AN4428
Application note

Best practices in the manufacturing process of MEMS microphones

Introduction

This application note serves as a reference concerning best practices in the manufacturing process of MEMS microphones.These products have undergone thorough quality and reliability testing as ST manufacturing processes have been carefully studied and developed to achieve highly reliable devices. *Section 1: Quality assurance* details the various tests performed on the microphones.

This document also provides recommendations to properly manage the microphones during processes performed by the customer such as verification of the device upon reception, proper handling of the device and production line considerations.

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1 Quality assurance

1.1 Reliability tests

This section lists all of the reliability tests performed on the microphones.

1.1.1 HTOL: high-temperature operating life

The device is stressed in a dynamic configuration, approaching the operative max absolute ratings in terms of junction temperature, load current, and internal power dissipation. This test is intended to simulate the worst-case application stress conditions. The test is performed to investigate typical IC failure modes like oxide faults and metal degradation and to check overall IC parametric stability.

1.1.2 HTS: high-temperature storage

The device is stored in an unbiased condition at the maximum temperature allowed by the package materials, sometimes higher than the maximum operative temperature. This test is performed to investigate the failure mechanisms activated by high temperature; typically wire-bond solder joint aging, data retention faults, and metal stress-voiding.

1.1.3 PC (JL3): preconditioning (solder simulation)

The device is submitted to a typical temperature profile used for surface mounting, after controlled moisture absorption. This test is done to investigate in general the effect of customer manufacturing soldering enhanced by package water absorption. As a standalone test it is used to investigate the level of moisture sensitivity. As preconditioning before other reliability tests it is used to verify that the surface mounting stress does not have an impact on the subsequent reliability performance.

1.1.4 TC: temperature cycling

The device is submitted to cycled temperature excursions, between a hot and a cold chamber in air atmosphere. This is done to investigate failure modes related to the thermo-mechanical stress induced by the different thermal expansion of the materials interacting in the die-package system. Typical failure modes are linked to metal displacement, dielectric cracking and molding wire-bond failure.

1.1.5 Electrostatic discharge (human body model, machine model, charged device model)

The device is submitted to a high-voltage peak on all pins, simulating ESD stress according to different simulation models. This test is needed to classify the device according to its susceptibility to damage or degradation by exposure to electrostatic discharge.

1.1.6 LU (CI): latch-up (overvoltage and current injection)

This test consists of forcing a current into an input pin or requiring a current from an output pin. Under these conditions, removing such a current, no change of the magnitude of the supply current must be observed. This is done to verify the presence of bulk parasitic effect-inducing latch-up.

1.1.7 THB: temperature humidity bias

The device is biased in static configuration minimizing its internal power dissipation, and stored at controlled conditions (ambient temperature and relative humidity). This test is aimed to investigate the failure mechanisms activated in the die-package environment caused by electrical field and wet conditions. It is mainly oriented to highlight typical failure mechanisms of IC in these conditions like electro-chemical corrosion.

1.1.8 LTS: low-temperature storage

The device is stored in an unbiased condition at the minimum temperature allowed by the package materials, sometimes lower than the min. op. temp. This is useful for investigating the failure mechanisms activated by extremely cold conditions for prolonged time.

1.1.9 Repeated free-fall

The device is subjected to repeated mechanical drops. This test is performed in order to check the robustness of the MEMS microphone when subjected to repetitive mechanical stress.

1.1.10 MS: mechanical shocks

The device is subjected to 10000 g / 0.1 ms, 5 shocks for each axis. It is intended to determine the compatibility of the component(s) to withstand moderately severe shocks as a result of suddenly applied forces or abrupt change in motion produced by handling, transportation or field operation.

1.1.11 VVF: vibration variable frequency

The device is subjected to a vibration with peak acceleration 20 *g*, 20 Hz to 2000 Hz where three perpendicular directions have been applied. The vibration variable frequency test is performed to determine the effect of vibration, within a specified frequency range, on the internal structural elements.

