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A System for Calibration and Reliability Testing of MEMS Devices Under Mechanical Stress

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Abstract

Microelectromechanical systems (MEMS) are employed in safety-critical fields such as automotive, aerospace and medical applications. In all these fields, reliability-related system characterization receives growing attention. This includes studies on the possible deterioration of the device during manufacturing, i.e. system test in the course of fabrication, and in the application. This paper reports on a setup and a method that enables the automated analysis of mechanical stress impact on MEMS devices. The system comprises a 6-inch compatible automated wafer stage with electrical probing capability combined with an impact control unit for the application of well defined forces to the MEMS device. The impact control unit itself consists of an xyz stage for the precise positioning of an impact object that is moved against a target in a force-controlled mode. The experiments allow optical inspection during force application and can be performed either on the wafer level or using single chips. This experimental setup presents a significant improvement over an existing setup that has been applied in characterizing various MEMS devices. It is improved with respect to the maximum applicable force, accuracy in force measurement, speed of force application, and repeatability. The new setup is characterized by a maximum static force of 10 N and accuracy in force measurement of 2 mN. Further, dynamic loads can be induced to the device under test at frequencies of up to 1 kHz. As an example, the paper describes the calibration of a highly sensitive cantilever-based tactile force sensor used in the metrology of microcomponents.

1 Introduction

Microelectromechanical systems (MEMS) are employed in safety-critical fields such as automotive, aerospace and medical applications. Therefore, their reliability is receiving growing attention. This includes both ensuring the correct functioning of a MEMS just after it has been fabricated, i.e., the manufacturing test and studying the possible deterioration of the device in its application. The latter issue is of special importance, as MEMS applications often intrinsically involve mechanical stress which could damage or destroy the microstructures [1].

The manufacturing test focuses on deciding whether a part is ‘good’, i.e., can be shipped to the customer, or ‘bad’. The reliability studies examine the device’s ability to retain the desired functionality in possibly harsh environments.

In this paper, we propose a system for fully automated wafer-level test of mechanical stress impact on the functionality of MEMS. The mechanical stress is induced by an impact object that exerts a force on the surface of the device under test (DUT). The applied force level, force duration, frequency of dynamic force loads and the location at which the force is applied are user-defined and can be precisely controlled. The measurement system can step over a 6-inch wafer without operator interaction and hence is well suited for long-term stress test runs. Electrical and optical inspections of device behavior before, during and after the application of mechanical stress to the DUT are available.

The system is modular, which implies a high degree of flexibility with respect to the DUT, the impact

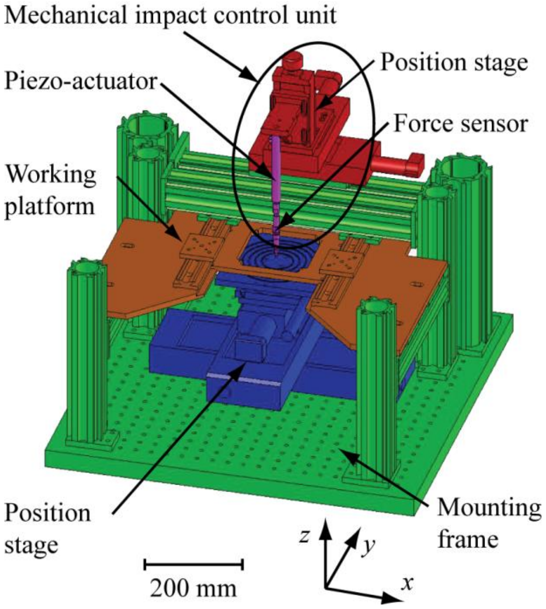

Figure 1: *Experimental setup consisting of two position stages, working platform, piezo-actuator, and a force sensor.*

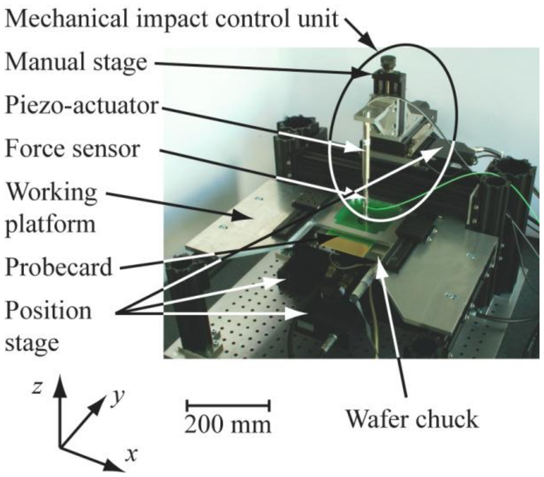

Figure 2: *Photograph of the measurement system with probcard used for electrically contacting the DUT, piezo-actuator to generate the force applied to the DUT, position stage to move the wafer with respect to the piezo-actuator.*

object and the type of analysis. Possible DUTs include micromechanical sensors such as accelerometers or gyroscopes, which have to be reliable in the presence of mechanical stress caused for instance by the plastic package. The devices may be CMOS-based MEMS or systems manufactured in one of the numerous bulk or surface micromachining MEMS processes. Even conventional non-MEMS ICs used in harsh environments are an interesting object of investigation. The impact object can be chosen freely out of a large number of possible candidates.

