Micro Electro-mechanical Systems Testing and Failure Analysis Challenges

MEMS are being seen as one of the most promising emerging technologies to advance the development of next generation wireless devices. MEMS promises to shrink devices, lower power requirements and, most importantly, enable new and cutting-edge applications.

By Ernest Worthman, Editorial Director

Although MEMS (Micro Electro-Mechanical Systems) have been around for a number of years, only recently has the technology started to hit the mainstream. Within the last five years, the rate of diversification of MEMS has increased notably into areas such as sensors and actuators, optical switches and reflectors, microfluidics and, of course, RF.
Since MEMS is a relatively young field in the more mature field of general IC design and manufacturing, MEMS design, fabrication, packaging and reliability testing are still in their infancies. Extrapolating that, this leads to a sparse historical knowledge base. Simply, this means that failure analysis support for production, packaging, testing and field operation, and the tools and techniques required to properly diagnose the root cause of failure, do not have a long history.

In the IC world, in general, procedures have matured so that standard IC test procedures, life testing and environmental conditions are well-documented and understood. Therefore, reliability testing can be standardized.

However, MEMS, due to their micro structure, are infinitely more sensitive to test and analysis procedures and variants, especially environmental variants, than their macro counterparts. And while there are tools available for MEMS testing (IC failure analysis tools and techniques), the expansion of MEMS devices and applications means that test procedures basically have to become dynamic.

When it comes to designing RF MEMS, the most unique parameter to them is frequency. Today, esoteric designs can be required to work well into the tens of GHz and can also have multiple and wide-bandwidth demands, posing tough challenges for MEMS devices. While today, MEMS devices are being successfully integrated into IC technology, many of the edge-of-the-envelope parameters for these designs are still on the drawing board.

Analyzing MEMS Failures

For RF MEMS, there are several areas that fall under the failure-analysis umbrella, but space will not allow for an in-depth analysis of all of them. That being said, there are two areas of interest that are closest to the center of the radar screen. One is the device metallurgy, a the second is NDT (Non-Destructive testing).

Today, in spite of advancements in analysis equipment, little is known or understood about contact properties and surface interaction at the micron scale. And since MEMS are micro, many known and documented NDT procedures cannot be used for such delicate devices.

When it comes to the metallurgy, critical parameters, such as contact area, asperity size and geometry and the number of asperities in contact, are critical in understanding contact mechanics. As such, much research is being done to try to understand surfaces properties, so failure-analysis databases can be built, and the industry can better understand the failure mechanisms associated with contact surfaces.

In the NDT area, most failures in switches are due to a shorting or opening of an open or &quotjoined&quot component respectively. The key issue here is locating the actual failed components without removing the top or side components. Again, this is micro technology. Opening macro devices for forensic analysis has a long history and size and fragility are not nearly as critical as with MEMS. With MEMS, the contaminants that will immediately pollute the device can be as large, or larger, than the MEMS components themselves, rendering any attempt to examine the devices moot. Further, it is often not possible to even remove the components to allow the surfaces to be examined.

Another area of interest is the surface roughness of contact devices. Again, macro device contact design is fairly well understood. The major design criteria for macro contacts are surface roughness and contact material, with respect to the application. In MEMS, some progress has been made and tools such as an AFM (Atomic Force Microscopy) can be used to assess limited areas. However, there are no readily available tools that can perform multiple measurements on single devices and on several devices in parallel at the same time. Such statistical information is required to understand the RMS and correlate these roughnesses from device to device, wafer to wafer and lot to lot.

Note: RMS roughness is defined as the Root Mean Square deviation of the surface from the mean surface level over some specific surface wavelength range, and is usually a function of thickness or time during a deposition roughness of a device

ESD &#151 A Critical Element

Of course, with any semiconducting device, Electrostatic Discharge (ESD) is a significant consideration for MEMS device design, and one that is a bit difficult to assess in failure analysis.

Obviously, ESD is particularly destructive to MEMS devices, in orders of magnitude less than macro devices.

One particular issue often found in various RF MEMS devices is the phenomenon of charge accumulation in the surrounding dielectric material. This type of failure is particularly detrimental to shunt switches, where charge is deposited into and through dielectric material.

Fundamentally, residual charge alters the V/I profile required to actuate the device when trying to pass a signal through it. This unique phenomenon is an accumulative process and can be difficult to isolate, since the variables here are time and/or cycles. Here, the challenge for failure analysis is to identify this failure mechanism before dielectric breakdown occurs, and determine how much charge is trapped in the dielectric material. If this can be captured, the amount of charge trapped in the dielectric material can be used to model the time required to failure under constant or cyclical response.

Conclusion

Progress is certainly being made in the test and measurement of MEMS components. However, the fact that they are becoming extremely diverse in their application and function presents significant new challenges to failure analysis techniques. What works in one case may not necessarily work in another.

While tools and techniques developed for macro analysis from the IC industry have been ported to MEMS, more MEMS-specific failure analysis tool sets need to be developed. The major challenges that the industry faces are those of NDT, large-scale analysis and knowledge bases.

The most promising direction is for industry, government and academia to collaborate and build an in-depth knowledge base that will support both MEMS development and reliability though test and failure analysis.