1.1.12 MTC: moisture and temperature cycling

The device is subjected to cycled temperature and moisture exposure. The test serves to investigate device robustness against the combined stress of moisture and temperature cycles.

1.1.13 Air compression

This test consists of applying high-pressure air into the sound inlet of the microphone. This application of compressed air is repeated five times for 1 sec from different distances. The test is performed using an air gun and its purpose is to check the robustness of the MEMs membrane. The device passes the test if there is no variation of the sensitivity.

Figure 1. Air compression test

The results of the ST MEMS microphone in terms of reliability are indicated in the table below. This table contains the data of the MP34DT01 used as an example.

Table 1. Reliability test results of the MP34DT01

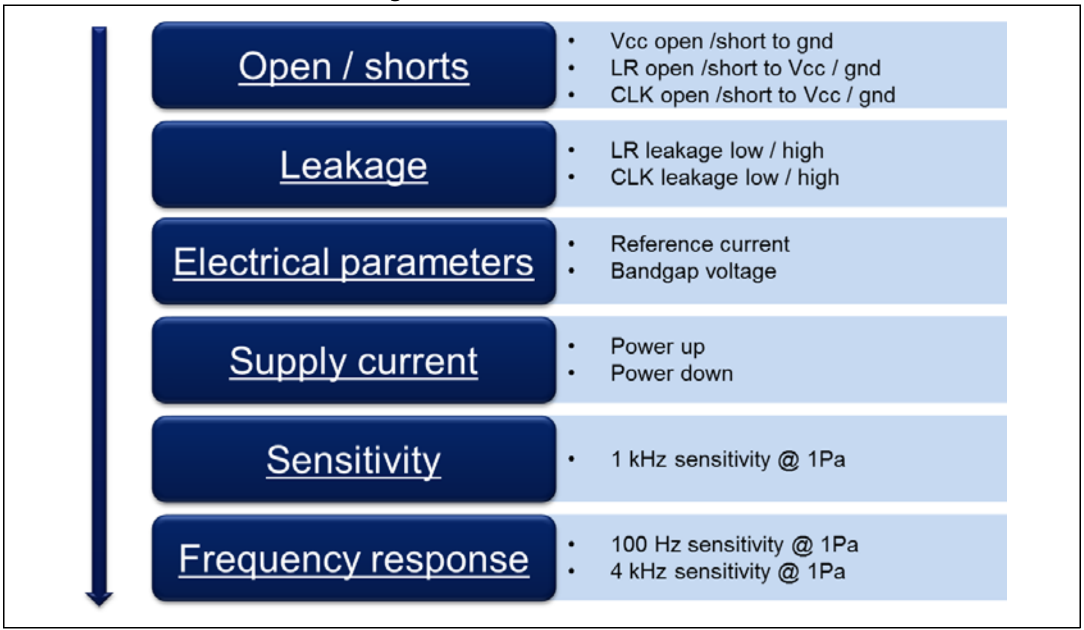
Test name	Condition/method	Period or frequency
Preconditioning (Jedec Level 3)	Moisture Sensitivity 3 1 Week at < = 30°C/60%RH Peak body temperature = 260°C Reflow profile = J-STD-020C	Final
HTOL	Vdd(max) = 3.6 V; Tamb = 125°C JESD22a108	168 H 500 H 1000 H
THB	Vdd(nom) = 1.8 V T = 85 °C / RH = 85% JESD22a108	168 H 500 H
HTS	Ta = 120°C JESD22a103	500 H 1000 H
TC	Ta cycling: -40°C/+125°C JESD22a104	100 Cy
LTS	Ta = -40°C JESD22a119	500 H 1000 H
ESD HBM	Voltage +/-2000 V J EDEC / JESD22-A114E	-
ESD MM	Voltage +/-200 V JEDEC/JESD-A115-A	-
ESD CDM	Voltage +/-500 V ANSI / ESD STM 5.3.1 ESDA	-
Latch-up and overvoltage	Current injection +/-200 mA overvoltage 1.5 x Vmax EIA/JESD78	-
Repeated free-fall	Drops from height = 1 m IEC 60068-2-32	300 drops
MTC	Ta cycling: +30°C/+65°C RH=+90%/+93% IEC 60068-2-30	144 H
MS	10000g/0.1ms 5 shocks for each axis MIL STD 883MIL	-
VVF	Vibration with acceleration peak 20G, variable frequency from 20Hz to 2000Hz; applied in three perpendicular directions for 16 minutes on each direction, 48 min total JESD22-B103B	48 min

