Solidus Technologies

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Article

Addressing the "MEMS One Test Dilemma

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Reduce MEMS test costs by verifying the dynamic mechanical behavior of your sensor elements at the wafer level.

With MEMS test costs as high as 50% of the product cost, the MEMS community is ready to overcome what has been called the Yole MEMS Law: "One product, one process, one package." and now "and one test"[i]. Solidus has solved the 'one test' with the introduction of the Solidus STI 3000 reconfigurable test platform. The STI 3000 system addresses a major obstacle in identifying MEMS sensor defects early in the manufacturing process by fully testing the mechanical performance of the sensor at wafer level. In addition, the subsystem STI 9000 can be used for final testing with the same robust software environment.

Final test is often the first effective test of sensor elements due to the need for sensor-specific stimulation. Often, the sensor die is assembled and tested before critical mechanical parameters can be detected and screened. Failure at final test means the loss of not only the micromachined structural element, but also the cost and process time associated with the package and signal conditioning electronics. Final test generally requires integration of ATE with sensor-specific stimulators such as shakers, rate tables, pressure controllers and sound sources. These systems have proven necessary and effective in producing high volumes of MEMS sensors, but suffer from high system costs and complex customization.

To address final test loss, manufacturers routinely use wafer test to evaluate the sensor's static capacitance and leakage behavior. Such methods are helpful in screening catastrophic failures but can fall short of segregating die by performance. This has led to the development of custom discrete equipment tests to add electrical or mechanical stimulation testing. Despite the sophistication of these systems, the lack of integration in the test system results in unacceptably high test times. Likewise, the resultant tests are too often incapable of screening for more subtle failures such as damaged structural elements or latent stiction behavior.

To provide an unparalleled level of testing capability at the wafer level, Solidus Technologies has developed the STI 3000 wafer test platform. The Solidus STI 3000 addresses wafer testing challenges by providing three critical test enablers: a reconfigurable wafer test platform, high-performance 'tester-in-head' electronics and Drive Sense Technology (Table 1). This results in the ***lowest product cost, lowest development cost and the most effective reliability screening***.

Table 1. STI3000 Performance Summary

Challenge	Resulting Issue	Solidus Solution	Outcome
Screening wafers	Yield loss of package and electronics	Reconfigurable wafer test platform	Lower product cost
Sensor-specific stimulation	Complex, custom test hardware	High performance, 'Tester-in-head' electronics	Lower development cost
Low-level signals	Inability to detect failure mechanisms	Drive Sense Technology	More effective screening

The STI 3000 system has been developed by a team of MEMS and ATE experts to provide an industry standard MEMS test platform. Because the platform is software configurable, the same hardware can be used for a broad range of MEMS products including accelerometers, gyros, microphones, magnetometers, light sensors and pressure sensors. The STI 3000 system places very high performance test hardware right at the probe card interface allowing for very low noise measurements with high precision. Testing speeds are highly optimized through embedded hardware and software routines. The result is typical die measurements that are completed in less than 1.5 seconds per die. Most importantly, Drive Sense Technology (DST), is a Solidus-developed, optimized interface technology that can evaluate a sensor's mechanical response at the wafer level. In summary, the STI 3000 provides:

- Faster Product Development Cycles
- Improved Product Test Yields
- Improved Product Quality
- Lower Manufacturing Costs
- High Return on Investment

STI3000 Platform

The STI 3000 (Figure 1, Table 2) includes the STI 9000 ATE system and the STI 3000E sub-system. The STI 9000 is a full function standalone ATE solution for packaged parts and interfaces to the STI 3000E, providing access to the standard software test suite. The STI 3000E is a full input/output measurement unit that conditions signals from and into the STI 9000 system and places the inputs and measures outputs on die through the probe ring. A custom probe ring provides physical interface to the die and is based on die layout and test requirements.

