An interferometric test station for massive parallel inspection of MEMS and MOEMS

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Abstract— The paper presents the optical, mechanical, and electro-optical design of an interferometric inspection system for massive parallel inspection of Micro(Opto)ElectroMechanicalSystems (M(O)EMS). The basic idea is to adapt a micro-optical probing wafer to the M(O)EMS wafer under test. The probing wafer is exchangeable and contains a micro-optical interferometer array. Two preliminary interferometer designs are presented: a low coherent interferometer array based on the Mirau configuration and a laser interferometer array based on the Twyman-Green configuration. The optical design focuses on the illumination and imaging concept for the interferometer array. The mechanical design concentrates on a scanning system and integration in a standard test station for micro-fabrication. The smart-pixel approach for massive parallel electro-optical detection and data reduction is discussed.

Micro-fabrication of Micro(Opto)ElectroMechanical Systems (M(O)EMS) on silicon or glass wafers is today performed in large volumes. . Each wafer often contains several thousand devices. In the production process it is necessary to test both passive and active parameters of structures [1]. Test systems for wafer-based M(O)EMS testing are available on the market today. However, the measurement of active parameters is particularly time consuming, and thus not well suited for on line testing in mass production. This is caused by the serial inspection approach. Also today's inspection systems are inflexible and expensive. Therefore new multifunctional inspection concepts are required based on the same technological platform as the rest of the production chain.

The EU-project SMARTIEHS [2] develops a novel inspection approach solving all challenges given above [3]. By introducing a wafer-to-wafer inspection concept the parallel testing of several dozens of M(O)EMS structures within one measurement cycle becomes possible. To obtain this an exchangeable micro-optical probing wafer is adapted and aligned with the M(O)EMS wafer under test. The probing wafer comprises an interferometer array. The configuration, spacing and resolution of the interferometer array are designed for each specific application. Furthermore, also the illumination, imaging and excitation modules are modular and can be moved from one interferometer array to another. The modules can thus be interchanged if the spatial distribution of the MOEMS structures or changed functionality so requires. The array configuration can be non-regular and optimised for time-efficient inspection strategies. More than 100 interferometers can thus be arranged on an 8-inch wafer and decrease the inspection time of a wafer by a corresponding factor. The pitch of the interferometer arrays is adapted to the pitch of the structures on the M(O)EMS wafer under test. The interferometer pitch is much larger than the pitch of the M(O)EMS structures, because of the size of the imagers. The structures are therefore tested in an interlaced manner.

The wafer-to-wafer concept addresses the production of complete interferometers in an array arrangement by standard micro-fabrication technologies.

In this paper the multifuncionality of the system is demonstrated by two different probing wafer configurations, 5x5 arrays of low coherent (LCI) and laser (LI) interferometers. An array of 5x5 smart-pixel cameras is designed for the detection of interferometer signals. The cameras feature optical lock-in detection at the pixel level [4].

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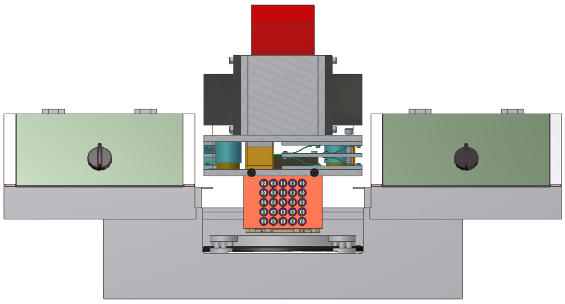

Fig. 1. CAD 3D representation of the SUSS test station (PA200) for M(O)EMS testing, with the inspection system attached at the scope mount of the prober.

The inspection system is mounted on a commercially available wafer handling and positioning system (SUSS prober – PA 200). The M(O)EMS wafer is mounted and positioned using the wafer chuck of the prober. Figure 1 shows a sketch of the prober and the inspection system integrated on the prober. The instrument configuration comprises two different interferometer arrays: a low coherent interferometer (Mirau) and a laser interferometer (Twyman-Green). Light sources are arranged in an array and positioned on each side of each interferometer unit. The light is guided by a beam splitter towards the probing wafer.

A glass wafer containing mini-lenses produced by standard micro-fabrication processes is used for imaging interference fringes towards the camera. A distributed array of 5x5 smart pixel imagers detects interferometric signals. Signal processing is based on the "on pixel" processing capacity of a smart pixel camera array which can be utilised for phase shifting or envelope maximum determination. An excitation system for the M(O)EMS structures is needed for active testing. A glass wafer consisting of Indium Tin Oxide (ITO) electrodes is applied for electrostatic excitation of the resonance frequency of the structures.

The semiautomatic prober system SUSS PA200 supplies chuck movement in x, y, z and rz (r - rotation). This is used for positioning and horizontal scanning of the M(O)EMS wafer. Furthermore, the scope adapter of the prober can be moved in x, y and z. This adapter is used to mount the inspection system. The inspection system can be divided into two main components – a drive unit and an optical unit. The drive unit carries high precision drive and springs. The raw positioning of the inspection system in z is done by the scope drive. However, the linearity and positioning accuracy of the scope drive is not sufficient for interferometric measurements. Therefore a separate high precision drive unit is designed. This ensures parallel alignment of a probing wafer with the M(O)EMS wafer by adjusting rx and ry. Furthermore, the high precision drive has to perform a highly uniform movement and positioning in z. LCI requires a scan over a range of 1mm with a linearity of 1%. LI requires positioning accuracies with a measurement error <10nm and high frequency position stability in the nanometer range.

Those high requirements are met in the design concept by integrating three single drive subsystems. A voice coils- based driving system is selected to obtain the travel range of 1mm. Three commercial interferometer systems deliver position signals with an accuracy of 3nm which enables a positioning accuracy of 10nm. The controller of the drive system will be realized by a rapid controller prototyping system, e.g. dSpace. The two interferometer modules are mounted on the optical unit. The design enables various adjustment possibilities of different optical components.