1.2 Final test information

After production the microphone must be screened to avoid shipping failing parts to the final customer. Both electrical and acoustic parameters are tested. First of all the microphones are tested in terms of electrical behavior. The ASIC, on each pin, is rigorously analyzed to find any occurrence of open circuit or shorts. Additionally the device is analyzed to check for any evidence of current leakage. Finally, reference voltages and current consumption are checked. Once the entire electrical parameters have been verified, the microphones are screened in terms of acoustic performance. It is sufficient to test the sensitivity and the frequency response in order to determine whether the microphone works properly or not. The sensitivity can be used to determine if the membrane is damaged in which case the THD, as well as the noise floor, is out of specification. Finally the sensitivity is checked across the audio band.

Each microphone is tested according to the previously mentioned criteria to avoid shipping failing parts.

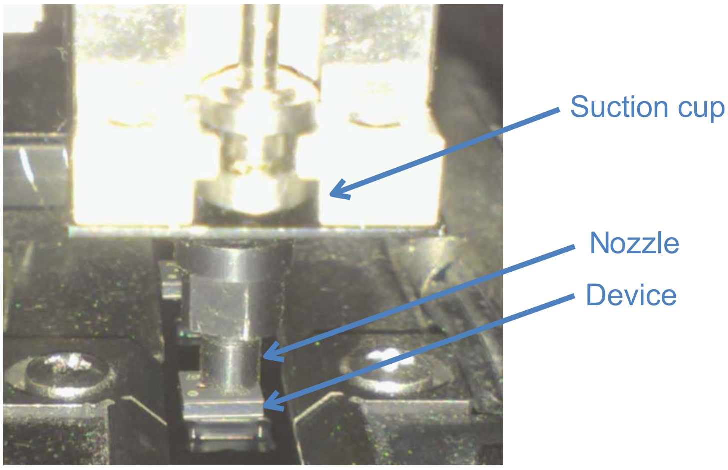
Figure 2. Final test checklist



1.3 Pick-and-place settings

The process of assembly of the printed circuit boards is fully automated owing to dedicated machines. Basically these machines are used for high-speed, high-precision placement of electronic components, like capacitors, resistors, or integrated circuits onto the PCB. These systems normally use pneumatic suction cups, and at the end, a nozzle accurately picks the device from a predetermined area.

Figure 3. Pick-and-place machine



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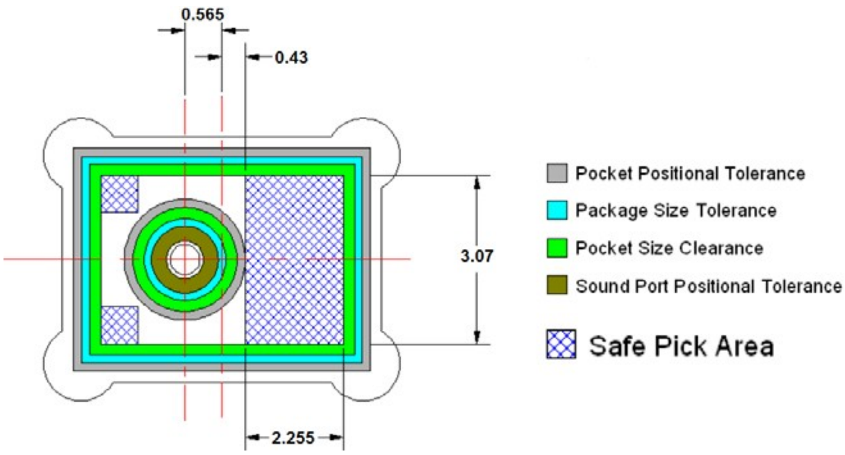
In the case of microphones, this process must be rigorously controlled since the position of the nozzle, the force involved in the pick and place, and the mechanical parameters can damage the structure of the microphone. Hence, a reference/safe pick area is defined for each microphone depending on the dimension of the package.

