Solidus Technologies

AN-1100
Application Note

MEMS Microphone Testing at the Wafer Level

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Introduction

MEMS microphones are a new class of acoustic sensors that have been miniaturized to the micro-level using fabrication techniques derived from the production of integrated circuits. These devices have improved performance over existing solutions and are soon likely to be available at lower costs. A key element of reducing cost is reducing the test costs through lower test times and product cost through more effective screening of the micro-machined sense elements. Wafer processing introduces the opportunity to test at the wafer level. Solidus Technologies has developed the STI 3000 wafer level test system to provide unparalleled screening of microphone performance before final packaging and test. The purpose of this application note is to outline test requirements, introduce the STI 3000 system and describe a typical MEMS microphone test sequence.

Background

MEMS microphones use a sensing element that is integrated in an electronics package with additional microelectronics. The sense elements are produced on silicon substrates or wafers, by fabricating microstructural elements that are optimized to transduce sound into electrical signals. MEMS microphones derive their operational principles from condenser type microphones developed at the turn of the last century. For a typical MEMS microphone the microstructural elements are a moving diaphragm of several microns thickness and fixed diaphragm of around 20 microns thickness that provides a fixed electrode. The diaphragm picks up the incident sound waves, acts as one plate of a capacitor, and the vibrations produce changes in the distance between the plates. In the presence of a bias voltage this vibration produces a change in capacitance which is sensed as a change in voltage.

MEMS microphones are rapidly gaining market share in applications such as cell-phones, computers, tablets and headsets. These applications have been traditionally dominated by electret microphones, which use a permanently charged material to replace the DC bias required on a condenser type microphone. MEMS microphones have advantages in size and performance and are soon to overtake electret microphones in lower cost. The opportunity for MEMS microphones is to provide the performance of a DC-polarized, condenser microphone at a fraction of the size and cost. MEMS microphones are smaller than electret devices because they use smaller area diaphragms enabled by thinner structural elements provided by precision semiconductor type deposition processes. MEMS enable smaller footprints and lower height with a more common surface board attachment. The elimination of charged materials provides better temperature performance and eliminates requirements for low assembly temperatures. Small sense element size and low cost provides a new configuration of multiple microphone die in array formats that can improve directionality and provide noise cancellation. Wafer level processing eases integration with CMOS and therefore amplifiers and A/D converters. This in turn has led to the development of digital interfaces which further improve immunity to RF and EMI.

Basic Operation

A typical MEMS microphone has a diaphragm that moves with motion of the incident sound waves. The diaphragm acts as one plate of a capacitor and the fixed substrate acts as the other plate of the capacitor. When a sound source is close to the diaphragm, the vibrations are produced which change the distance between the plates. The vibration is measured in the system as a change in voltage proportional to the change in the plate capacitance.

For the basic diaphragm system, the capacitance is $C = Q/V$, where Q = charge in coulombs, C = capacitance in farads and V = potential difference in volts. Neglecting fringing, the capacitance is $C{=}\epsilon A/d$, where ϵ is the permittivity of the material between the gap, A is the area of the diaphragm and d is the gap height. The plates are biased with a fixed voltage, which acts to produce a nearly fixed charge Q. As the capacitance changes, the charge across the capacitor does change very slightly, but at audible frequencies it is essentially constant. When the diaphragm moves with an incident sound wave there is a change in gap which in turn causes a change in capacitance: $\Delta C=\epsilon A/\Delta d$. The fixed charge provides a voltage change of $\Delta V=Q/\Delta C$, and

$$\frac{\Delta V}{V}=\frac{\Delta CQ}{CQ}=\frac{d}{\Delta d}$$

Thus for the basic concept, we see output proportional to $1/\Delta d$ and in turn expect ΔV to be linearly proportional to the motion caused by the sound waves for small diaphragm motions. The capacitance of the capsule (around 5 to 100 pF) and the value of the bias resistor (100 MΩ to tens of GΩ) form a filter that is high-pass for the audio signal, and low-pass for the bias voltage.

Performance Parameters

Microphones are specified by several key parameters that will be discussed here. These are the sensitivity, frequency response and dynamic range. Sensitivity is the electrical output of the microphone as a function of a standard acoustic input. The standard reference input is a 94dB sound pressure level (SPL) signal at 1kHz sine. This is also referred to as a 1 Pa pressure level. The sensitivity is generally provided in decibels (dB) and is typically negative. Higher sensitivities therefore have lower absolute values. Sensitivity will trade off with headroom, such that a higher sensitivity microphone will reach the maximum output at a lower input which will cause distortion.

Frequency response is the electrical output of the microphone at a fixed input over a given frequency range. The frequency range of interest for a microphone is typically the same as the human hearing range of 20Hz to 20kHz. Generally the parameter is specified as a range expressed as units of ±x dB across a specified frequency range. As the microphone system is a second order mechanical oscillator system it is customary to specify a 3dB roll-off point. The roll-off is at −40 dB/decade and is referenced to the output level at 1kHz, normalized to 0dB. A typical measured frequency response is shown in figure 1. An ideal microphone will have a very flat response over a range of 20 to 20kHz.