2 Experimental Setup

The new measurement setup is a major redesign of a former system [4]. The previous setup has proven its capability in a variety of different measurements. As an example, it was used to characterize 3D silicon force sensors [5]. Important sensor characteristics such as stiffness of the silicon structure and fracture load were determined. In addition, it was possible to show in a longterm test that there is no degradation of the sensor signals in the first 50 000 load cycles.

During these measurements some drawbacks of this first setup become obvious. As an example, the maximum force was limited to 3.6 N due to the stiffness of the entire setup. The new version of the setup is now able to apply forces up to 10 N achieved by a stiffer design of the entire setup and the replacement the piezo-actuator of the mechanical impact control unit. Further, the maximum frequency of force application frequency has also been an issue. It was increased from 20 Hz to 1 kHz.

2.1 Mechanical Assembly

The mechanical part of the measurement system (Figures 1 and 2) can be divided into the following components. First, the *positioning stage* (blue) is used for wafer stepping. The second component is the *working platform* (brown) equipped with different holders for a probecard and optical measurement systems. Finally, the so called *mechanical impact control unit* (red and pink) responsible to generate the forces to be applied to the DUT.

The *positioning stage* consists of two linear stages (OWIS LIMES 120) with a traverse path length of 200 mm mounted in x and y direction enabling the access of any chip on a 6-inch wafer. Furthermore, the positioning stage comprises a third linear stage (OWIS HVM 60) for the wafer positioning in z direction and a rotation stage (PI M-036). The rotation stage is used eliminate the misalignment of wafer axes and positioning stage axes after placing the wafer on the vacuum chuck. The absolute positioning accuracy of the wafer in the measurement system is better than 3 µm.

The *working platform* is mounted above the positioning stage and holds a probe card. In this way, it is possible to measure the electrical response of the DUT during force application. However the measurement system is not restricted to the use of a probecard as it is also possible to apply standard probe heads. In addition, if it is necessary to measure the deflection of the DUT caused by the applied force, an optical measurement system can be mounted on the working platform.

The most important component of the entire measurement system is the so called *mechanical impact control unit*. This unit consists of two xy linear stages (OWIS LIMES 90) with a traverse path length of 30 mm and a positioning accuracy of 100 nm. A manual z stage for a coarse approach of the piezo-actuator is mounted on top of the two linear stages. This is necessary due to the fact that the piezo-actuator for force generation has a traverse path length of 90 µm only. The positioning accuracy of the piezo-actuator is better than 2 nm. This allows a precise application of force and respective deflections of the DUT. The piezo-actuator is equipped with a force sensor able to measure forces up to 50 N with an accuracy of 2 mN.

2.2 System Control

Figure 3 shows a schematic view of the complete mesurement setup. The measurement setup is fully controlled by a PC using LabVIEW®. The electrical and optical gauges are connected via the GBIP Bus with

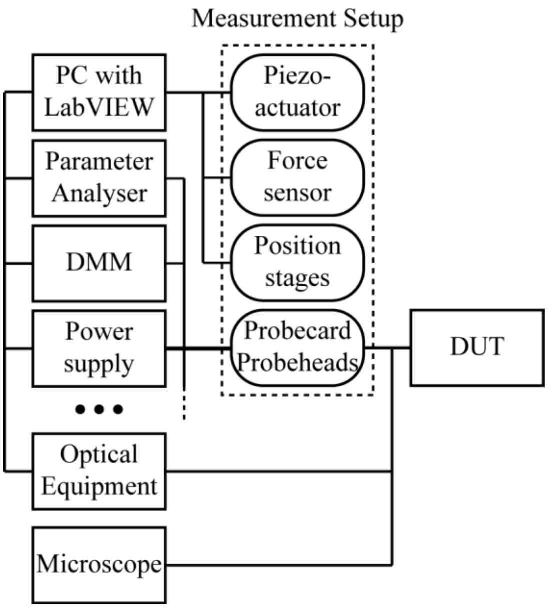

Figure 3: *Schematic view of the system. The DUT is connected to the gauges for electrical measurement via a probecard or probeheads. The microscope is used for optical inspection of the DUT and the optical equipment for measuring the deflection of the DUT.*

the PC. This enables to add any further gauge required for a certain measurement without any problem. The piezo-actuator and the force sensor are connected to the PC via RS232. This enables faster communication between these three components needed for the force adjustment control. An adjustment control for the deflection is not need, due to the fact that the controller of the piezo-actuator already has one implemented.

The microscope is used to assist the coarse alignment of the DUT with the impact object. The other optical equipment may be mounted on the working platform to measure for instance the deflection of the DUT during the measurement.

3 Experimental Results

The new measurement setup has already been applied for a variety of different measurement tasks. Among others, we could successfully determine the fracture load of (i) neural probes developed in the framework of the European project NeuroProbes, (ii) a improved version of a 3D force sensor [4] and nickel beams deposited by electroplating using the LIGA process.

