proceedings

MDPI

Abstract

Development of Piezoelectrically Driven Quasi-Static 2D MEMS Mirrors with Extremely Large FoV for Scanning LiDARs †

Paul Raschdorf , Jeong-Yeon Hwang , Lena Wysocki , Lianzhi Wen, Jörg Albers, Gunnar Wille, Erdem Yarar and Shanshan Gu-Stoppel *

Fraunhofer Institute for Silicon Technology, 25524 Itzehoe, Germany; paul.raschdorf@isit.fraunhofer.de (P.R.); jeong-yeon.hwang@isit.fraunhofer.de (J.-Y.H.); lena.wysocki@isit.fraunhofer.de (L.W.); lianzhi.wen@isit.fraunhofer.de (L.W.); joerg.albers@isit.fraunhofer.de (J.A.); gunnar.wille@isit.fraunhofer.de (G.W.); erdem.yarar@isit.fraunhofer.de (E.Y.)

* Correspondence: shanshan.gu-stoppel@isit.fraunhofer.de; Tel.: +49-4821-17-1424

† Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

Abstract: In this paper, a piezoelectrically driven quasi-static MEMS mirror is developed for a scanning LiDAR system. Finite element method (FEM) simulations are used to optimize the design of the MEMS scanner. With special emphasis on the shape and thickness of the actuators, they are optimized to reach a maximum static total optical scan angle (TOSA) of 30°. Their influence on the resonance frequency at dynamic modes and the material stress are investigated. In this study, two designs are compared with respect to their FEM simulation results. Currently, the devices are manufactured in the cleanroom. The manufactured samples will be characterized and the measurement results will be published in future works.

Keywords: MEMS; MEMS mirror; design optimization; silicon technology; optics

Citation: Raschdorf, P.; Hwang, J.-Y.; Wysocki, L.; Wen, L.; Albers, J.; Wille, G.; Yarar, E.; Gu-Stoppel, S. Development of Piezoelectrically Driven Quasi-Static 2D MEMS Mirrors with Extremely Large FoV for Scanning LiDARs. *Proceedings* **2024**, 97, 124. https://doi.org/10.3390/proceedings2024097124

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 29 March 2024

1. Working Principle of a MEMS Scanner

The special feature of the quasi-static MEMS scanner [1] is its large actuators. The quasi-static tilting shown in Figure 1a is achieved by applying a DC voltage of ±100 V, as demonstrated in Figure 1b(i). A maximum field of view (FoV) as high as 30° × 30° is achieved when +100 V are applied to the actuators Q1 and Q2, leading to an inward motion, and when −100 V are applied to the actuators Q3 and Q4, leading to an outward motion. This leads to a tilt of the mirror plate, as shown in Figure 1a.

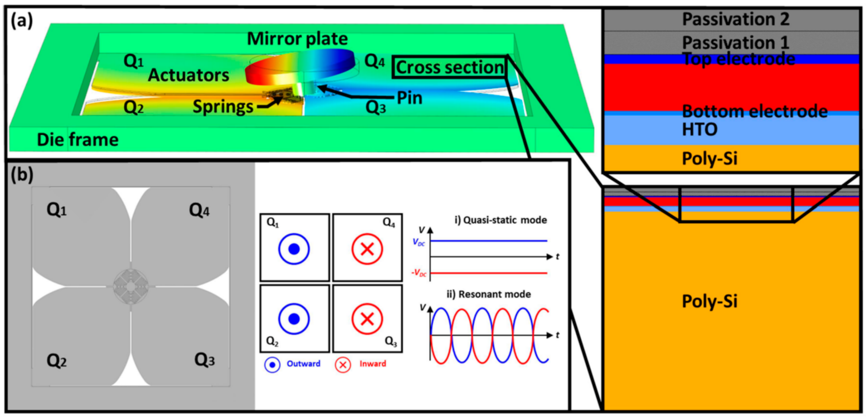

Figure 1. (**a**) Static tilting of the quasi-static MEMS scanner. It amounts to 30° TOSA at ±100 V DC voltage applied across the piezoelectric actuators. A cross-section of the deposited thin film stack on the actuators is shown on the right. (**b**) Left: Quasi-static MEMS scanner, as seen from below. The mirror plate is not visible

since it is covered by the actuators. Right: Driving voltage for static (**i**) and resonant (**ii**) modes. The left actuators move outward and the right ones move inward under positive and negative voltage, respectively. This leads to a tilting of the mirror plate along the vertical axis.

