Design of a micro-optical low coherent interferometer array for the characterisation of MEMS and MOEMS

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1 Introduction

The EU-project SMARTIEHS (SMART InspEction system for High Speed and multi-functional testing of MEMS and MOEMS) develops a new inspection concept for MEMS and MOEMS (M(O)EMS) testing at the wafer level [1]. The inspection systems on the market today are based on a serial approach inspecting one M(O)EMS structure at the time. In SMARTIEHS a parallel wafer-to-wafer inspection concept is adopted from the electronic probing cards in the micro electronics industry. A micro-optical probing wafer is aligned with the M(O)EMS wafer under test.

The 4-inch probing wafer contains a 5x5 array of micro-optical low coherent interferometers, inspecting shape and deformations of 25 M(O)EMS structures within one measurement cycle. The measurement time can thus be reduced by a factor of 25, scaling with the no. of interferometers on the probing wafer. A 5x5 channel smart pixel camera array detects and demodulates the interference signals [2].

The design of the micro-optical low coherent interferometer array is presented. The configuration of the array elements is based on a Mirau interferometer. The main challenge is to use standard micro-fabrication processes to produce the micro optical interferometer array.

2 Optical design of the micro optical interferometer array

Fig.1a) shows the configuration of the optical unit of the instrument. The light from a 5x5 LED array is directed via a cube beam splitter towards the probing wafers positioned above the M(O)EMS wafer under test. The M(O)EMS structure is imaged via the beam splitter and the interference signal is recorded by the smart pixel camera array. The whole unit is scanned in z-direction by an external scanning system [1].

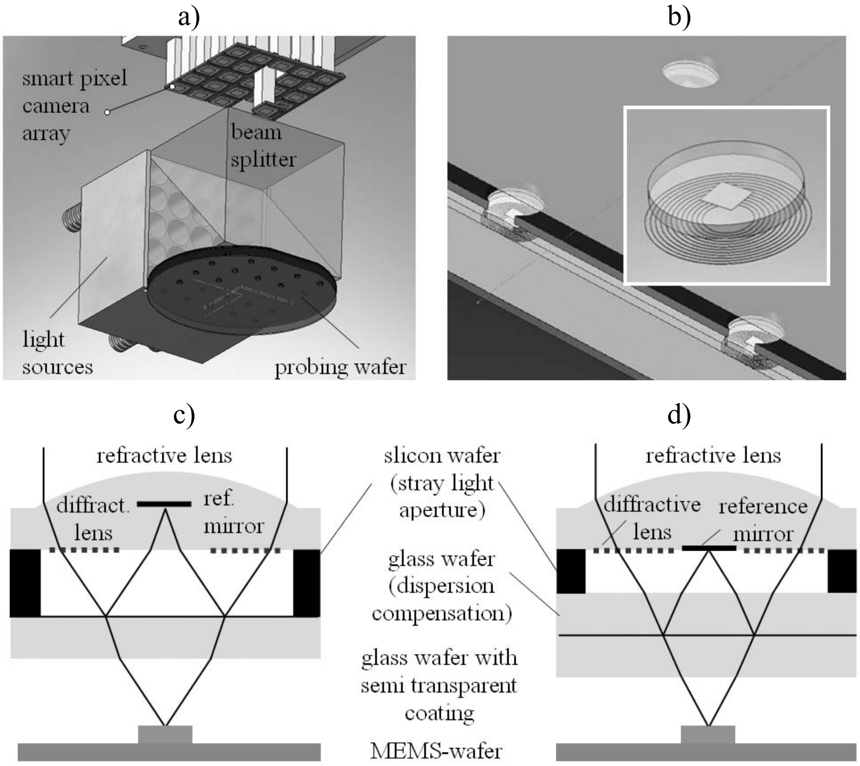

Fig. 1. Lay out of the optical unit: a) instrument configuration, b) close-up of the probing wafer with interferometer configuration (magnified interferometer inserted), c) and d) cross sections of two different configurations for the low coherence interferometer.

The interferometer array consists of a set of wafers that are bonded or glued together forming a wafer stack (fig. 1b). The essential parts are: a microlens array, a reference mirror array, and a beam splitter wafer.

Two different designs of micro-optical Mirau interferometers are developed (fig. 1c and 1d). In both configurations all micro optical components are produced on one single wafer to avoid additional alignment of the wafer stack. Configuration d) requires an additional glass wafer for dispersion compensation. Here the mirror can also be positioned on the topside of the compensation wafer, which however requires a wafer alignment step during bonding and additional spacers between beam splitter wafer and reference mirror wafer.

The optical requirements for the imaging lens of the Mirau-interferometer can barely be fulfilled by a single plano-convex micro-lens. Therefore, these lenses are combined with diffractive elements designed for compensating spherical- and, more important, chromatic aberrations. The design of both optical elements has been performed by using the optical design software ZEMAX [3].

