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Silicon based in-situ measurement system for flex loads on MLCCs in PCB manufacturing chain

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ABSTRACT

A new in-situ monitoring method of mechanical loads acting on MLCC (multi layer ceramic capacitors) devices during the PCB manufacturing chain is presented in this paper. A S^3MD (**s**tress **s**ensitive **s**urface mounted device) is designed as a silicon based package equivalent with strain sensitive pattern for an 0805 SMD chip device. Metal thin film resistors of Cu55Ni45 and Ni65Cr35 are used as resistive strain sensitive elements. A solderable termination is created to get the solder mounting option. Bending tests like descripted in AEC Q200 “Board Flex” were done to obtain the load limits for different MLCC termination types. Therefore a suitable PCB is designed with 4-terminal-sensing. Different bending speeds are performed to characterize the possibility to analyze creeping behavior of the solder or adhesive joint with the S^3MD sensor elements. Finally a depaneling process with rotary blade is performed with an in-situ measurement of the load intensity acting on the devices during the process depending on the cutting edge distance.

1. Introduction

Multi-layer ceramic capacitors are widely used in the electronic manufacturing. However, due to the brittle character of the base material they are vulnerable to flex loads which are created by mechanical processes like depaneling or screwing the board into a housing. In case of overloads they react with characteristic flex cracks failure. In this case a strongly decrease of the capacitance is recognizable. In further use impurities and moisture infiltrate and create a short-circuit path which can destroy the whole circuit. In the past the MLCC manufacturers created electrode designs to avoid the appearance of a parasitic current path in case of cracking by losing capacitance overall. Another strategy is to place two devices in series to have a redundant insulation. However these are also avoiding strategies and do not solve the problem. In the past there were some activities to measure the loads during the processes by using foil strain gauges. Therefore the strain gauges were placed on an unassembled board. But due to using unassembled boards the mechanical overall system is significantly changed. The stiffness of highly populated boards is highly dependent on the mounted devices. Further the used strain gauge measures the strain of the board surface. However the mechanical interface between the board and the device is the solder joint and is totally neglected in this procedure. In the past several different approaches were done to use silicon based sensors for stress analysis in the electronic packaging environment [1–4]. In this paper a new method is presented to evaluate the acting mechanical loads on an MLCC during the manufacturing process. A silicon-based packaging equivalent with strain sensitive pattern is used to characterize the acting loads under real circumstances and considering the solder joint properties. We call this new type of sensor devices S^3MD (**s**tress **s**ensitive **s**urface mounted device). Due to substitution of an MLCC device with such an S^3MD sensor device at a vulnerable location, the loads at the device location can be measured during specific processes.

The method is divided into two parts. First, a characteristic in the AEC Q200 Board Flex experiment is generated with the S^3MD sensors. This experiment is a standardized bending test, which is used to qualify the withstanding of ceramic capacitors to bending loads. With corresponding bending experiments with S^3MD sensors the strains can now be detected at the S^3MD components. In the result corresponding values for strain at the sensor elements and deflection of the PCB board can be obtained. The second part is the measurement in the process. The S^3MD devices are mounted in exchange of an MLCC and at the sensor occurring strains at the sensor are measured during the process. By using the characteristic out of the first step the measured strains can now be converted in a value of equivalent deflection regarding to the AEC Q200 “Board Flex” experiment. It should be noted that the values are not comparable with the real stresses occurring at an MLCC. But with this

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Fig. 1. AEC Q200 Board Flex experiment, which is used to qualify ceramic capacitors regarding to their durability to bending loads.

Table 1
Used material properties in the FE-model of the standardized bending test of the AEC Q200.

Volume	Material	Young's modulus	Poisson ratio
PCB	FR4	22.6 GPa (Experiment)	0.13 [6]
SMD base body	Silicon ⟨1 1 0⟩	170 GPa [7]	0.28 [8]
	Glass MEMpax®	62.7 GPa [9]	0.19 [9]
Pads	Copper	125 GPa [10]	0.34 [11]
Solder	SAC	69.3 GPa [12]	0.29 [12]
ICA	EpoTek H20E	4.3 GPa [13]	0.31 [13]

method a connection can be established between the real occurring stresses during the manufacturing process and the abstract method of qualification because of the equivalence in respect to the device geometry and the material behavior.