Figure 4 shows a cantilever based tactile sensor system which has been characterized in detail with the novel setup. The sensor and its fabrication sequence are detailed in [6]. It comprises a platform (1.8×1.8 mm) with bonding pads, a membrane (thickness 60 µm) suspended cantilever (length 7 mm, width 150 µm, thickness 380 µm) and a piezoresistive sensor element integrated in the membrane hinge.

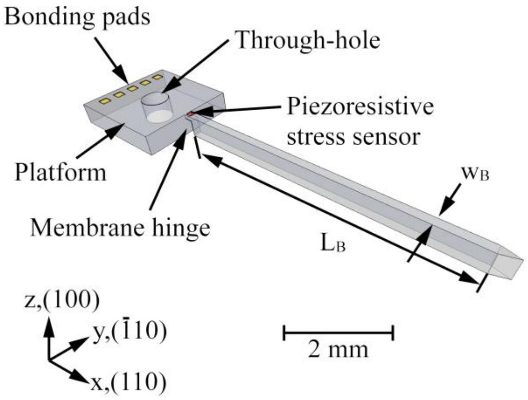

Figure 4: *Schematic drawing of the cantilver-based tactile sensor suspended by a thin membrane hing with a thickness of 60 µm (cantilever length L_B=7 mm width w_B=150 µm) [6].*

In a first step, the location of the cantilever tip has to be determined using the following sequence: (1) Alignment of cantilever and setup with respect to the *xy* axis; (2) coarse placement of the impact object close to the cantilever tip; (3) vertical deflection of the beam by 20 µm and (4) movement of the impact object along the beam towards the tip. The beam tip is defined as the position where the force sensor of the impact control unit no longer detects any force exerted by the beam. Figure 5 shows the extracted relative position of the cantilever tip for five consecutive measurements with a standard deviation of 370 nm.

For the determination of the beam stiffness, the impact object was moved 50 µm away from the cantilever tip. At this position, the force-displacement characteristic of the beam was measured 50 times as shown in Figure 6. An average beam stiffness of 199 N/m with a standard deviation of 1.7 N/m is obtained. Each measurement required 5 s. The combination of a force-displacement and a voltage-displacement measurement is shown in the Figure 7. The sensor shows a force sensitivity of 9.74±0.05 mV/V/mN.

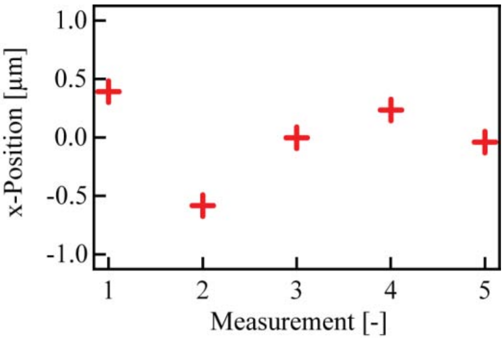

Figure 5: *Estimated position of the beam tip with a standard deviation of 370 nm*

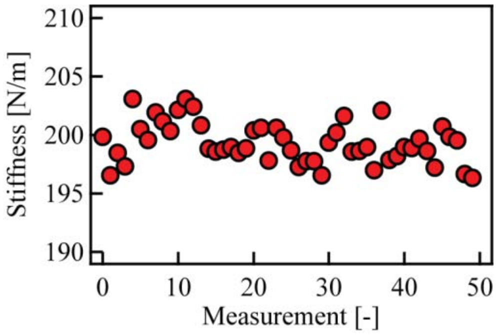

Figure 6: *Extracted stiffness from 50 force displacement measurements of the cantilever based sensor with a membrane thickness of 60 µm.*

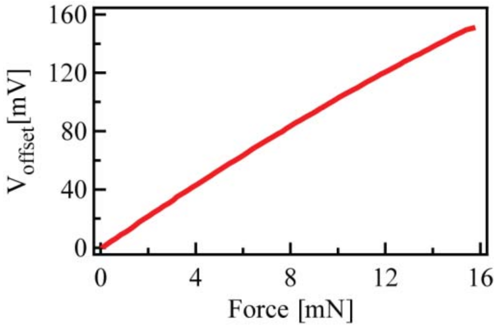

Figure 7: *Voltage-force characteristic of the cantilever based sensor with a membrane thickness of 60 µm*

4 Conclusions

We implemented a modular test system for wafer-level electrical inspection of MEMS under mechanical stress. Test parameters such as force level, frequency and location are programmable, and the impact object can easily be exchanged. Wafers with diameters up to six inches can be stepped automatically through the system. Consequently, the system is suited for characterization and accelerated stress screens for different types of MEMS.

While studying and improving the reliability of the device under test is an important application of the equipment, our long-term goal is to enhance our understanding of defect mechanisms in MEMS. Of particular interest is the applicability of structural test methods based on fault models to MEMS testing as suggested in [7]. A further field of investigations is the quantitative analysis of the influence of built-in self test and self repair structures on MEMS reliability [8].

Acknowledgement

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