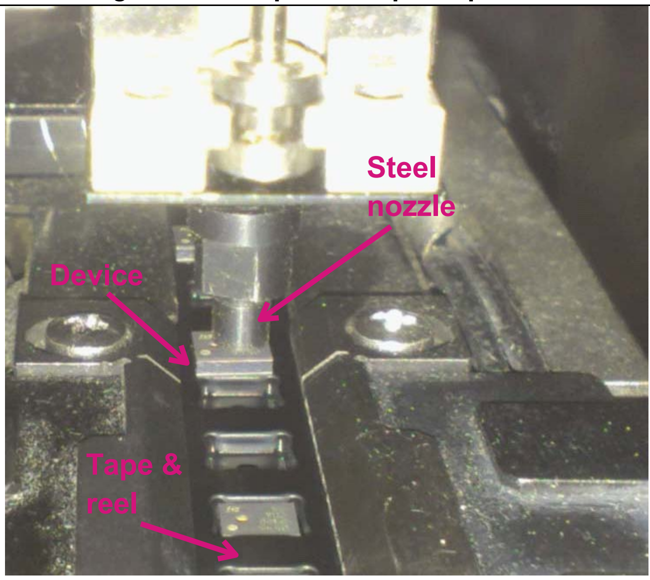
The reference pickup area for the generic 4x5 top-port MEMS microphone is shown in *Figure 4*.

Figure 4. Picking area for 4 x 5 microphones



Basically the safe area has been set in order to not pick up the component by the top of the microphone sound port, thus preventing damage to the MEMS membrane or an incorrect pickup and placement. Additionally this safe area has been dimensioned, considering the tolerances of all the mechanical parameters involved in the process, i.e. position of the sound inlet, microphone package dimensions and pocket dimensions.

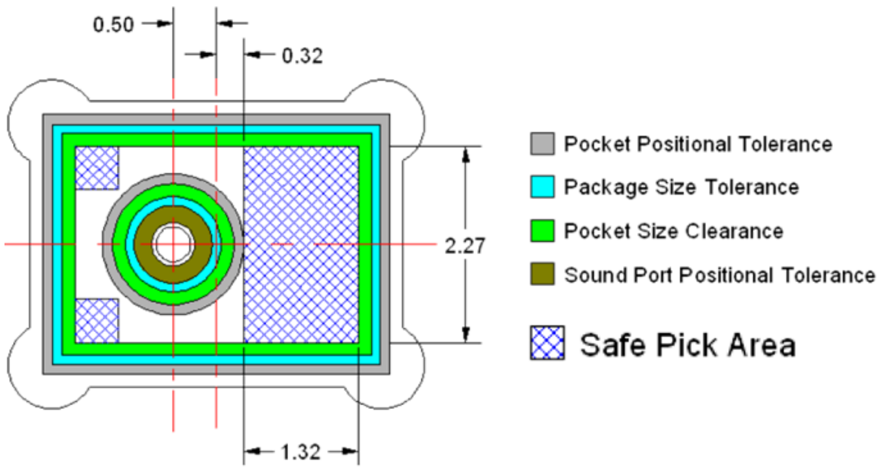
Figure 5. 4 x 5 pick-and-place process



The nozzle for picking up a 4 x 5 microphone is commonly a steel picker with a cylinder shape respecting the safe area indicated in *Figure 4: Picking area for 4 x 5 microphones*. The vacuum port at the bottom side of the picker is a hole with a diameter of 1 mm.

