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Optical Position Feedback for electrostatically driven MOEMS-Scanners

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Abstract

For MOEMS scanner mirrors which do not have intrinsic on-chip feedback, position information can be provided using optical methods, most simply by using a reflection from the backside of the mirror. The timing signals from precisely placed fast differential photodiodes can be used for resonant scanner mirrors performing sinusoidal motion with large amplitude. While this approach provides excellent accuracy it cannot be directly extended to arbitrary trajectories or static deflection angles. Another approach is based on the measurement of the position of the reflected laser beam with a quadrant diode. In this work, we present position sensing devices based on the latter principle showing first experimental results from the implemented devices.

Introduction

Electrostatically driven MOEMS scanner mirrors have important applications in various fields of optics, telecommunication and spectroscopy. They gain more and more importance to satisfy the industry demands for for many opto-mechanical applications, where light-weight, miniaturizable, and cheap solutions are needed[1,2,3,4,5,6].
Position feedback, providing accurate information about mirror deflection angles is an important issue for many applications. Several different principles exist, which can provide information about the mirror deflection angles. The capacitance variance can be used to detect the zero-transition and estimate the speed and amplitude of resonant MOEMS mirrors . This was demonstrated using an especially adapted integrated circuit and a 250 Hz mirror. However this signal is very weak even with specially designed electrode structures. Another approach consists in the fabrication of piezoresistive areas on the springs and measurement of their deflection dependent resistance signal. While both approaches provide the advantage of direct integration on the MEMS component and as such provide a high potential for miniaturization, at the current stage, they do not provide sufficient accuracy for all applications. Optical detection techniques promise higher accuracy and are applicable to MOEMS devices, which do not have an intrinsic on-chip feedback. Most simply this concept is realised by using the reflection from the backside of a MOEMS scanner.
In previous work, we have presented a compact device based on the accurate measurement of timing signals using fast differential photodiodes, which can be used with resonant scanner mirrors performing sinusoidal motion with large amplitude. While this approach provides excellent accuracy (phase accuracy better than 1/10000) for high frequency scanners, it cannot be directly extended to arbitrary trajectories or static deflection angles. In this work, we present an alternative position sensing device based on position sensitive detection using a segmented detection. Accurate position feedback can enable closed-loop control of the MOEMS devices and, thus, will significantly improve their performance and applicability.

Electrostatically driven MOEMS mirrors

Micromechanical scanner mirrors are fabricated at the Fraunhofer IPMS using CMOS compatible technology[7]. An example is shown in Fig. 1. They consist of a plate suspended by torsional springs and comb like driving electrodes. The vertical sides of the electrodes and the mirror plate form a variable capacitance which is decreasing with increasing deflection angle of the mirror plate. An applied voltage generates an electrostatic torque which accelerates the plate towards its rest position[8]. When driving with a fixed driving frequency the mirror will oscillate with half this frequency. Since the mirror motion starts from random fluctuations, in this driving scheme there is an ambiguity concerning the direction of the

motion. Thus, for electrostatically driven resonant scanner mirrors, position feedback must be provided for any application, which requires information about the actual mirror motion.
On the other hand, quasistatic MOEMS mirrors, as the ones developped at IPMS very recently[9,10] feature out of plane electrodes which leads to a very different behaviour. Application of a constant potential leads to static deflection of the mirror. In this case, the direction ambiguity is resolved. Exact calibration might be sufficient for many tasks. However, for optimum operation, closed loop control is preferential, which, again, requires a position feedback signal.
In previous work, we have developed a compact device comprising optical position sensing, and driver electronics, with closed loop control, capable of driving resonant MOEMS micro-mirrors[11,12]. With some effort, the approach can be extended to 2D scanner mirrors, which significantly increases the complexity of the device. In the following we will show a different position sensing scheme using quadrant diodes. The latter scheme is more generally applicable and directly provides position information for both axes of a 2D mirror. In particular it also works with quasistatic mirrors.

Fig. 1: electrostatically driven 2D-Micro Scanning Mirror

Optical Position Encoding using a Quadrant Detector Scheme

Position detection can be provided by sending the light, which is backreflected from the mirror onto a position sensitive photodetector. This can be a position sensitive photodiode (PSD), a quadrant diode or simply four separated detectors. The relative signals from these detectors then provides information about the direction of the backreflected light and thus the tilt angle of the mirror plate.

