DOI 10.5162/EUROSENSORS2025/TP27

On the design of a magnetically driven quasi-static MEMS micromirror

Perla Malagò[1]*, Clement Fleury*[1]*, Stefano Lumetti*[1]*, Luiz Enger*[1]*, Sara Guerreiro*[1]*, Adrien Piot*[1]*, Anton Lagosh*[1]

[1] *Silicon Austria Labs GmbH, Europastrasse 12, 9504 Villach, Austria*
perla.malago@silicon-austria.com

Summary:

This paper focuses on the design of a magnetic MEMS micromirror featuring linear and non-contact actuation, low-power, and compact size with respect to state-of-the-art magnetic micromirrors. The proposed device operates in the low-frequency regime and finds application in satellite and optical communications. The results show that it is possible to realize a compact micromirror exhibiting performance surpassing the state-of-the-art micromirrors employed in similar application fields.

Keywords: Magnetic MEMS, micromirrors, fast prototyping, satellite communications, quasi-static applications

Introduction and motivation

Nowadays, magnetic MEMS are used for a wide range of applications, including micromirrors, accelerometers, gyroscopes, torsion sensors and gradiometers [1, 2]. Usually, magnetic MEMS including permanent magnets and micro-coils offer functionalities like sensing, actuation and energy harvesting and are employed in several application fields such as automotive, biomedical, space, and IoT [3-4]. This work focuses on the design of a magnetic MEMS micromirror. On one hand, state-of-the-art magnetic MEMS micromirrors feature low power consumption, fast response times and large scan angles. On the other hand, the integration of permanent micromagnets suitable to produce the magnetic fields required for the generation of large electromagnetic actuation forces remains a critical challenge that makes most of the magnetic MEMS micromirrors bulky and expensive compared with their counterparts based on piezoelectric, electrostatic and thermoacoustic transduction mechanisms [5]. Here, the Authors propose a magnetic micromirror featuring low power consumption, large scan angles, downscaled size, and highly linear response. Such a device is suitable for space applications like optical or satellite communications, where state-of-the-art micromirrors rely on bulky structures and an actuation mechanism based on high-power electric motors.

System description

The system includes an array of permanent magnets as well as micro-coils fabricated on the suspended micromirror plate around the reflective area (see Fig. 1).

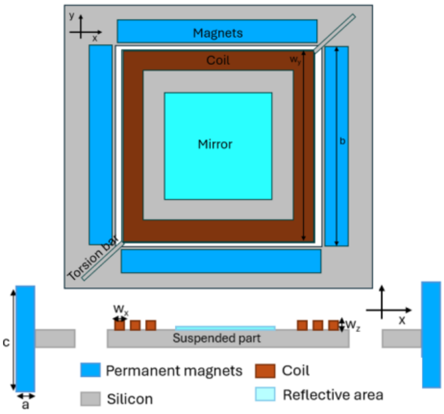

Fig. 1. Schematic representation of the magnetic MEMS micromirror together with its critical components and the corresponding cross-section.

The MEMS micromirror exploits the Lorentz force arising from the interaction of the electrical current through the micro-coils with the magnetic field generated by the permanent magnets to actuate and control the motion of the suspended region. The system and its critical components are described by the following parameters: magnet width (a), length (b) and thickness (c), and magnetization vector (m_x, m_y, m_z); number coil turns (n_w), coil wire thickness (w_z), width (w_x) and length (w_y), electric current flowing across the coils (i). For the envisioned application, the reflective area has in-plane dimensions of 5 x 5 mm^2 while the size of the entire suspended region including the coil system is 9 x 9 mm^2. The system is designed to fulfill the following target specifications: power losses (PL) < 400 mW, field of view (FoV) of ±15°, and low-frequency operation (< 100 Hz).

Methods

The design of the magnetic MEMS micromirror is carried out by combining two different approaches: finite-element methods for mechanical simulations and analytical calculations for the design of the magnet-coil system. Mechanical simulations are performed using the COMSOL Multiphysics software [6] to determine the minimum pressure required to achieve FoV = ±15°. Electromagnetic simulations are based on the open-source Python package "Magpylib-force" that allows for fast (microsecond) computation of magnetic fields and electromagnetic force between magnets and current-carrying wires [7], thereby enabling to the time-efficient investigation of a wide range of system parameters.

