The Role of a Compact Low Voltage FE-SEM in MEMS Analysis

Application Note

Introduction

MEMS (microelectromechanical systems) are considered to be part of semiconductor micro technology. MEMS are important as accelerometers in cell phones, PDAs, and motion sensitive video game controllers. MEMS have played an increasingly larger role in the "sensory intelligence" of everyday devices from clothes washers and dryers to airbag deployment in automobiles to ink-jet printers.

MEMs are manufactured using key applications of semiconductor technology; especially lithography, etching, multistep metallization, and die preparation. MEMS bridge the integration of computing and communication technology with motion sensing technology. MEMs technology is also important in biomedical devices and medical diagnostics.

Materials characterization in the MEMS industry focuses on analyzing and characterizing photolithography and line integrity, failure and defect analysis of finished MEMS, and advanced materials development for creating new nanostructures. Reliable and low cost MEMS in military, aerospace, and automotive applications require sophisticated tools in all aspects of the product lifecycle from materials and process development, to problem solving, and failure analysis.

MEMS analysis typically includes image analysis, metrology, metallization, and surface characterization.

Typical analysis includes but is not limited to the following:

- Image – Optical, FE-SEM (including EDS) and FE-AES images of MEMS on wafer or depackaged

Figure 1. Overview image of depackaged Z-axis accelerometer.

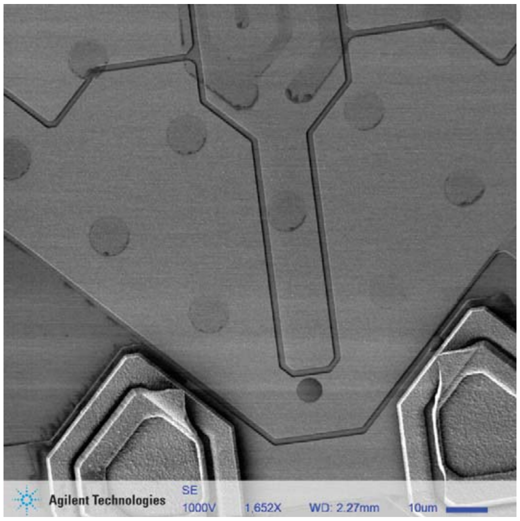

Figure 2. Zoomed in view of top side contact locations.

- Surface – FE-AES survey, x-y mapping, and depth/composition profiles
- Chemical analysis – FT-IR microspectroscopy analysis, SEM based EDS analysis
- Structural – FE-SEM and TEM cross-sectioning, X-Ray imaging
- Electrical and mechanical characterization
- Relating visual images with operating function, or failure (electrical or mechanical)
- Relating chemical composition and electrical data with operating function or failure
- Relating internal structure, or failure, to the design, engineering, manufacturing, or operation

Of the multitude of scientific instrumentation used to characterize MEMS, SEM is one of the most common instruments. Because of the ubiquitous need for SEM images in MEMS analysis, a new breed of instruments, the compact or bench top SEM, is garnering attention. These smaller SEMs will not replace the full suite of analytical capabilities of the full-size instruments; however, their ease of use and quick, high resolution images allows for operators with a wider range of SEM skill level. The compact SEM improves overall efficiency and analysis time, allowing researchers to quickly image the MEMS when only an image is needed to guide further analysis.

Agilent's 8500 compact FE-SEM is a low voltage, field emission SEM which employs a novel electrostatic lens design. This innovative design allows for high resolution imaging of MEMS devices, typically without the need for metal coating. The 8500 FE-SEM was used to image three types of MEMS: atomic force microscope (AFM) cantilevers, airbag accelerometers, and resonators.

Airbag Accelerometers

The design is conceptually simple —a central control unit monitors a number of related sensors within the vehicle, including accelerometers, impact sensors, wheel speed sensors, brake pressure sensors, and seat occupancy sensors. When the requisite activation threshold has been reached or exceeded, the airbag control unit will trigger the ignition of a gas generator causing propellant to rapidly inflate a fabric bag. As the vehicle occupant collides with and squeezes the bag, the gas escapes in a controlled manner through small vent holes. The airbag sensor is typically a MEMS accelerometer, which is a small integrated circuit with integrated micro mechanical elements. The microscopic mechanical element moves in response to rapid deceleration, and this motion causes a change in capacitance, which is detected by the electronics on the chip that then sends a signal to deploy the airbag.

