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Automatic Imaging Based Wafer-Level In-Line Measurement for Piezoelectric MEMS Mirrors

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Summary:

This work presents the hard- and software development of a customized setup, to determine the total optical scanning angle (TOSA) and respective resonance frequency of resonant MEMS-scanners on wafer level during in-line testing. These electrical measurements are usually used to evaluate piezoelectric layer quality and to monitor the manufacturing process. However, the mechanical properties of the complete MEMS-scanners are characterized manually which limits high volume process. The integration of the mechanical measurements into the automated in-line testing leads to a drastic measurement time decrease as well as vastly improved resolution on imaging technique base.

Keywords: MEMS mirror, piezoelectric, silicon technology, MEMS optical component

Motivation

During the fabrication of silicon technology-based processes, in-line tests are conducted to monitor fabrication processes and yields.

The in-line characterization of a MEMS-scanner is an essential part of its process flow. It involves several electrical measurements to characterize leakage current and dielectric strength of the piezoelectric material and the quality of electricity conducting metal layers. Those are important parameters to evaluate single layers or layer stacks. However, the complete MEMS-scanner device is usually characterized based on the maximum TOSA shown in Figure 1 and the respective mechanical resonance frequency of the working mode(s) of the system.

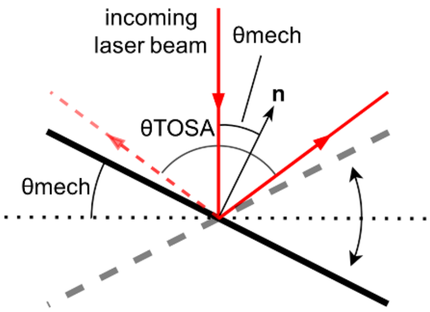

Fig. 1. Illustration showing the relation between the mechanical angle θ_{mech} and the TOSA θ_{TOSA} of an oscillating mirror plate in two directions with the normal vector n.

This is in most cases a manual labor process limiting high-volume production. An automated in-line measurement on wafer level is an excellent alternative that enhances time effectiveness and improves the optimization of process steps.

Resonant MEMS-Scanners

An automatic measurement setup has been developed for the resonant MEMS-scanners as shown in Figure 2.

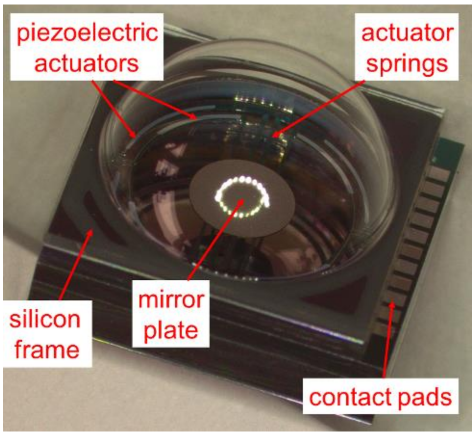

Fig. 2. Microscope image of a resonant MEMS-scanner. When an electric field is applied to the metal electrodes on the top and bottom of the piezoelectric material, the actuators bend up or down. This leads to a tilting movement of the mirror plate. In mechanical resonance, caused by a sinusoidal volt-

age, a laser beam can be deflected by more than 100° TOSA in a single axis [1].

Electrical and mechanical Measurement

During the routine in-line testing several parameters are characterized electrically. Those include among others leakage currents of the piezoelectric layer and sheet resistance of poly-Si layer. The resonance frequency of the system is characterized as well.

This electrically measured resonance frequency from the classic in-line measurement and the mechanical resonance frequency differ since during mechanical drive more non-linear effects from material stiffening and air resistance occur. This describes the behavior of a Duffing oscillator. [2]

To measure the mechanical resonance frequency and the maximum TOSA, the electrical resonance frequency is used as a starting point. The applied AC frequency is increased incrementally, while an increase in TOSA is observed. The mechanical resonance frequency is reached at the maximum deflection angle.

The optical TOSA measurement of a resonating MEMS-scanner is shown in Figure 4.

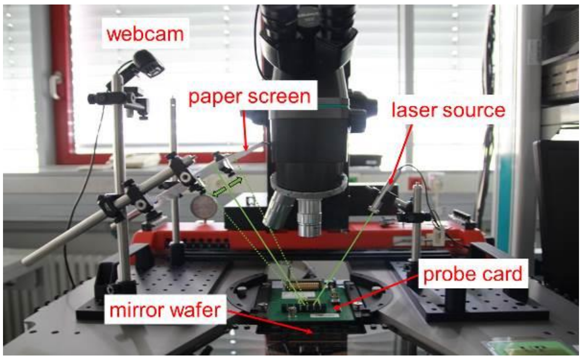

Fig. 4. Optical measurement setup placed inside a semi-automatic wafer-prober with integrated wafer and the respective probe card. An incident laser beam is reflected by an oscillating mirror plate. The resulting one-dimensional scan pattern is projected on a screen. The screen is recorded by a camera. The dotted lines show the geometric limitations of the setup in the wafer prober. Scanning angles exceeding the limits are blocked.

Software and Integration

The hardware is accompanied by a software upgrade that allows the process control unit to measure optical scanning angles and their respective mechanical resonance frequencies.

A developed image process software analyzes the recording of a deflected laser beam in the L*a*b color space to separate the deflected scan pattern from the background. By calibration, the length of the resulting illuminated line is translated to a deflection angle.

Improvements

The developed system poses significant improvements compared to the manual measurement. The time consumption is reduced by a factor of 10 while the resolution is increased from ±2° to ±0.1°.

Outlook

Due to the setup in the semi-automated wafer prober, the deflection angle is geometrically limited to 20°x20°. In consequence, the MEMS-scanners cannot be driven to their maximum possible TOSA. However, a reproducible small TOSA at a comparatively low voltage for several chips gives a good estimate on possible mechanical failures.

To integrate the system into the main process flow of resonant MEMS-scanners, further optimizations are needed. Therefore, different designs of piezoelectric resonant- and quasi-static- as well as electrostatic MEMS-scanners have been tested on wafer level. With their varying resonant behaviors, the tradeoff between low measurement time and frequency step size for resolution increase can be refined. This will lead to a more efficient and resilient system.

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