The safe pickup area for the 3 x 4 microphone is almost the same but with different dimensions due to the different package outline. As shown in the previous design, the following area has been dimensioned, also considering the tolerances of all the mechanical parameters involved in the process; i.e. position of the sound inlet, microphone package dimensions and pocket dimensions. The 3 x 4 safe area is indicated in the following figure.

Figure 6. Picking area for 3 x 4 microphones

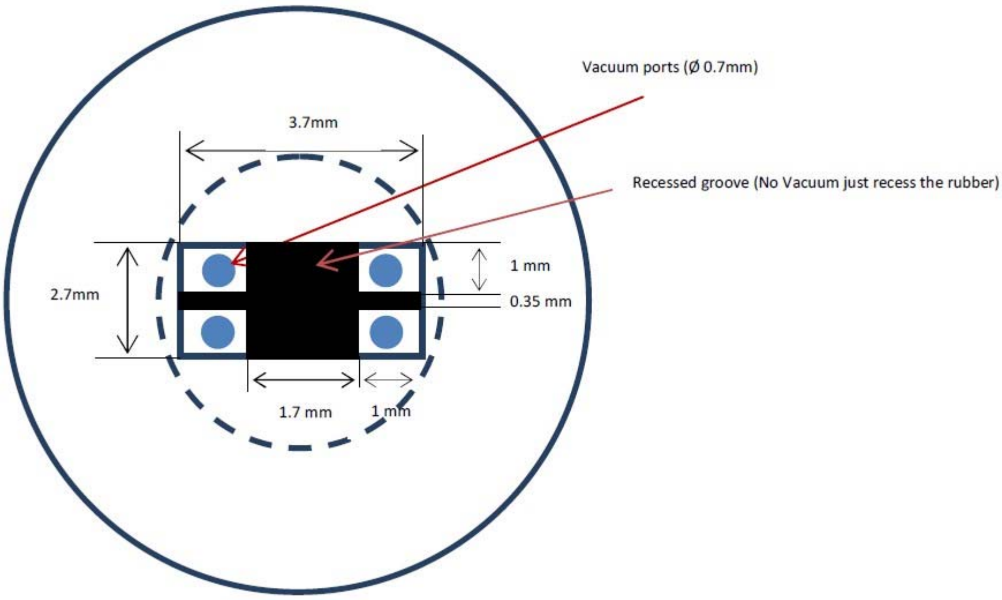


To optimize the microphone yield, a dedicated picker has been designed to fully fit the allowable safe area; hence, the currently used nozzle for the 3 x 4 microphones has 4 vacuum holes for each corner (refer to *Figure 7*).