Figure 1. STI3000 System Configuration

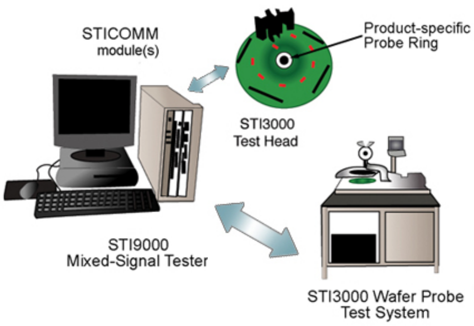


Table 2. STI3000 System Configuration

SubSystem	Purpose	Location
STI3000E	Probe head level switching and signal generation and conditioning	Probe Station
STI9000	Full function ATE test system	Bench Top
Product-specific probe ring	Probe wafer pads	STI3000
Probe Station	Index of die on wafer	Test Floor

Figure 2. STI3000 Type II Probe Head Test System

The STI 3000 system provides a full complement of platform resources. In addition to high performance PMU, DIG and DDS resources, the STI 3000 provides the STI Drive Sense Technology (DST) resource. DST provides a set of linked resources to simplify the measurement of mechanical characteristics by providing a mechanically optimized measurement that is fully calibrated relative to the desired mechanical parameters. In addition, the STI 3000 system provides 256 I/O channels, 50 MHz data rate and has 2 high voltage drivers. Additional testing capability can be added through the I2C interface such as audio and magnetic sources.

Table 3. STI3000 Resources

Platform Resources	Name	Qty	Key Specifications
STI Drive Sense Technology	DST	8	Embedded
Parametric Measurement Units	PMU	8	1pA sensitivity, 12 bit forcing
Digitizers	DIG	8	1 MHz, 16 bit
Direct Digital Synthesis	DDS	8	12MHz, 8 bit
Capacitance Measurement	CMR	4	24 bit
I2C Communications Bus	I2C	2	Additional stimulus control

The STI 3000 system provides advantages that cannot be achieved with alternative systems. First, the DST measurement system is specifically tailored to the MEMS testing applications. The inputs and outputs are scaled to the electrostatic and mechanical configurations of modern micromachined structures. The linked resources are available with simple code requests and data is compiled and analyzed according to embedded routines. Second, high performance hardware is used to assure the repeatability and precision of the measurements at the scale of microstructure measurements. Careful system design assures minimization of parasitics throughout the measurement chain. High performance analog and digital electronics assure the lowest possible noise levels and produce the signals and measure the responses. Third, the system is backed by a team of test and product experts that can assure a fast and effective measurement. Each system is delivered with specific test routines that are developed for each product. Extensive characterization is completed on customer wafers at the factory to develop critical testing capability for production testing and often product development. Test routines are developed and then submitted to rigorous validation processes utilizing statistics and robust engineering.

Application Specific Testing

A measurement matrix for evaluating MEMS element performance is shown in Table 4. Leakage and Capacitance measurements can typically be performed on any MEMS device. Likewise, using DST, a sensitivity measurement can be made from the electromechanical response of the structural elements. Dynamic response parameters differ slightly for different products but share the same basic test procedures of frequency dwells, frequency sweeps and step responses. The parameters of interest are associated with the specific performance analysis techniques. Gyro quadrature can be effectively measured using the STI 3000 system with inputs placed in the drive loops and outputs sensed in the sense loops

Table 4. Measure Parameters by Product

Product	Leakage	Capacitance	Sensitivity	-3dB Roll-off	Q	Quadrature	Step response	Damping	ROM
Accelerometer	✓	✓	✓	✓	✓		✓	✓	✓
Gyro	✓	✓	✓	✓	✓	✓	✓	✓	✓
Microphone	✓	✓	✓	✓					✓
Magnetometer	✓	✓	✓						✓
Pressure Sensor	✓	✓	✓				✓		✓
Touch Sensor	✓	✓	✓				✓		✓
Light Sensor	✓	✓	✓						✓

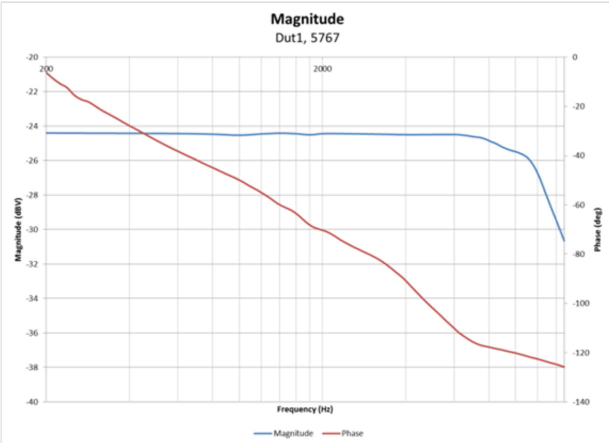
A typical test flow for evaluating MEMS element performance and screening die for assembly is described here. (see Table 3). The test flow consists of a leakage test, capacitance test, sensitivity test and a frequency response test. The tests are completed with a single probe touch and interconnection of the required resources is handled in the switching array.