Design and simulation: results

The results of the mechanical simulations show that a pressure P_t = 150 N/m^2 on the micromirror plate is required to achieve FoV = ±15°. Several system parameter sets (a, c and i) satisfying the target requirements and enabling the generation of an electromagnetic actuation force corresponding to the required P_t are identified via electromagnetic simulations: the results are summarized in Fig. 2(a) and (b) for a fixed coil design having n_w = 24, w_z = 20 µm, w_x = 20 µm and w_y = 8 mm corresponding to a total resistance R = 33.1 Ω.

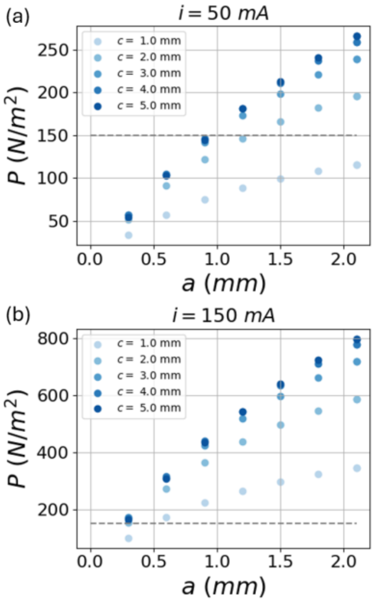

Fig. 2. Pressure as a function of the magnet width (a) for different magnet height (c) for an electrical current flowing in the coil of (a) i = 50 mA and (b) i = 150 mA. The dashed grey lines indicate P_t.

Fig. 2(a) shows that, for i = 50 mA and PL = 40 mW, it is possible to achieve P > P_t by adopting system designs where a > 1 mm and c > 2 mm. Fig. 2(b) demonstrates that, by increasing the coil current to i = 150 mA (PL = 370 mW), P_t can be achieved by reducing the permanent magnet size to a > 0.5 mm and c > 1 mm, which opens the possibility of realizing a more compact micromirror with equal performances.

Conclusions

This paper shows that it is possible to design a compact magnetic MEMS micromirror for low-frequency applications by combining mm-size permanent magnets and micro-coils. Sets of system parameters fulfilling the target performance requirements are determined. Future work will be devoted to microfabricating the magnetic micromirror and to testing its performance as well as to including magnetic field sensors suitable for closed-loop device operation.

References

[1] D. Niarchos, Magnetic MEMS: key issues and some applications, *Sensors and Actuators A: Physical*, 109 1–2, 166-173 (2003); doi: 10.1016/j.sna.2003.09.010

[2] O. Cugat, J. Delamare, G. Reyne, Magnetic micro-actuators and systems, *IEEE Transactions on magnetics* 39.6: 3607-3612 (2003); doi:10.1109/TMAG.2003.816763

[3] S. Lumetti, P. Malagò, D. Spitzer, S. Zaruba, M. Ortner, Computationally Efficient Magnetic Position System Calibration, *Engineering Proceedings*, 2(1), 72 (2020); doi: 10.3390/ecsa-7-08219

[4] J. Yunas, B. Mulyanti, I. Hamidah, M. Mohd Said, R. E. Pawinanto, W. A. F. Wan Ali, ... & Yeop Majlis, B. Polymer-Based MEMS Electromagnetic Actuator for Biomedical Application: A Review, *Polymers*, 12(5), 1184 (2020); doi: 10.3390/polym12051184

[5] M Ahmad, M Bahri, M Sawan, MEMS Micromirror Actuation Techniques: A Comprehensive Review of Trends, Innovations, and Future Prospects, *Micromachines*, 15.10: 1233 (2024); doi: 10.3390/mi15101233

[6] https://www.comsol.com/, accessed 12.03.2025

[7] P. Malagò, F. Slanovc, M. Ortner, L. Enger, M. Montagnese, P. Smaliukas, J. Bardong, I. Shishkin, C. Novotny, S. Horvath, A. Rusconi and S. Lumetti, Design of magnetic MEMS micro-speakers, *Journal of Physics: Conference Proceedings*, (2025).

Acknowledgements

This work has been supported by Silicon Austria Labs (SAL), owned by the Republic of Austria, the Styrian Business Promotion Agency (SFG), the federal state of Carinthia, the Upper Austrian Research (UAR), and the Austrian Association for the Electric and Electronics Industry (FEEI).