

Exploring the Role of Micro-Valveless Pumps in Drug Delivery

Micro-Electro-Mechanical Systems

MEMS drives micro-scale device exploration, notably in biomedical sectors with embedded microfluidic devices. Micropumps, crucial for drug delivery and chemical analysis, rely on electromagnetic actuation. Valveless-actuated micropumps are common in this field, reflecting the evolving microfluidic landscape.

Micro-valveless-actuated pump

This application note investigates a micro-valveless pumping mechanism comprising an electroplated permanent magnet and a fixed micro coil. By applying current to the coil, fluid is propelled through the pump via electromagnetic force. PDMS is selected for its flexibility, allowing for precise flow rate control with minimal electrical input. Figure 1 showcases the prototype and actuation mechanism.

Figure 1 - A picture of the fabricated micro-pump [1] a). and its schematic illustration b).

CAD Model

In this analysis, the magnetostatic module of EMS, coupled with structural study, computes and visualizes the mechanical deflection of the flexible membrane subjected to magnetic loads from the coil-magnet interaction. Figure 2 illustrates the design of the micro-pump.

Figure 2 - a): 3D isometric view of the micropump b): a cross-sectional view of the micro-pump.

The following tables define the dimensions of the main model components:

Table 1 - PDMS diaphragm design

Material	Radius (μm)	Thickness (μm)	Elastic limit force (μN)
PDMS	1950	80	315

Table 2 - Coil design

Material	Inner Radius (μm)	Outer Radius (μm)	Width (μm)	Turns	Resistance (?)
Copper (Cu)	1250	1725	25	10	3.23

Table 3 - Magnet design

Material	Radius (μm)	Thickness (μm)	Distance from coil base (μm)
CoNiMnP	1150	20	620

Material Properties

Table 4 - Material properties

Material	Density (Kg/)	Magnetic permeability	Electrical conductivity (S/m)	Elastic Modulus (Pa)	Poisson's ratio	Magnetization Coercivity (A/m) Remanence (T)
Copper (Cu)	8900	0.99	5.7 E+07	Not required		Not required
PDMS	1030	1	0	0.75 E+6	0.49	
Glass	Not required	1	0	Not required		
CoNiMnP		1.88	0			47700 0.3

Electromagnetic Inputs

The inductor coil is modeled as a solid coil supporting a current input range of 0.4 to 1 A RMS.

Mechanical boundary conditions

Fixed boundary conditions are applied to the lateral cylindrical surface of the PDMS membrane, as depicted in Figure 3.

Figure 3 - Applied mechanical boundary conditions

Meshing

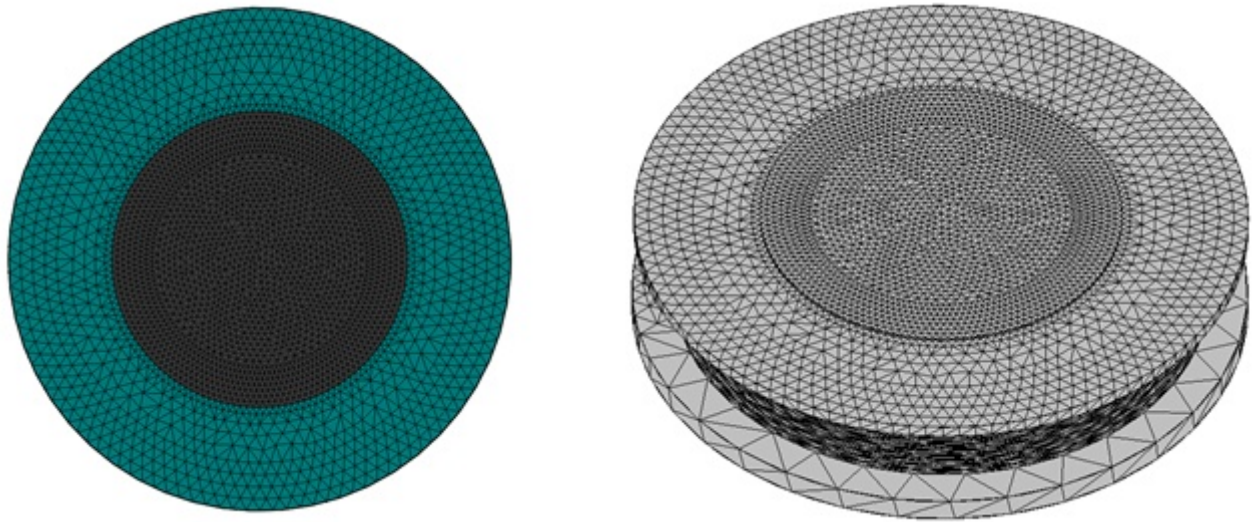


Figure 4 - Top and isometric view of the meshed model

Results

To achieve the required actuation force and diaphragm deflection as specified in reference [2], numerical simulations were conducted using the EMS tool. Various current inputs ranging from 0.4A to 1A were applied, and the corresponding results are depicted in the figures below. Figure 5 illustrates the variation of the resultant magnetic force concerning the applied current inputs. Remarkably, there is a high coherence between the results obtained from the EMS tool and those referenced in [2].

Figure 5 - Magnetic force variation versus current inputs for both Reference [2] and EMS results.

