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Optical simulation for an optimized wafer level optopackage for 2D-micromirrors

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Abstract

The Fraunhofer Institute for Silicon Technology in Itzehoe has developed vacuum encapsulated dual-axis scanning micro-mirrors, for high-resolution laser projections [1]. Since parallel orientation of the glass cover to the micro-mirror results in a bright laser spot in the projected image, a wafer level packaging with an inclined glass lid was developed to eliminate the reflex in the image. To determine the quality requirements and the design specifications of the new package, optical simulations were performed in Zemax\textsuperscript{®}. For this purpose, the influence of the surface curvatures on the laser beam was examined. A further study was focused on the avoidance of secondary reflections, resulting in a disturbing ghost images superimposing the projected image.

Keywords: silicon micro machining, MOEMS, glass forming, micro-mirrors, wafer level packaging, Zemax, optical simulation

1. Introduction

Electrostatically driven micro-mirrors show a tremendous improvement in their deflections when operated in vacuum [2]. A suitable packaging for the micro-mirror must guarantee the tightness and the optical access to the mirror. Conventional vacuum encapsulation on chip level like TO-housings are limited to special applications due high costs, in contrast to wafer bonding offers a cost effective way for vacuum encapsulation due wafer level packaging.

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Fig. 1: Left (Flat cover): The reflex results in a bright laser spot in the image; Right (Inclined window): The reflex is out of the picture.
A parallel alignment of the glass window to the mirror can be achieved with conventional MEMS techniques, but due to partial reflections of the laser beam on the glass surfaces a bright spot in the center of the projected image is created. An anti-reflective coating can reduce the intensity of the observed central reflection only to a certain extent. However a complete reflex elimination in the image can be only obtained using an inclined optical window with respect to the mirror surface (Fig.1).

2. Motivation

The challenge is to accommodate inclined optical windows on a wafer so that a hermetic sealing of the micro-mirror wafer is feasible in a standard wafer bonder. Beside the inclined transparent glass window, the packaging must have a cavity of several 100 μm depth, that the micro-mirror can achieve the required deflection angle of 15° without contact to the glass cover. For this purpose Fraunhofer ISIT has developed in recent years a new fabrication process based on hot-viscous forming of glass wafers [3]. Since the resolution of the projected image depends on the achievable deflection angles of the micromirror and the divergence of the laser beams, the resolution of the projections can be affected by distortions of the evenness of the tilted window. To determine the quality requirements of the windows, optical simulations were performed with the software package Zemax®.

![Demonstration of a projection with ghost images.](image)

Beside the primary reflection higher order reflections on the transparent window can also affect the quality of the projected images. While the primary reflection is a result of partial reflections of the incoming laser beam on the glass cover, the secondary reflection is caused by reflections of the projected image at the glass surfaces which are directed backwards on the micro mirror plate where the reflected image is again projected on the screen (Figure 1, right). This reflection produces a secondary image superimposing the original picture and leads to an enormous reduction in the contrast range of the projected image. Tertiary reflections describe attenuated additional images generated from reflections within the material of the glass window. Due to their low intensities they rarely affect the image quality.

3. Zemax® model

Zemax® simulations simulate lenses and optical set-ups by ray tracing. The following simulated optical system consists of a laser, an optical imaging system, consisting of the mirror and the tilted glass lid, and a screen plane that receives the projected image (Figure 2, left).

![Left: 3D drawing of the complete system; Right: Illustration of the simulated system in Zemax®. The greatest distance between center and primary reflex can be achieved when laser beam and normal vector of the window surface lie in one plane.](image)

With defined geometrical parameters, the intensity distribution of the laser beam or the beam divergence for 1D and 2D micromirrors can be determined. The simulation model uses the geometry of the micro-mirrors available at Fraunhofer ISIT. Figure 2 (right) illustrates the overall structure of the system modeled in Zemax®. The distance from the screen to the mirror is set to 2 m, while for the mirror diameter 1 mm and a deflection of 10° is assumed. Based on the mirror layout a window size of 3x4 mm (inner surface) was defined, wherein a glass window thickness of 0.725 mm was used in the simulations. Furthermore, a tilt angle of 15° for the window and 20° for the incident laser beam in relation to the standby position of the mirror has been assumed.
4. Simulation results

4.1. Influence of surface curvature to the laser beam

Beside contrast range the resolution is the most important characteristic parameter for the quality of a projected image, which can be reduced on the relative size of the laser spot in relation to the dimensions of the image. The size and shape of the laser beam can be greatly changed by deviations in the evenness of the surface of the glass window. Depending weather the curvature is in or outside, the laser beam can be significantly expanded or focused until it reaches the projection screen.