Dynamic range is a parameter that describes the linear response range of the microphone. The dynamic range is the difference of the quietest linear response SPL from the loudest linear response SPL. This is generally the maximum input minus the level at which the microphone first responds.

Testing Approach

The approach described here is to use the Solidus STI3000 to provide a comprehensive test at the wafer level and avoid costly fall-out at the final test stage. The STI3000 wafer-level test system is a reconfigurable ATE test system designed to interface to industry standard probe stations and is ideal for testing MEMS microphones. The STI3000 can provide an electromechanical stimulus that is well correlated to the final input conditions. Very small signals can be detected eliminating the need for on-chip or ASIC amplification. The system not only provides static capacitance and leakage behavior measurements as with conventional wafer test equipment but can provide significantly more information about the die. This includes functionality, performance parameters and more importantly screening in catastrophic failures. The DST methodology provides critical information about the element's structural integrity, including detection of contamination (particulates), stuck or cracked elements, and other process anomalies. A typical wafer level test can be completed under 1.5 seconds/die. The system works equally well for die and sensor level characterization and can provide considerable data validating parametric design models or problem solving.

Wafer level sense element fabrication opens the opportunity to test before assembly and integration. As typical for any sensor, final test is often the first effective test of microphone sensor elements due to the need for sensor-specific stimulation. The microphone sensor die is generally assembled and tested before critical mechanical parameters can be evaluated 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. Furthermore, microphone-specific stimulation requires integration of automated test equipment (ATE) with sound sources. These systems are effective, but suffer from high system costs and complex customization.

STI3000 Platform

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 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 second 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.

The STI 3000 configuration includes the STI 9000 ATE system and the STI 3000E sub-system (Figure 1, 2 and Table 1). The STI 3000E provides high performance test electronics at the probe ring. The STI 9000 is a full function standalone ATE solution for packaged parts and interfaces to the STI 3000, providing access to the standard software test suite. A custom probe ring provides physical interface to the die and is based on die layout and test requirements.

Figure 1. STI3000 System Configuration

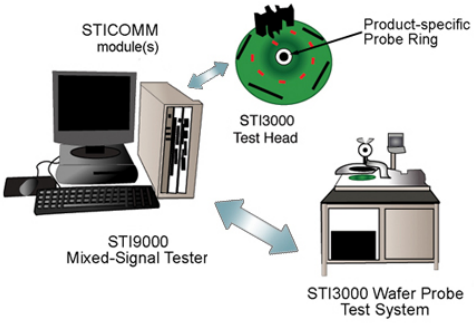


Table 1. STI3000 System Configuration

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 (Table 2). In addition to high performance PMU, DIG and DDS resources, the STI 3000 provides the STI 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 2. 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

Microphone Testing

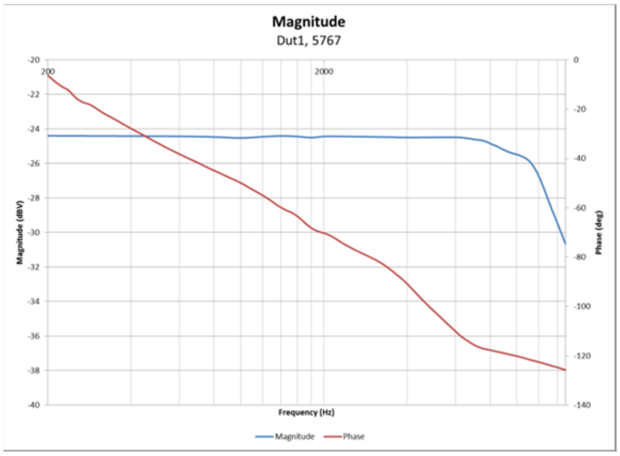
A typical test flow for evaluating element performance and screening die for assembly is described here for a MEMS microphone (Table 3). The test flow consists of a leakage test, capacitance test, sensitivity test and a frequency response test. The tests are completed with a single probe touch and interconnection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

Table 3. Test Flow

Test	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

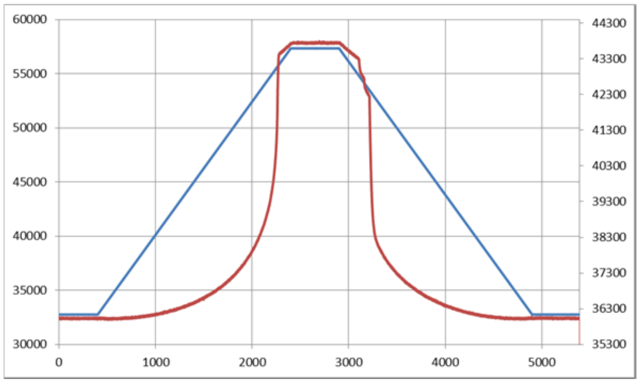
The first test is a leakage test and is carried out by placing a fixed voltage across the diaphragm and the fixed electrode. The current is then measured across the pads by measuring very low picoampere-level currents. The second test is a capacitance test which is carried out by placing a fixed voltage across the diaphragm 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, 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 diaphragm 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 develop 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 provides value during wafer level testing for MEMS microphones.

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

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