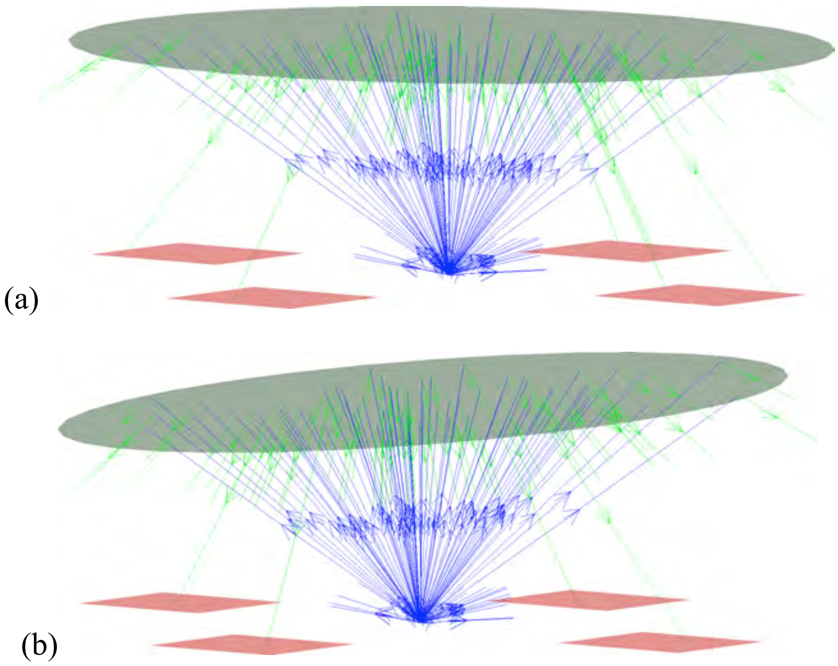


Fig. 2: Schematic of the quadrant detection scheme. A central lightsource emits light, which is backreflected by the mirror to illuminate the four photodetectors. (a) mirror at zero deflection. (b) mirror with 5° deflection in the x-direction.

In this work we used a sandwich-like geometry, with a lightsource placed at a certain distance behind the mirror backside and surrounded by four photo detector segments. This configuration is very compact and can be realised relatively easily, e.g. using two stacked electronic boards. The detector axes are oriented at 45° with regard to the axes of rotation of the mirror. The positions of the detectors can advantageously be labeled in analogy to the compass points, as NW, SW, NO, and SO[13], which will be used in the following.
In order to determine the deflection angle of the mirror, we calculate the relative differential intensity *RDI* for each axis from the intensity signals I_{xx} of the individual photodetectors.

$$RDI_X = \frac{(I_{NW} + I_{SW}) - (I_{NO} + I_{SO})}{I_{NW} + I_{SW} + I_{NO} + I_{SO}}$$

$$RDI_Y = \frac{(I_{NO} + I_{NW}) - (I_{SO} + I_{SW})}{I_{NW} + I_{SW} + I_{NO} + I_{SO}}.$$

Over a limited range of mirror deflection angles we get a linear characteristic with minimal crosstalk of the two axes. This range is determined by several parameters, in particular the divergence ange of the light, the size of the detector and the distance between mirror and detector. This relatively simple behavior can only be obtained in the situation where all four detector areas are illuminated. Furthermore the illuminated surface must be significantly larger than the gap between the detector areas.
In this set-up two different situations can occur. For small divergence angles of the light source the detector surface is only partially illuminated and the signal is dominated by the location of the center of the beam which illuminates the diodes in an asymmetric way. This is also the basis for the use of quadrant diodes in applications for laser beam pointing stabilization.
For small distances and a large divergence of the light source, we can assume that the light cone completely covers all four detectors for any tilt angle of the mirror. In this case the main cause for differences in relative illumination of the detectors comes from the change in optical path distance between light source and the detector areas. This leads to a change in the cone angle and thus the relative illumination intensity hitting the detectors.
These two situations have opposite tilt-angle dependence and this interplay has to be carefully considered. Parameters which enter into play and which partially influence each other include: the distance between mirror and detector, the distance between the detectors, the diameter of the mirror and the divergence of the lightsource, the form of the mirror surface, the intensity distribution of the light and the active area of the detectors.