The refractive lens has a circular surface shape with a diameter of 2,5mm and a sag of 162µm. The diffractive element has been considered in the system design as a radial symmetric phase function

$$\varphi(r) = a_1\, r^2 + a_2\, r^4, \tag{1}$$

which is realized as a diffractive surface profile. The design software then accounts for the special chromatic behaviour of this structure and the parameters a_1 and a_2 are optimised for the current system. By including the r^4 term in the design also the spherical aberrations of the imaging are reduced considerably [4].

The light intensity budget is the most critical challenge when using LED illumination in combination with a high speed smart pixel camera. The available light intensity limits the signal-to-noise ratio (SNR) and thus the demodulation frequency of the smart pixel camera. Less than 5% of the light passing through the illumination aperture is transmitted through the optical system towards the camera. To optimise the light efficiency all non-functional surfaces are anti-reflection coated.

Furthermore the size and shape of the reference mirror is optimised. Our micro optical design uses square mirrors instead of the circular mirrors in the conventional Mirau design, to increase the light efficiency. The size is slightly larger than the field of view to allow for some misalignment. If the light efficiency can be improved considerably even an unstructured semi transparent layer could be used, to minimise the alignment requirements.

The production variations of the focal length of the micro lenses can lead to defocused images in the array structure. As compensation the imager chips and the LED mounts can be moved individually along the optical axis to focus each channel separately. Unfortunately this will change the magnification.

Thickness variations of the glass wafers (typically 20µm) have minor influence. They can cause a depth variation in the focal plane in the interferometer channels and a mismatch between object and reference arm. As a result the position of the coherence region and the focal distance are separated. Furthermore dispersion effects occur reducing the contrast of the interference fringes slightly. Pre-selection of high quality planar wafers can help to avoid these effects.

Deformation of a wafer reduces the uniformity of the systems and will have a similar effect. The probing wafers must thus be mounted without introducing mechanical stresses and the system should be vibration isolated from the environment.

Stray light generates cross talk between the interferometer channels. To avoid this, a silicon aperture wafer is included in the design. It can be used as a spacer between the glass wafers or on top of the structure. Furthermore the backside of the reference mirror should be covered with a highly absorptive or diffusively reflective layer.

3 Micro fabrication process of the interferometer

The optical design of the interferometers requires large microlenses. The challenge is to fabricate these large lenses with high surface quality. As a first step, lens moulds are fabricated by chemical wet etching on a silicon wafer. The large size and sag implies a challenging multi-step etching process, combining anisotropic and isotropic wet etching of silicon [5,6].

Then the microlenses are replicated by a glass reflow process. The silicon wafer containing the moulds is anodic bonded to a borosilicate glass wafer in a vacuum environment. Heating the wafers melts the glass and fills the moulds. A first attempt can be seen in fig. 2. The back surface of the glass is polished to reach the needed thickness and optical quality of the glass substrate. Finally, the microlenses are released by etching away the silicon [6]. An alternative technique is the direct moulding of polymer.

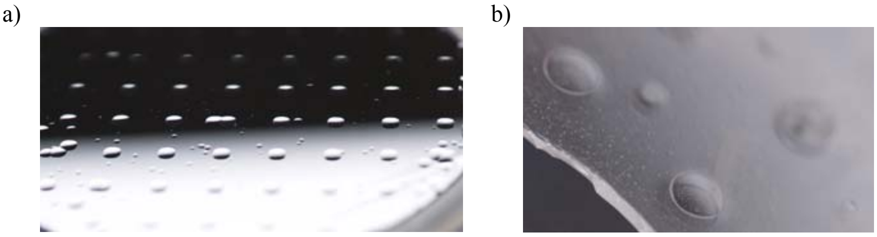

Fig. 2. a) First test of Si moulds. The diameter is successfully reached unless some surrounding defects appear. b) Glass lenses from the mould in before backside polishing

The fabrication of the diffractive structure will be done by laser lithography with the technique of continuous profile writing where a photo resist is exposed sequentially with an intensity modulated laser beam. A subsequent development process leads to a resist profile whose local height is proportional to the applied exposure dose at this position.

The resulting resist profile is then transferred into the final optical structure by UV reaction moulding onto the backside of the lens substrate. The latter process will be performed in a special mask aligner on the whole wafer at once [7]. This gives sufficient alignment accuracy between the refractive lens positions and the diffractive correction structure.

The reference mirror array and the beam-splitter are fabricated by standard micro-fabrication techniques on glass wafers. The reference mirrors are created by lift-off of a 100 nm thick aluminium layer deposited by evaporation. The beam splitter wafer can be realised with different splitting ratios using a multi-layer deposition by Low Pressure Chemical Vapour Deposition (LPCVD).