2. Design Optimization

The FoV is maximized by closely investigating the spring system and the actuators of the MEMS scanner to increase the scanning area of the LiDAR system.

2.1. Thickness

The thin film stack is deposited on a 725 µm thick Si substrate that is covered with an epitaxially grown poly Si (Epi-poly Si) layer (see Figure 1a). The manufacturing process is described in [2]. The influence of the Epi-poly Si thickness is investigated in order to optimize the device performance. Accordingly, a stiffer spring design with a poly Si thickness of 50 µm is compared to a softer design with a poly Si thickness of 25 µm. At an increased thickness, the resonance frequency of the dynamic modes is doubled from 770 Hz to 1564 Hz. In return, TOSA under DC drive decreases from 29.90° to 10.36°. Furthermore, the maximum material stress in the spring system increases by approximately 55% and reaches 2.91 GPa. In summary, a stiffer design shows larger resonance frequencies as well as material stresses at lower TOSA.

2.2. Actuators and Springs

In two of our own designs, the influence of the spring system and attachment of the actuators to the die frame is investigated. One stiffer design has 9 meanders in each spring system and actuators that are attached completely to the frame, as presented in [1], whereas the second softer design has 13 meanders in each spring system and partially released actuators, as shown in [3] and Figure 1b.

The results are comparable to the findings in Section 2.1. The softer spring system shows a TOSA of 29.90°, which is ten times larger than the TOSA of the stiffer system. In conclusion, the optimization of the spring system of the device is most important for the reachable scan angle.

2.3. Outlook

The next steps of the research include the manufacturing and characterization of the fully functional MEMS scanners. As a final task, the best-performing scanners will be integrated into a LiDAR system as part of a laser scanning unit.

Author Contributions: Conceptualization and Writing—Review and Editing (P.R., J.-Y.H., L.W. (Lena Wysocki), L.W. (Lianzhi Wen), J.A., G.W., E.Y. and S.G.-S.); Methodology and Software (P.R.); Visualization and Writing—Original Draft Preparation (P.R.); Supervision, Project Administration, and Funding Acquisition (S.G.-S.). All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Fraunhofer flagship project NeurOSmart (840282).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to legal restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Gu-Stoppel, S.; Lisec, T.; Fichtner, S.; Funck, N.; Eisermann, C.; Lofink, F.; Wagner, B.; Müller-Groeling, A. A highly linear piezoelectric quasi-static MEMS mirror with mechanical tilt angles of larger than 10°. In Proceedings of the MOEMS and Miniaturized Systems XVIII, San Francisco, CA, USA, 2–4 February 2019; p. 1093102.
2. Gu-Stoppel, S.; Lisec, T.; Claus, M.; Funck, N.; Fichtner, S.; Schröder, S.; Wagner, B.; Lofink, F. A triple-wafer-bonded AlScN driven quasi-static MEMS mirror with high linearity and large tilt angles. In Proceedings of the MOEMS and Miniaturized Systems XIX, San Francisco, CA, USA, 1–3 February 2020; p. 1129304.
3. Sun, C.; Liu, Y.; Li, B.; Su, W.; Luo, M.; Du, G.; Wu, Y. Modeling and Optimization of a Novel ScAlN-Based MEMS Scanning Mirror with Large Static and Dynamic Two-Axis Tilting Angles. *Sensors* **2021**, *21*, 5513. [CrossRef] [PubMed]