For both failure analysis as well as device performance characterization, MEMS accelerometers are depackaged to expose the active device which can be characterized. Low voltage FE-SEM images of a depackaged MEMS accelerometer are shown in Figures 1–8.

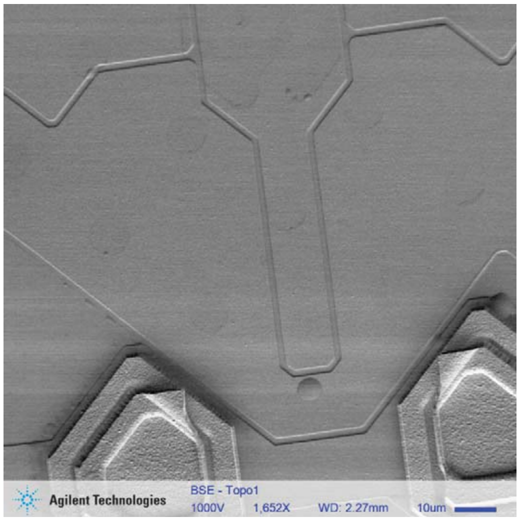

Figure 3. Zoom in topographic shaded view of top side contact locations.

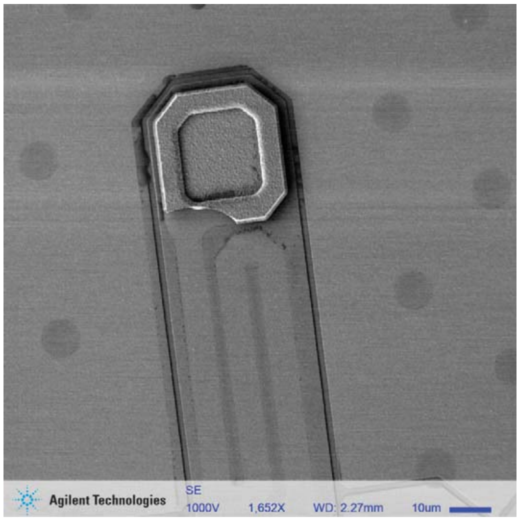

Figure 4. Zoom in image of spring contact.

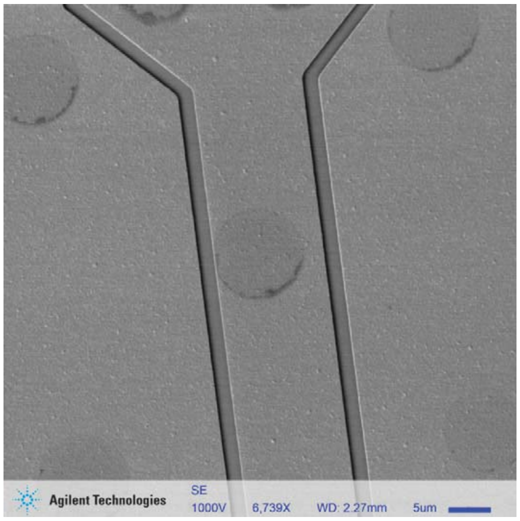

Figure 5. Zoom in view of top side contact locations showing surface roughness of the device.

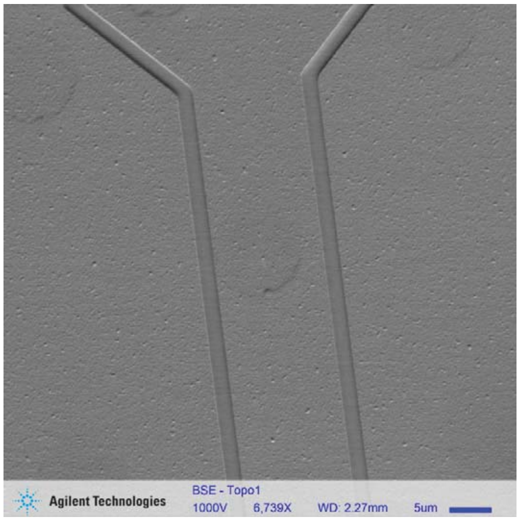

Figure 6. Zoom in topographic shaded view of top side contact locations showing surface roughness of the device.