The optical unit of an inspection system consists of two optical modules, one containing the LI array and one - the LCI array. Figure 2 shows a CAD 3D representation of the optical unit.

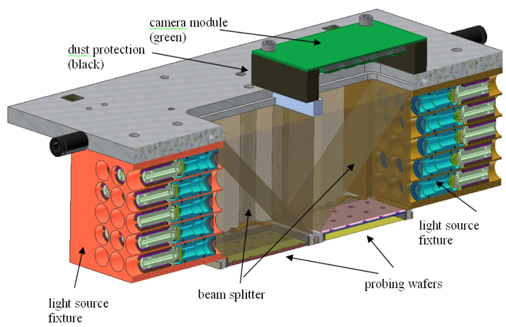

Fig. 2. CAD 3D representation of one of the optical units connected with the camera array

The smart pixel camera (on top) is moveable between the two modules. It is shown in the position for detection of laser interferometer signals. The light source illuminates the M(O)EMS object via a cube beam splitter. The centre of the illumination aperture is thus aligned with the centre of the imaging lens and the centre of the object along the optical axis. The optical axis is deflected 90° by the beam splitter. The centre of the active area in the corresponding camera images the M(O)EMS structure under inspection. Care has been taken to mount the probing wafers without introducing tension in the wafers. Any bending of the wafers will introduce variations in the optical path length in the interferometers and misalign the optical system.

The illumination modules are configured as a matrix of light sources, i.e. light emitting diodes (LED) or laser diodes (LD).

For low coherence interferometry a micro-optical approach of the Mirau configuration is applied. The illumination is realized by an LED array.

Figure 3 shows the preliminary design of the interferometer array. It consists of 2 separate wafers. The lens wafer is carrying imaging lenses and a reference mirror. The beam splitter wafer is a glass wafer with a partly reflective coating on the upper side.

The imaging lens consists of a refractive micro-fabricated mini lens with a diameter of 2,5mm and a diffractive correction lens manufactured on the lower side of the lens wafer. The beam splitter wafer divides the incoming light into a reference beam and an object beam. The reference beam is reflected by the reference mirror positioned in the centre part of the lens. The object beam is reflected back from the M(O)EMS structure under test. Both beams are interfering in the beam splitter wafer. The interference fringes are imaged onto the camera, where the smart pixels detect and demodulate the interference signal.

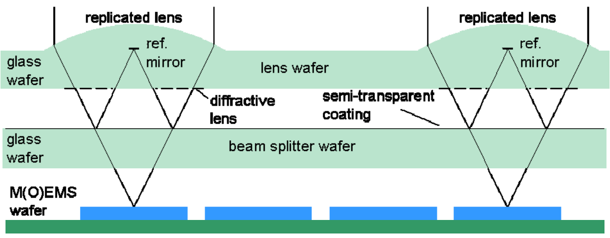

Fig. 3. Preliminary design of a low coherent Mirau interferometer configuration in a matrix approach

LI has the Twyman-Green interferometer configuration as it is proven to be an efficient setup for active full-field M(O)EMS testing [1]. The preliminary design of the LI is shown in Figure 4.

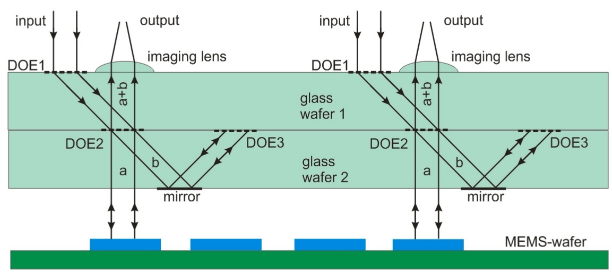

Fig. 4 Preliminary design of the laser based Twyman-Green interferometer configuration in a matrix approach.

The illumination system is realized by a laser diode matrix and an aspheric lens. One laser diode is dedicated to one interferometer channel. The interferometer is formed by two wafers. The top wafer is a thick glass wafer with a diffractive optical element DOE1 etched on the surface. This grating diffracts an incident collimated beam in order to illuminate the beam splitting diffraction structure DOE2. The second wafer is also a glass wafer and contains DOE2, DOE3 and a mirror surface. DOE 2 divides the incoming light in an object and a reference beam The transmitted light of DOE2 forms the reference beam. The DOE3 plays the role of a reference mirror. The diffracted light of DOE2 is directed towards the object surface and forms the object beam. Both beams are recombined by DOE2 and interfere. The interference pattern is imaged by the imaging lens integrated on the glass wafer surface and captured by the camera. The full image of a smart pixel camera consists of the matrix of sub-images given by the interferometer matrix.

The presented inspection system realises a parallel approach for the production test of M(O)EMS. The instrument concept is based on a probing wafer inspecting more than 100 M(O)EMS structures within only one measurement cycle which enables the reduction of measurement time by a factor of more than 100. Furthermore, a multifunctional approach is demonstrated based on interchangeable probing wafers produced by standard micro-fabrication processes. This multifunctional approach of the measurement concept allows the inspection of passive and active parameters within the same inspection system. Two different micro-optical interferometer configurations are presented; the Mirau type low coherent interferometer for shape and deformation measurements and the Twyman-Green type laser interferometer for measuring resonance frequency and spatial vibration mode distribution.

A novel distributed smart pixel camera is developed. It consists of the 5x5 matrix of a smart pixel imager. The smart pixel approach enables "on pixel" demodulation of an interference signal and thus contributes to data reduction and short measuring time. The project is now focussed on final micro-optical interferometer design and the production of a probing wafer.

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