Figure 7. 3 x 4 new design nozzle

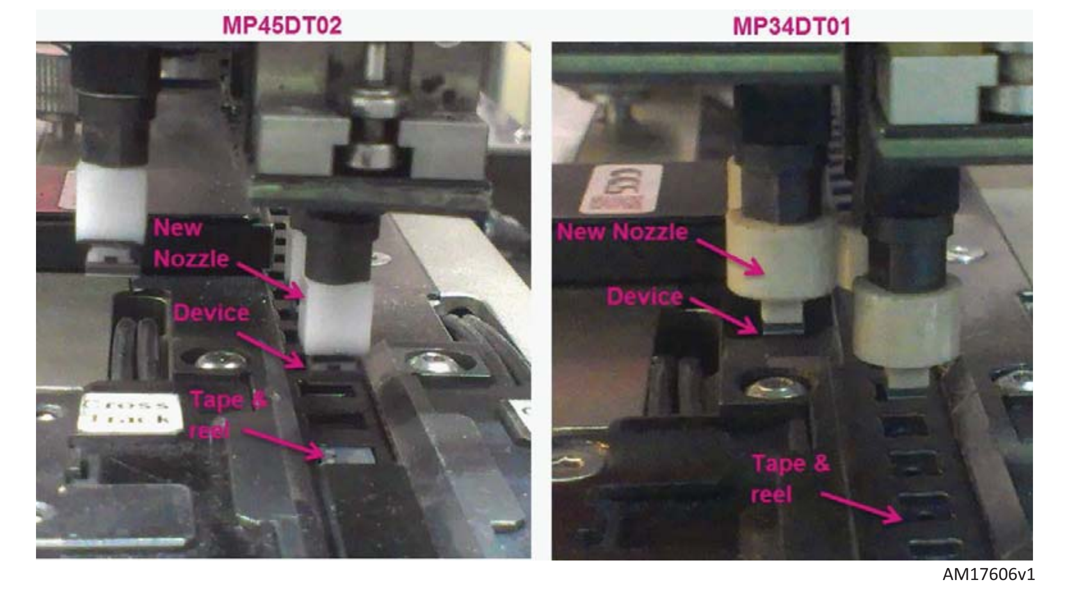
This design ensures that the holes for the vacuum and the air blow are always away from the porthole of the device (4 vacuum ports at the corner of the device). Additionally, the new design has also a recess, in the form of a cross, allowing the porthole to be left always at atmospheric pressure. Under these conditions, the membrane will not suffer any sudden air disturbances during the picking or placing of the device in the tape and reel. *Figure 8* shows the detailed mechanical dimensions of the new picker, the positioning of the vacuum holes and the width of the recess.

Figure 8. Picker mechanical details for HLGA 3 x 4 microphones



The safe areas of the 4 x 5 and 3 x 4 microphones are identical and differ only in the dimensions. The safe area of the 4 x 5 microphones includes the safe area of the 3 x 4 microphones; hence, despite this difference, the 4 vacuum port nozzle can be used for both microphone packages. The following figure shows the usage of the 4-hole picker in the ST production line (finishing).

Figure 9. Actual pick-and-place nozzle used in ST manufacturing facilities



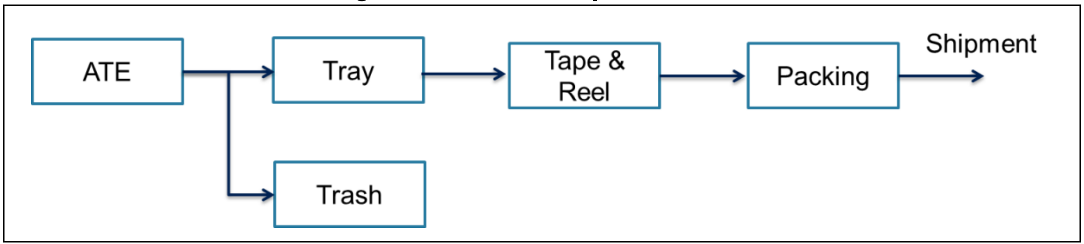
Finally, other parameters must be rigorously controlled for the proper handling of the device: the force of the vacuum and the pressure of the nozzle on top of the microphone package. The pressure of the nozzle depends on the velocity and the height during the picking of the device but also depends on the force set for the placement of the nozzle on the safe area. To correctly control the forces involved during the pick-and-place process, the following indications must be respected:

- Do not allow more than 7 psi[a] vacuum force
- Usually the picker is set to a minimum distance from the component (100-200 µm)
- Recommended placement force on the safe area is below 500 g

1.4 Pre-shipment

The flowchart below represents the back-end process from testing to shipment. Basically the devices are tested according to electrical and acoustic parameters (ATE), they are placed in a tray, then they are placed in a reel using the automatic pick-and-place machine and finally the microphones are packaged and shipped to the customer.

Figure 10. Back-end process flow



a. 1 kPa = 0.145 psi (lb/in²) = 0.0102 kgf/cm² = 0.0098 atm maximum allowed pressure on microphone package

2 Customer manufacturing considerations

2.1 Customer handling recommendations

The purpose of this section is to summarize, for typical failures that can occur in the customer's production line, an explanation of the issue first and then to propose a solution or even give a recommendation to avoid these failures, usually caused by mishandling of the device.