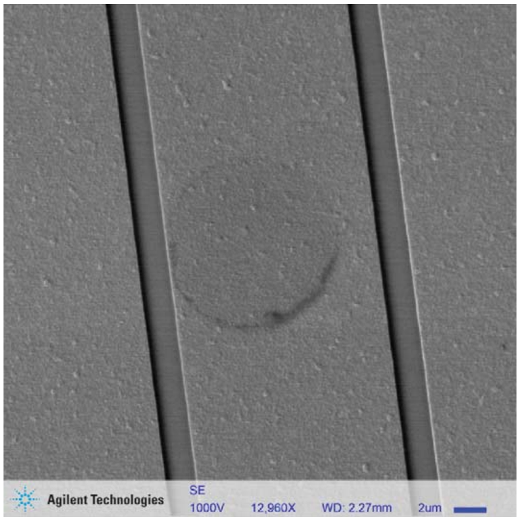

Figure 7. Zoom in view of a single top side contact location showing surface roughness of the device.

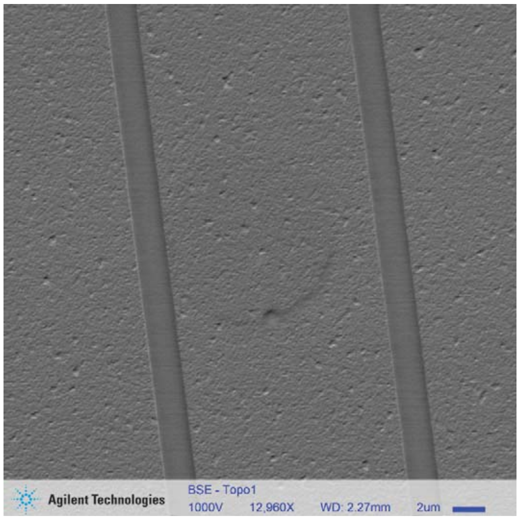

Figure 8. Zoom in topographic shaded view of a single top side contact location showing surface roughness of the device.

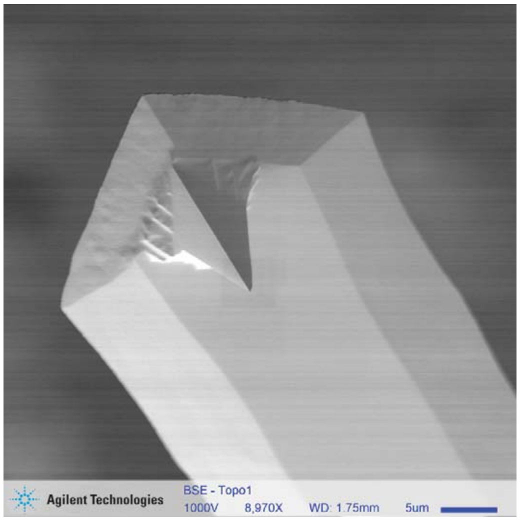

Figure 9. Conductive silicide alloy tip which does not need metallization for electrical measurements.

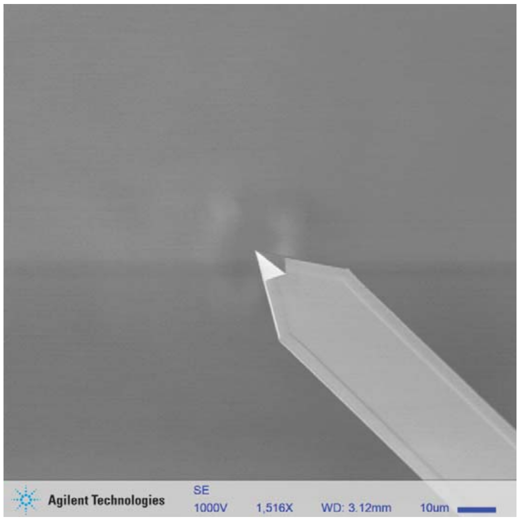

Figure 10. Metallized tip for AFM electrical measurements.