In the simulations the alteration in the dimensions of the laser beam was calculated depending on the assumed shape of the glass surfaces e.g. weather the lower side (concave-plan), the upper side (plan-convex) or both sides of the glass cover possessed a single curvature (concave-convex) (Fig. 3).

In the simulation only an outward bending of the glass window was considered, because in preliminary experiments all deviations of the glass windows were directed outward.

If the glass cover possesses a plano-convex form, the cover plate acts as a focusing lens with a positive refractive power. Up to a sagittal height of 0.5 μm the diameter of the laser beam is reduced significantly. Above a sagittal height of 0.5 μm, the laser spot is clearly distorted and parallel stretched to its angle of incidence on the projection plane, while perpendicular the beam diameter is significantly reduced. If the glass cover has a concave-convex shape which corresponds to a meniscus lens with equal radii, the pixel remains unchanged in its form and only a small lateral shift in the image plane can be found. It is unfavorable in particular when the plane cover glass is deviated in a concave manner on the inside or the outside glass surface, because the imaging effects as a dispersing lens which expands the pixel dimensions. The simulations confirm the theoretical estimations, that convex or concave protrusions of the cover glass can be tolerated up to a total height of 200 nm [3].

4.2. Secondary reflections

In addition to the suppression of the primary reflex, it is important to avoid disturbing superimposed images caused by higher order reflections. The most relevant of these image artifacts, the secondary reflection arises by back-reflections of the projected image at the glass surface on the micro-mirror. This results in an enlarged and weakened version of the original image, which superimposes the projected picture and become clearly visible in the pictures contrast (Fig. 1, right).
Despite their relatively low light intensity, this doubled image affects the contrast range of the image. When a micro-mirror only describes a one-dimensional movement, the primary and the secondary reflex reflections can be separated from the narrow area of the image by a suitable angle for the incident laser beam. Figure 4 (left) shows the reflected pixels due to the mirror operation from $\pm 15^\circ$ in the X-axis. The laser beam was coupled perpendicular to the inclined surface of the window.

The situation is completely different when a 2D mirror is used. Here the secondary image cannot be avoided due to the spatial extent of the image. At an incidence angle of $20^\circ$ of the laser beam produces a secondary image in a range of $-15^\circ$ to $+10^\circ$ in the X-axis of the mirror. To improve the visibility of the secondary and tertiary reflections, the dynamic range of the simulation results have been greatly increased (Fig. 4, right). As a result the tertiary reflections within the glass cover leads to additional pixels (T1, T2) which do not belong to the secondary image.

A complete suppression of the secondary image can be achieved in 2-dimensional micro-scanner merely by an improved cover designs and slight acentric positioning of the micro-mirror under the lid. Through an adjustment of the position of the micro-mirror by 700 $\mu$m on the chip and an increase of the distance between micro-mirror and glass cover to 1.3 mm an operation of the 2D micro-mirror between $\pm 15^\circ$ in the X-axis and $\pm 9^\circ$ in the Y-axis without the appearance of an superimposed secondary image can achieved. In this case, the size of the glass lid must be adapted to 4x4 mm (inside) and 5x5 mm (external) respectively.

![Fig. 5: Left: Optimized micro-mirror structure to avoid the secondary image. Right: Representation of the pixels with an optimized design. The micro-mirror can operated in the range of $\pm 15^\circ$ (X-axis) and $\pm 9^\circ$ (Y-axis) without producing a superimposed image.](image)

5. Conclusion and outlook

The simulations showed that outward directed convex or concave curvatures in the glass cover up to a height of 200 nm had no significant effect on the image quality and can be tolerated. In contrast to one-dimensional micro-mirrors higher order reflections on the glass window leads in encapsulated 2D micro-mirrors to visible artefacts which cannot be avoided by simple means.

In further simulations it was found that an adapted position of the micro-mirror under the glass cover and an increase of the distance between mirror and window together with a small enlargement of the window eliminate the secondary image over a wide operation range of the mirror. The focus in the near future is on the preparation of an optimized glass cover wafer. Figure 6 delivers an impression of an 8” wafer with inclined windows (left) and a hermetically encapsulated micro-mirror at wafer level (right).

![Fig. 6: Detail views of: an 8” wafer with inclined glass-covers (left) and a wafer level vacuum packaged mirror with an inclined glass window (right).](image)

References

