techniques enables manufacturing people to identify contamination that can result in defective products. Identification of the failure source provides the root-cause and enables solution of the problem.

Figure 4. Large Particle of Residue (Sample #2) Carbon and Fluorine Maps

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