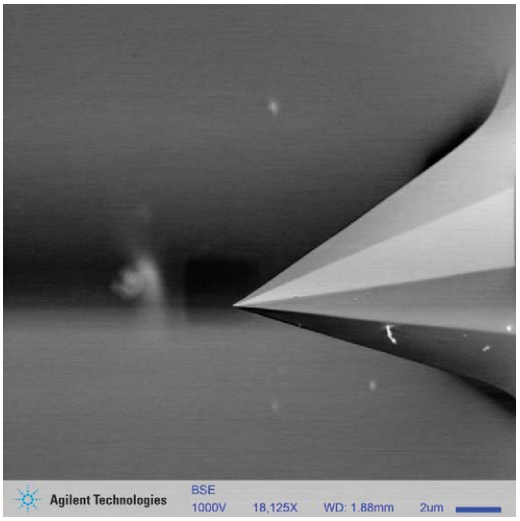

Figure 11. Metallized tip for AFM electrical measurements which has a larger tip radius to improve electrical contact.

AFM Cantilevers

The atomic force microscope (AFM) has become a powerful tool for investigating surfaces on an atomic or nanometer scale. An AFM consists of a sharp cantilevered tip that is raster-scanned with sub-nanometer precision over a surface. The interaction forces between the tip and sample cause a minute cantilever deflection, which is sensed by optical deflection to produce a topographical map of the surface on the nanometer or atomic scale. Since its invention, the AFM has been used not only to view surface structures, but also to probe electrical, magnetic, van der Waals, adhesion, and chemical interactions between the tip and surface. The sharpness of the tip is often a fundamental resolution-limiting parameter. When the tip and sample are in contact, the contact area increases with the radius of curvature of the tip. Furthermore, the sample features appear widened or convoluted by the tip. Although not commonly thought of as a MEMS device, AFM cantilevers are microfabricated using standard MEMS processing. Therefore, characterizing AFM cantilevers can be done using the same suite of analyses that are typically used to characterize MEMS.

Low voltage FE-SEM images of three different AFM cantilevers used in electrical measurements are shown in Figures 9–11.

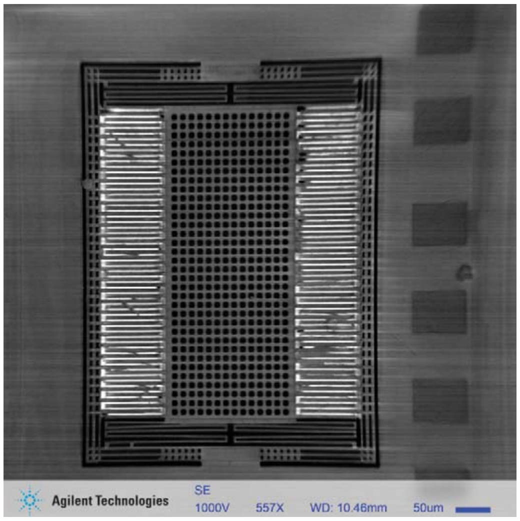

Figure 12. Overview image of MEMS resonator.

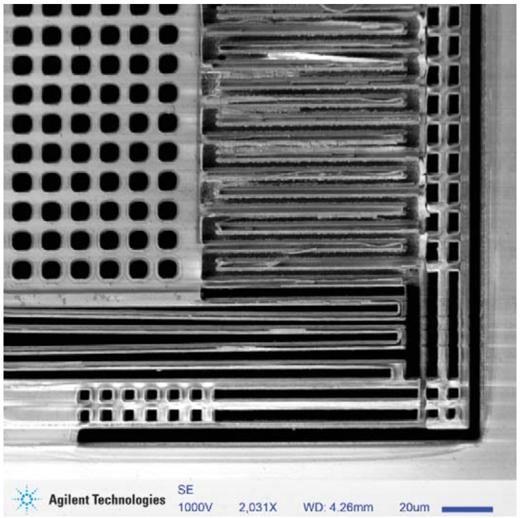

Figure 13. Zoom in view of metallization delamination defects.

Resonators

Since the advent of industrially manufacturable MEMS, companies have been trying to replace quartz oscillators with silicon MEMS-based oscillators as the frequency reference in clock and timing oscillators. Developments in semiconductor process technology, packaging, and the integration of circuitry have enabled some progress for MEMS resonators. These resonators are basically time-base generators, or references. A separate electronic oscillator provides the input signal that forces the device to vibrate at a precise frequency. Those vibrations are captured and their output amplified by a gain buffer. A phase-locked loop (PLL) captures and distributes the reference signal generated by the resonator-oscillator pair.