Under the influence of the magnetic force, the PDMS diaphragm bends upwards, reaching a maximum deflection of $15.08 \mu\text{m}$ under $16.5 \mu\text{N}$, corresponding to a current input of 0.9A (Figure 6). These findings closely align with the desired membrane displacement specified in Reference [2], enhancing the micro-scale pump's capability to achieve substantial membrane deflection while minimizing energy consumption.

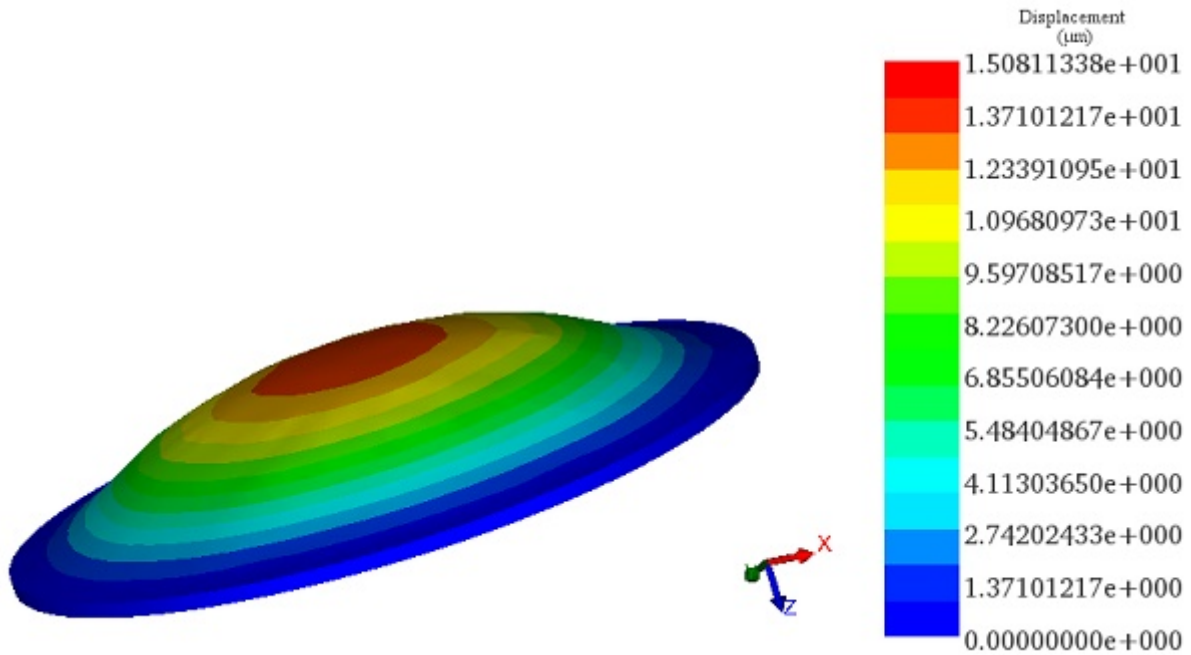


Figure 6 - Resultant deflection of the PDMS membrane for a current input of 0.9A

Figure 7 provides a secondary comparison between the simulation results from Reference [2], analytical [2], and EMS. It illustrates the 2D plot variation of membrane deflection against the magnetic force obtained for the current range [0.4A..1A]. This comparison reaffirms the excellent agreement among the various results and underscores EMS's capability to accurately estimate the magneto-mechanical behavior of micro-pump actuation, particularly under low currents.

Figure 7 - Variation of membrane displacement versus the magnetic forces.

Conclusion

This application note delves into the advancement of Micro-Electro-Mechanical Systems (MEMS), particularly focusing on a micro-valveless pumping mechanism for applications in drug delivery and chemical analysis. The mechanism, leveraging electromagnetic actuation, features a unique design incorporating an electroplated permanent magnet and a fixed micro coil. The use of Polydimethylsiloxane (PDMS) for the flexible membrane allows for controlled fluid propulsion through electromagnetic forces with minimal electrical input, highlighting the pump's efficiency and precision.

The study employs the magnetostatic module of EMS, coupled with structural analysis, to compute the mechanical deflection of the flexible membrane under magnetic loads, showcasing the interaction between the coil and the magnet. This analysis provides insights into the operational dynamics of the micropump, demonstrating its potential for precise flow rate control in microfluidic applications.

Results from various current inputs ranging from 0.4A to 1A reveal a direct correlation between the applied current and the resultant magnetic force, as well as the membrane's deflection. These findings not only validate the EMS tool's accuracy compared to the referenced data but also emphasize the micropump's capability to achieve significant membrane deflection with optimized energy use.

In conclusion, this application note illustrates the effectiveness of electromagnetic-thermal NDT in advancing MEMS technology for biomedical applications. By accurately simulating the magneto-mechanical behavior of micro-pump actuation, it underscores the potential of MEMS devices in enhancing drug delivery systems and chemical analysis through innovative microfluidic solutions.

References

- [1]- Lee, Chia-Yen, Hsien-Tsung Chang, and Chih-Yung Wen. "A MEMS-based valveless impedance pump utilizing electromagnetic actuation." *Journal of Micromechanics and Microengineering* 18.3 (2008): 035044.
- [2]- Chang, Hsien-Tsung, et al. "Theoretical analysis and optimization of electromagnetic actuation in a valveless microimpedance pump." *Microelectronics journal* 38.6-7 (2007): 791-799.