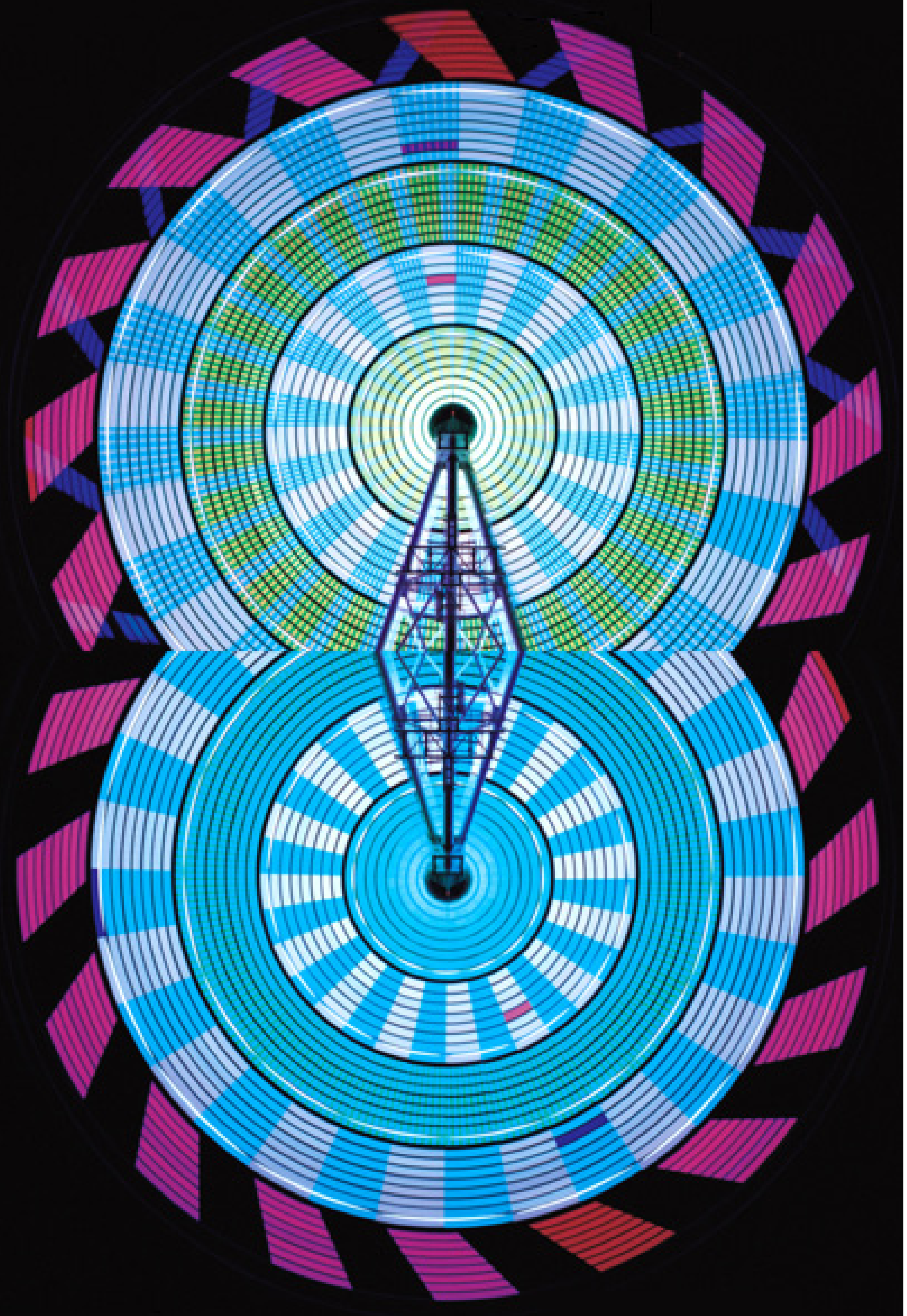

Single Mask 3-Phase Electrostatic Rotary Stepper Micromotor

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Outline

Background

- Skew angle compensation in HDD

Micromotor design

- 3-phase stepper motor with a flexural pivot bearing
- Previous motor *(presented at MEMS 2009)*
- New design