One of the most highly touted features of MEMS based resonators is the promise for integration they offer to integrated circuits for timing circuits. Fabricated in silicon using standard bulk etching processes, MEMS resonators can in principle be tied to oscillator circuits and PLLs on the same silicon substrate. This would allow the clock and timing generators, in conjunction with the resonator, to be built in a monolithic low-profile semiconductor package. This package could then be used in high-volume assembly. Therefore, silicon MEMS-oscillator combinations are promoted as single chip component replacements for separate crystal oscillators in computers, communications equipment and consumer devices.

Low voltage FE-SEM can be used to inspect these resonators for defects prior to the devices being packaged. Examples of incomplete removal of photoresist and metallization adhesion issues are shown in Figures 12–25.

Conclusions

Low voltage compact FE-SEM provides ease of use and a straightforward technique for high resolution imaging of MEMS structures, typically without the need for metal coating to dissipate charge buildup. Although the application range of the MEMS examined spans many levels of sophistication in materials, design, and processing, the morphological features of interest and defects could easily be investigated with the Agilent 8500 FE-SEM.

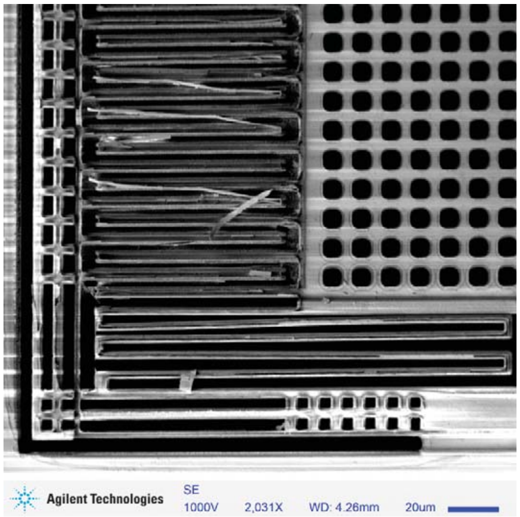

Figure 14. Zoom in view of metallization delamination defects.

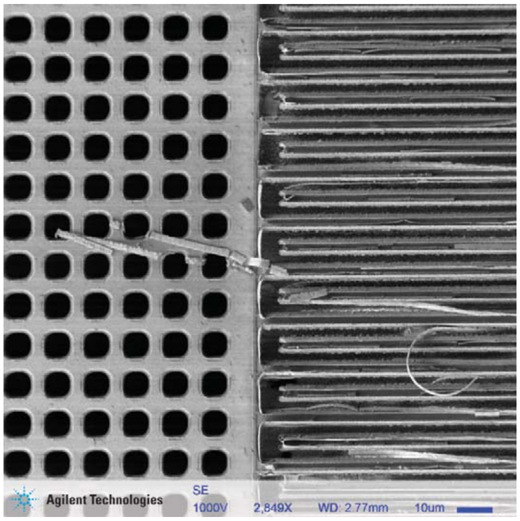

Figure 15. Zoom in view of metallization delamination defects.

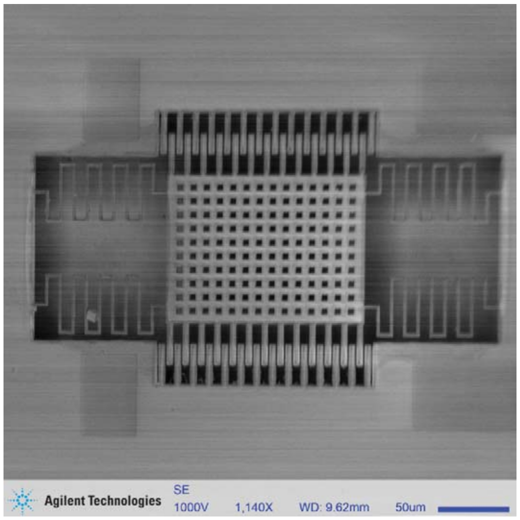

Figure 16. Overview image of MEMS resonator.