2.1.1 Contaminations

When the component provides a PDM output that when listened to or measured shows poor SNR performance or very noisy output, the issue is typically due to contamination of the MEMS membrane.

Contamination during PCB sawing, during PCB cleaning or washing can occur in a customer's production line. Further contamination can happen during device soldering if a vapor phase soldering process is used for the reflow or some soldering paste accidentally drops inside the sound inlet.

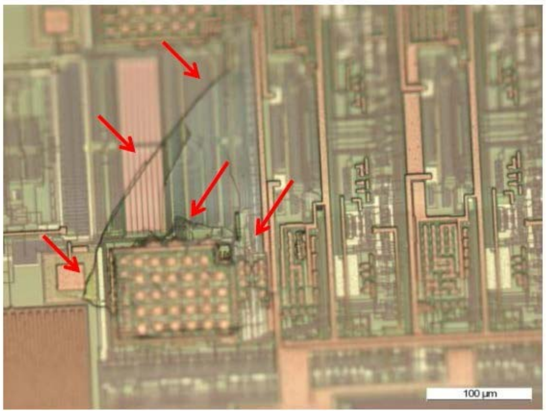
To avoid these types of contaminations, the sealing of the sound inlet with foam/tape before sawing to prevent dust from entering the microphone is recommended. As a matter of fact, using a vapor phase soldering process must be avoided to prevent membrane damage and contamination.

2.1.2 Electrical overstress (EOS)

When the component does not show any signal at the output or the output is tied to GND (or to Vcc), most probably the ASIC has been submitted to an electrical overstress.

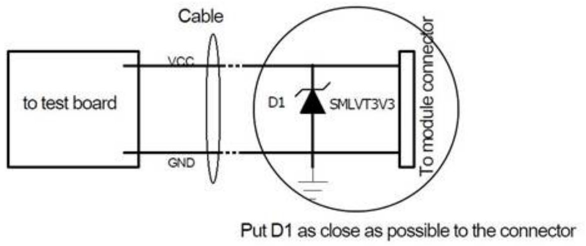
Electrical overstress is an unexpected electrical phenomenon, like a high-voltage discharge, that can cause irreversible damage to the ASIC such as burned areas or voids in the silicon.

Figure 11. Example of EOS



To avoid this issue, it is highly recommended to verify the supply voltage vs. microphone operative and max absolute voltage specifications, or also to verify the voltage ripple when doing hot plug to testing jigs. A diode (spike suppressor) can be included in the testing equipment using the following configuration.

Figure 12. Spike suppressor configuration



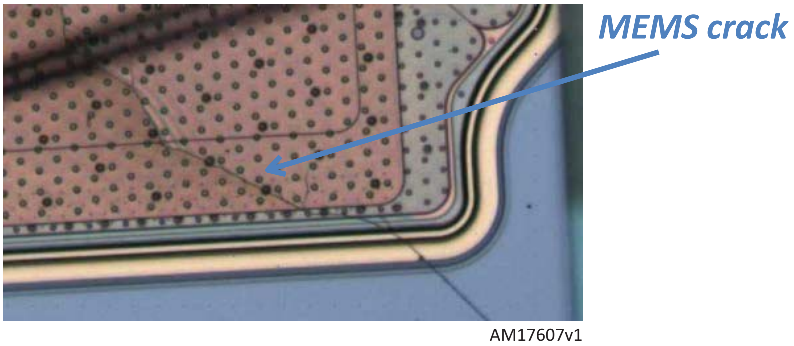
A spike can also be caused by an electrostatic discharge. ESD can be a problem when there is a wrong or poor connection of the operators or of the equipment to ground. Additionally it must be carefully checked that ESD does not exceed the declared values of the components. Improving ESD protection in the production line is highly recommended in order to avoid this kind of issue.