Results

In our implementation, we used a prototype quadrant diode, which has a hole at the center through which LED based illumination was realized. This detection units was implemented in a compact form on a PCB board which could possibly be placed on the backside of a MEMS device.

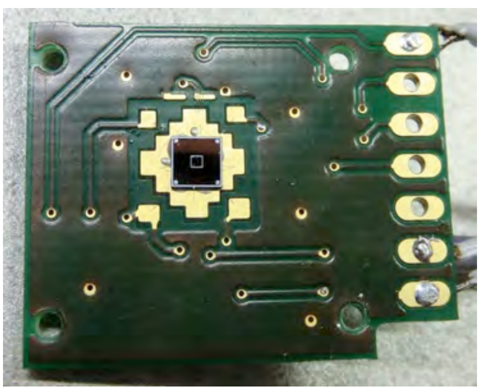
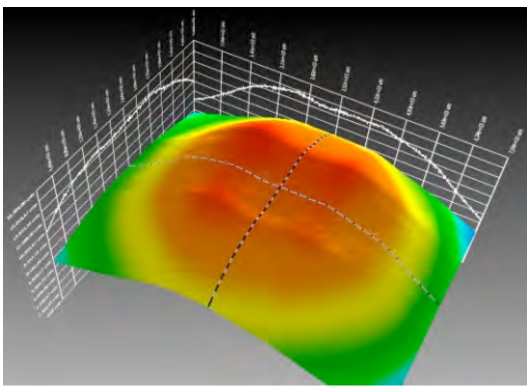
(a)  (b) 

Fig. 3: (a) Position detection unit using a quadrant diode with a central hole for illumination. (b) Beam characteristic s of the central LED

Under these conditions, we obtained a nearly linear relationship between RDIx and the mirror tilt angle, while RDIy stays relatively constant. Fig. 3 shows the test-board together with the profile of the light-cone, which is crucial for the performance of the device. Fig. 4 shows the results we obtained.

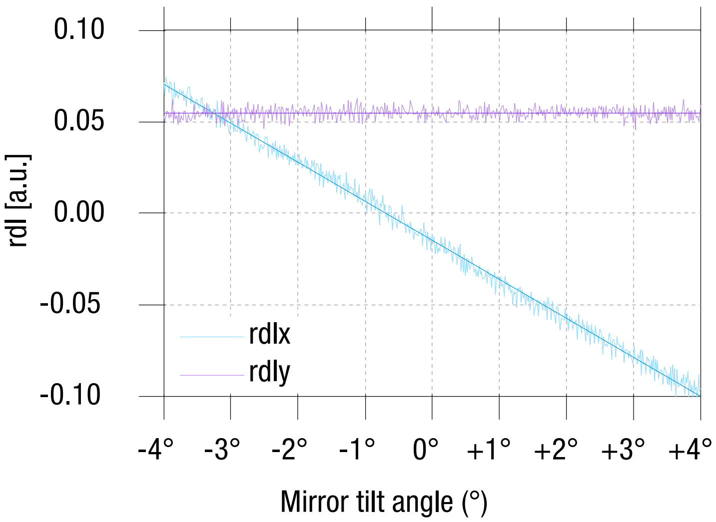


Fig. 4: Position signal (RDIx and RDIy) as a function of mirror tilt angle around the y axis.

The error in angle was estimated from the noise on the calculated signal to be about 0.3°. This corresponds to a relative error of about 3% for the measurement range.
It must be noted that the error reported here is the sum of all contributions, since we used the raw data without any filtering or averaging operations. Assuming statistical noise, averaging over 100 measurements will reduce the the error to 0.003, which can be acceptable for many applications. Still it is an order of magnitude higher than what we observed previously for resonant scanner mirrors using the triggerdiode approach[12].
More detailed investigations of noise sources and possibilities for improvement are ongoing.

Conclusions

In this article we presented a novel optical position detection system suitable for MOEMS scanner mirrors. For mirrors driven with high frequency at resonance, measurements of timing signals from trigger diodes can provide accurate access to amplitude and phase of the mirror motion. However, this is not applicable to determine static deflection. Position sensitive detection of a back reflected light cone using a quadrant detector with a central hole can provide position information also for static mirrors and arbitrary trajectories. In our first tests the accuracies obtained with the latter technique were in the percent-range, which must still be improved. On the other hand, it has the possibility of very compact and simple implementation.

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