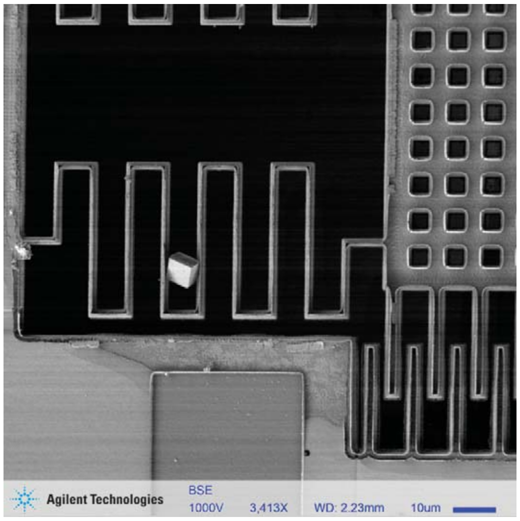

Figure 17. Zoom in view of photoresist defects and cube-shaped contamination particle.

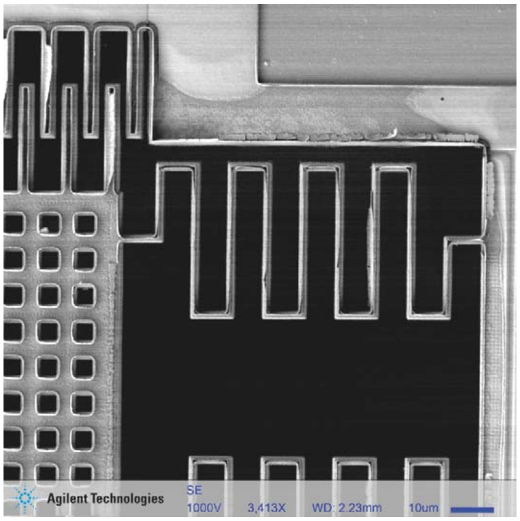

Figure 18. Zoom in view of photoresist defects.

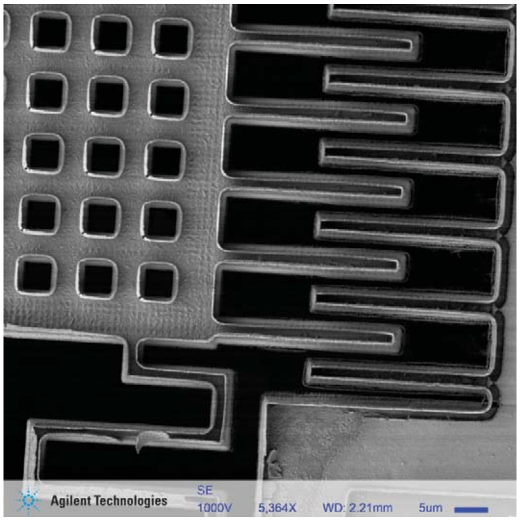

Figure 19. Zoom in view of photoresist defects.

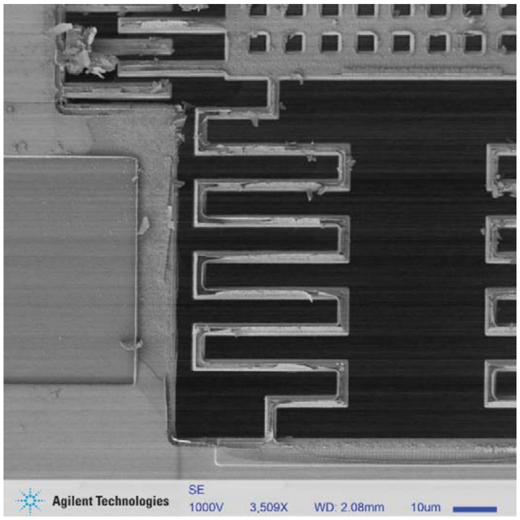

Figure 20. Zoom in view of photoresist and metallization defects.

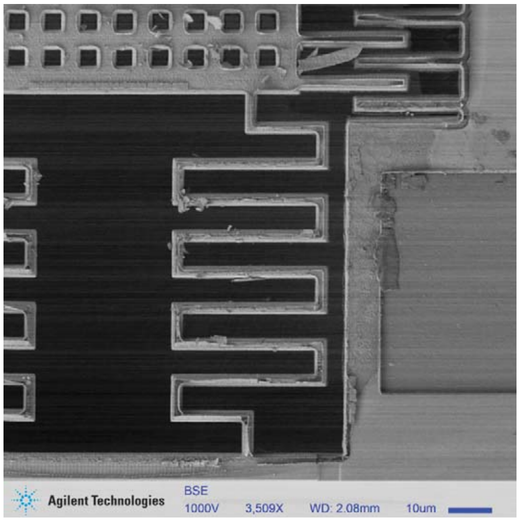

Figure 21. Zoom in view of photoresist and metallization defects.