Table 5. Generic Test Flow

Test	Typical Conditions	Response
Leakage	1V	Current, pA
Capacitance	1V, CMR	Capacitance, pF
Sensitivity	1Vpp, 3Vdc, 1000Hz	dBV
Frequency Response	1Vpp, 3Vdc, 200Hz to 20kHz, 200Hz increments	dBV

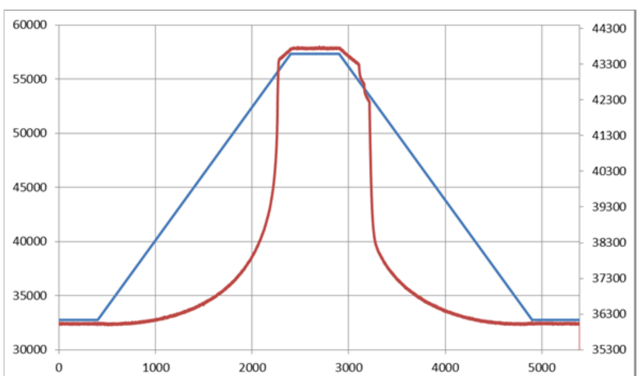
The first test is a leakage test and is carried out by placing a fixed voltage across the moving structural element and the fixed electrode. The current is then measured across the pads by measuring very low picoampere-level currents. The second test is a capacitance test which is carried out by placing a fixed voltage across the moving structural element and the fixed electrode. The capacitance is then measured across the pads by measuring very low picoampere-level currents. The third test is a sensitivity test. For sensitivity and frequency response tests the STI 9000 ATE unit generates a digital voltage drive stimulus that is conditioned into an analog signal by the STI 3000E subsystem. This AC source signal is output to the die probes and drives the sensor element. The STI 3000E then measures the element response, conditions the response signal and then the signal is in turn processed and digitized by the ATE response subsystem. The resulting processed data is saved for further analysis and can be evaluated real-time to screen defective die. Specifically, the element is driven through a series of sinusoidal dwells generated from digital patterns at constant amplitude and the element output response is measured at each frequency. The final test measures the frequency response (Figure 3), where the element is driven through a generated sinusoidal sweep pattern with constant amplitude and increasing frequency. The element output response is measured over time and data is processed using a fast fourier transform (FFT).

Figure 3. Frequency Response Test Results



A range of motion test is useful in evaluating the wafer processes and can often detect potential reliability issues. The range of motion test places a voltage sufficient to pull the diaphragm structure to the fixed electrode, a condition called ‘pull-in’. Generally this test is completed on a subset of die to evaluate the processing of a single wafer. (Figure 4) shows the input and output of a typical pull-in test. An input voltage that is ramped linearly to a peak voltage is placed between the diaphragm and the fixed electrode. Here the voltage peaks at 7.5V and the microphone diaphragm pulls in between 7 and 7.5 volts and appears to compress up to 7.5 volts. Note there is a slight decompression when beginning the ramp down as the figure shows two small releases before a final ‘unsnap’.

Figure 4. Range of Motion Test Results



Other Test Considerations

With all MEMS testing, care must be taken to assure the die is in a stress-free and distortion-free condition. At the wafer level, this means the wafer must be in a flat and stable condition. The test state of the moving element may require that vacuum is not present at the diaphragm openings and that airflow is not hindered by the wafer chuck or other impediments. Solidus has worked extensively to come up with unique methods and designs to provide solutions to many of these fixturing problems common at wafer probe.

In conclusion, utilizing Solidus Technologies suite of test hardware, software and industry expertise in the MEMS market space can resolve the “MEMS One Test”.

A U.S. patent is pending on Drive Sense Technology.

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[i] The MEMS Test Quagmire, Bryon Moyer, Electronic Engineering Journal, December 19, 2011