4 Scanning requirements

The demodulation scheme in the smart pixel camera requires that the frequency of Doppler shift of the interference signal generated by the scanning velocity, is matching the demodulation frequency generated in the synchronous in-phase and quadrature channels of the demodulator [2]. The Doppler shift is typically 1-50kHz and is given by a trade-off between short measurement time (fast scanning) and reduced data transfer requirement and SNR (slow scanning).

The demodulation frequency is set individually in each camera. This allows for variations in centre wavelength of the light sources in the array.

In order to obtain a stable translation of the entire probing wafer, three independent translation stages are needed on three sides of the optical unit. Each of them needs to fulfil the requirements on scanning speed accuracy set by the demodulator. It has been found that the requirement on the deviation for a slow scanning speed is 1%. The requirement on high frequency deviations is $\lambda/20$.

5 Experimental results

A 5-channel interferometer array based on micro-optical components is developed (fig. 3) to test the design principles. In difference to the described design five bulk imaging lenses (aspheric glass lenses, aperture Ø3mm) and a standard CMOS camera (Micron) are used.

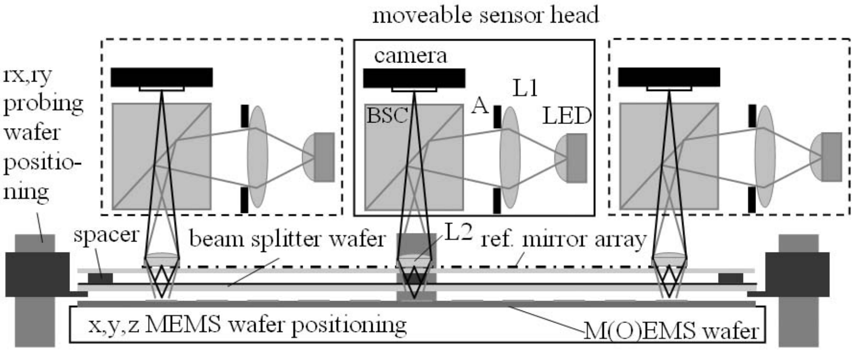

Fig. 3. Experimental setup, sensor head can be positioned at 5 different structures of the MEMS wafer (L1-bulk illumination lens, L2-bulk imaging lens, A-illumination aperture)

The demonstrator is applied to a commercially available MEMS object (Melexis IR sensor 81101BA). Five different structures on the wafer are measured (fig.4). The setup is optimised on the centre structure regarding focus and fringe contrast. Then the sensor head is moved to the corresponding corner of the wafer. The fringe pattern is found by adjusting the z-position of the MEMS wafer, simulating a z-scan. The interference fringes in the position of highest contrast are shown in fig. 4. The necessary adjustment is in the range between 5-20µm. It can be seen that the corner images are slightly defocused and contain fringes. However, the fringe contrast is sufficient over the whole wafer. This proves the feasibility of the interferometer design and the instrument concept.

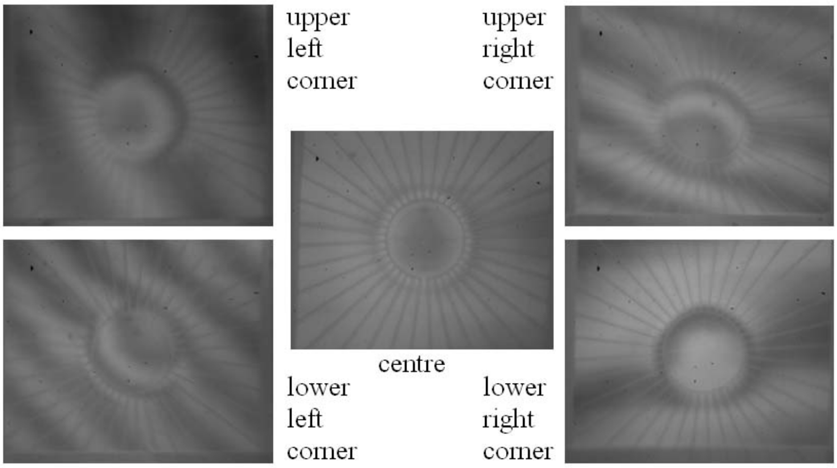

Fig. 4. Experimental results: interference fringes from 5 different MEMS structures on the corresponding position on the wafer when readjusting the z position in the range of 5-20µm

6. Conclusions

The novel design of a micro optical, low coherent interferometer array based on a Mirau configuration is presented. The design challenges imposed by the array approached are in particular: differences in focal lengths of the lenses, different centre wavelengths of the LED sources, the light budget, thickness variations of the glass wafers, stray light, and the accuracy of the scanning system. The refractive microlenses are corrected by a diffractive structure to improve the imaging quality. All micro optical components are produced by standard micro fabrication processes. A wafer based, five-channel setup is developed to proof the feasibility of the wafer based interferometer design. The preliminary experimental results, based on bulk lenses and one standard CMOS camera, show that interference fringes can be observed over the whole wafer area.

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