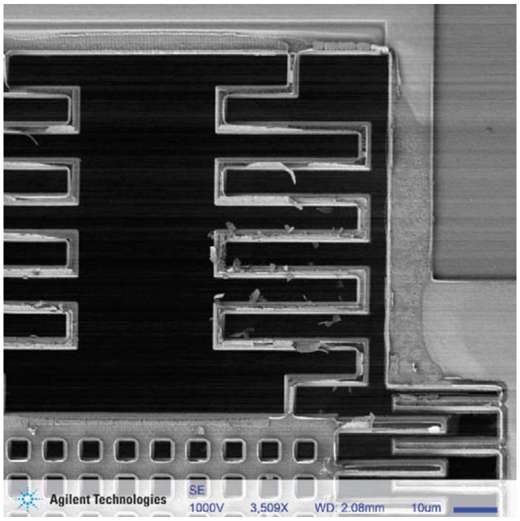

Figure 22. Zoom in view of photoresist defects.

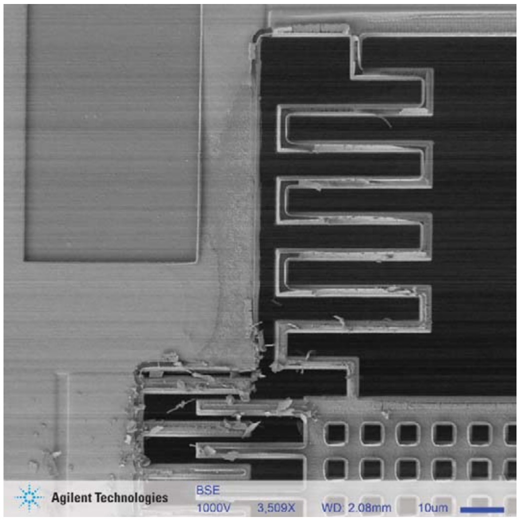

Figure 23. Zoom in view of photoresist and metallization defects.

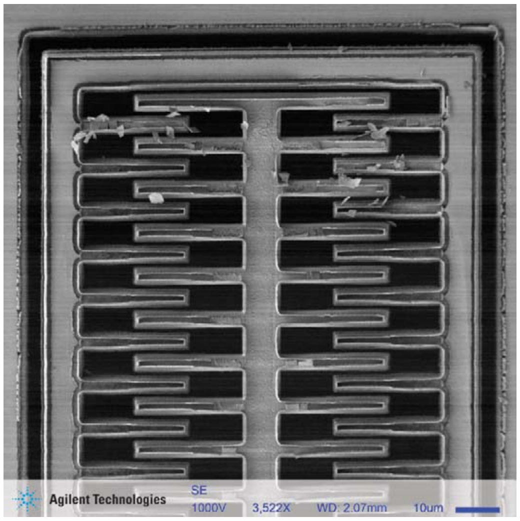

Figure 24. Zoom in view of photoresist and metallization defects.

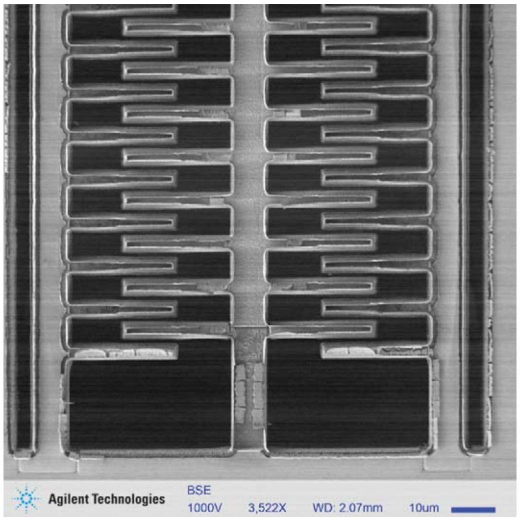

Figure 25. Zoom in view of photoresist and metallization defects.

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