2. Simulation of the AEC Q200 "Board Flex"

As mentioned above the durability of MLCC in respect to bending loads is qualified in the AEC Q200 Board Flex experiment [5]. This is a 3-point-bending test which specifications are shown in Fig. 1. Common MLCCs are graded on the dielectric specified to withstand a bending deflection h_b of 2 mm, 3 mm or 5 mm (flex term type). Therefore the metering capacity of the strain measuring sensor elements needs to cover these loads.

FE simulation was used to verify the range of the occurring strains on the top and bottom side of the SMD base body during the AEC bending test. A quarter model was designed with the geometric specifications of the AEC bending test. The used material properties are given in Table 1.

Three types of assembly technologies were modeled to estimate the influence of the different assembly technologies on the later sensor response. The first is the standard SMD chip soldering with a solderable sidewall and a solder meniscus. The second type is the soldering without a wettable sidewall and subsequently without a solder meniscus. This configuration is interesting because of the 2D characteristic of the wafer based fabrication processes. The pattern on the top and bottom side can be created on wafer level. An optional sidewall metalization has to be done sequentially after a first dicing process. Therefore it is necessary to estimate the influence of the meniscus on a later sensor response and to consider the necessity of this technological effort. The third type is the use of ICA instead of solder material. This is important for assemblies on heat sensitive materials, e.g., in the 3D MID (Molded Interconnect Devices) technology.

The results of the FE simulation of the acting strain on the device top side is depicted in Fig. 2. It can be seen that the different degrees of freedom between the type with meniscus and the types without meniscus result in a divergent strain characteristic. The soldering with meniscus shows a elongation whereas the soldering and gluing without meniscus show a compression with one order of magnitude higher intensity.

On the device bottom side, however, the occurring strain characteristic depends only slightly on the assembly configuration. In the configuration soldering without meniscus the simulation provides a 11.2% higher strain value than with meniscus, which can be explained by increasing degrees of freedom of the sidewalls. In the configuration with conductive adhesive the simulation provides a 6.0% lower strain value, which results from the lower modulus of elasticity and the associated stress-compensating effect of the adhesive layer. The results of the bottom side are depicted in Fig. 2.

The higher strain at the bottom side was expected because of the direct contact with the bended substrate. Also in the well-known flex crack failure mode the crack nucleus starts at the bottom side of the capacitor and propagate upwards. The reduced strain at the top side is explainable because of the reduced number of degrees of freedom due to the fixing of the sensor element by the solder material especially at the variation with wettable sidewalls and a solder meniscus.

Based on these results the device bottom side is identified as the suitable position to place the strain sensitive pattern. The strain

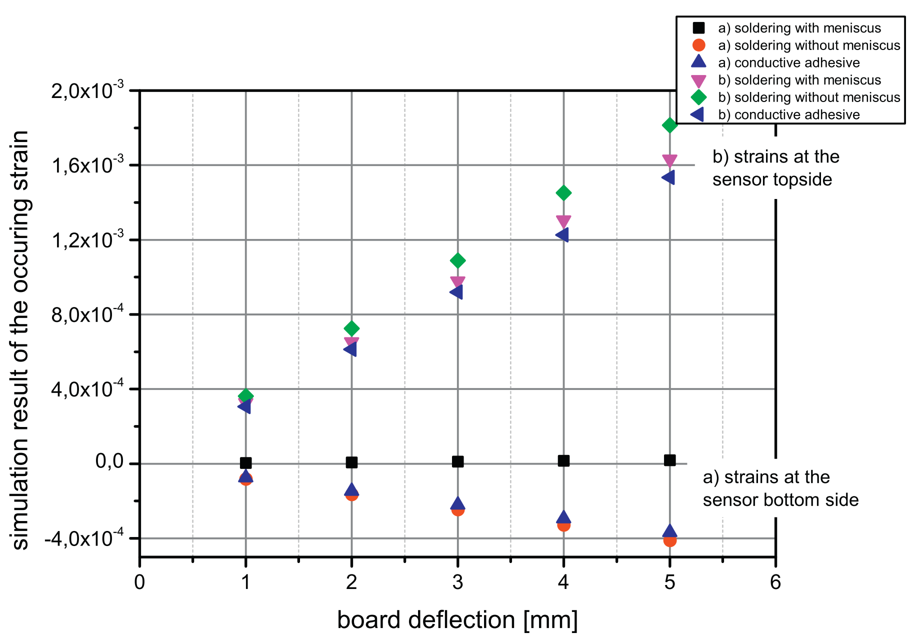

Fig. 2. Simulation results of the appearing strain at the bottom side (a) and the topside (b) on different deflections in the AEC Q200 Board Flex experiment.