2.1.3 Mechanical overstress

If the component sensitivity is excessively far from the specification value, most probably the membrane has been damaged. Such damage is typically caused by a mechanical overstress.

The ASIC in the component is working properly, but performing a visual inspection reveals that the MEMS microphone membrane is damaged. The membrane can be affected by cracks or voids due to heavy mechanical overstress. Such stresses can be caused by multiple reasons. When the microphone is mounted on a module, it is important to control the module assembly on the final equipment (typically a laptop). During the assembly the screwdriver can hit the microphone damaging the membrane. In general, high shock events, above 10,000 g, can happen at other instances during handling due to equipment design or configuration. Mechanical shocks can also be caused by the pick-and-place equipment, for example if the nozzle does not pick in the proper area or if the machine picks or places the device with excessive force. Finally, also the usage of air to clean PCB can be dangerous if the pressure is too high.

Figure 13. MEMS sensor crack example



To avoid the issues listed above, the customer must pay attention in setting the production line parameters such as the path of the screwdrivers on the modules (if any) and carefully set the equipment to avoid any kind of dangerous shocks. A further recommendation is related to the pick-and-place equipment. ST strongly recommends using the nozzle with 4 vacuum holes specifically designed to minimize the issue related to mechanical overstresses in production line. For the same reason, the forces involved in the pick-and-place process must be controlled. High pressure (few bars) for long distances (few mm) can make the part reach velocities around 3 to 5 meter / sec. In case of impact the resulting shock can be much higher than 10, 000 g. During the picking process the picker is set to a minimum distance to the component (100-200 µm). Conversely, regarding the placing process, the recommended force must be set below 500 g. As a last recommendation, if using an air gun to clean the PCB, ST recommends limiting the pressure of the air flow.

2.1.4 Cavity detachment

The malfunctioning of the device in terms of any audio parameter, sensitivity, SNR, frequency response, THD, can be related to the detachment of the cavity.

The detachment of the cavity is a phenomenon where one a portion of the package is detached. This can be caused by free-fall of components over a rigid surface from more than 1 meter. Another possible reason is the cutting of the PCB if there is the need to separate different sections of the board. Cavity detachment is typically caused by mechanical overstresses but can also be caused by thermal stresses. As a matter of fact, if the reflow profile differs from the standard one, the glue on the package can be weakened, losing its fixing capability. As a last reason the detachment can be caused by a force exceeding 2.5 g for tape removal (when tape is applied to cover the microphone inlet for top-port devices).

Figure 14. Cavity detachment example

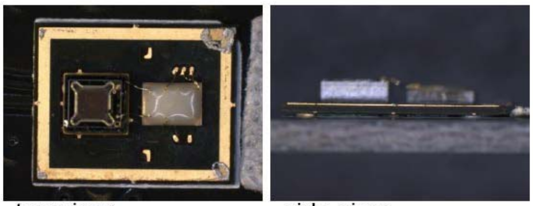
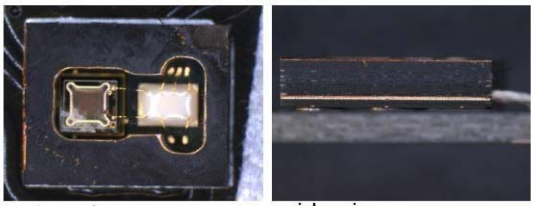


Figure 15. Cavity ceiling detachment example



To avoid detachment of the cavity, a good practice is to avoid any mechanical overstress as listed in *Section 2.1.3*. Additionally, following the ST recommended reflow profile and reducing the force to 1 kg for tape removal are further advised.

Appendix A Bibliography

1. IPC/JEDEC J-STD-020D.1. Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices
2. STMicroelectronics - AN4211 Guidelines for soldering MEMS microphones
3. STMicroelectronics internal document: Good Practice using MEMS microphone in Production Line v1.31
4. STMicroelectronics MP34DT01 reliability report

3 Revision history

Table 2. Document revision history

Date	Revision	Changes
09-Jan-2014	1	Initial release.