Modeling and characterization

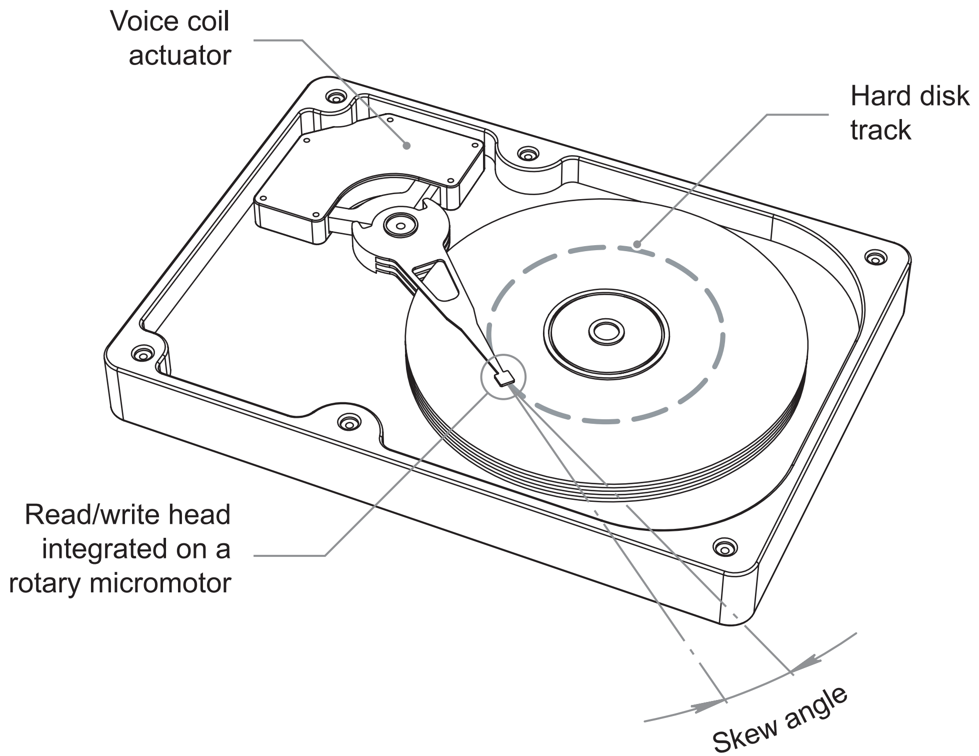
- Modeling
- FFT measurement method
- Experimental characterization

Conclusion

Background

Skew angle compensation in Hard Disk Drives

Background | Skew angle compensation in HDD



Skew angle variations:
+/-15° (3.5" HDD)

→ Affects fly height profile and read/write characteristics

Skew angle correction can further improve HDD capacity and performance

Proposed solution:
Piggyback micromotor

Targeted performance:
- Rotational range: 30°
- High speed: 10°/ms
- Open-loop operation

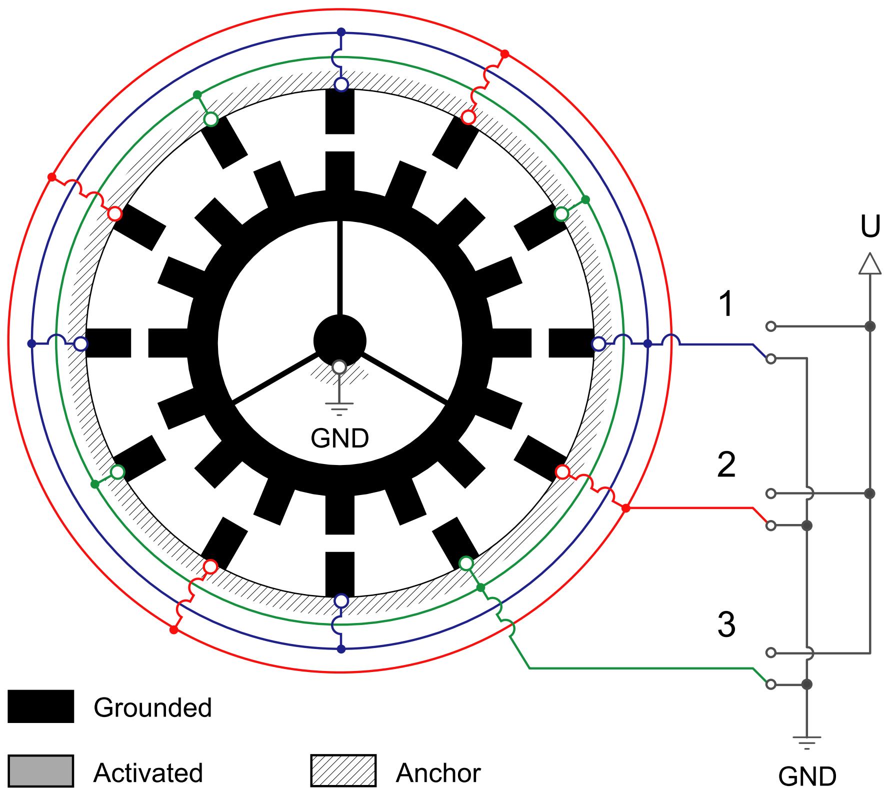
Piggyback

Legend (off)

Micromotor design

- 3-phase stepper motor
  with a flexural pivot bearing
- Previous results
  (presented at MEMS 2009)
- New design

Variable capacitance micromotor with flexural pivot bearing



Step 1 | Step 2 | Step 3

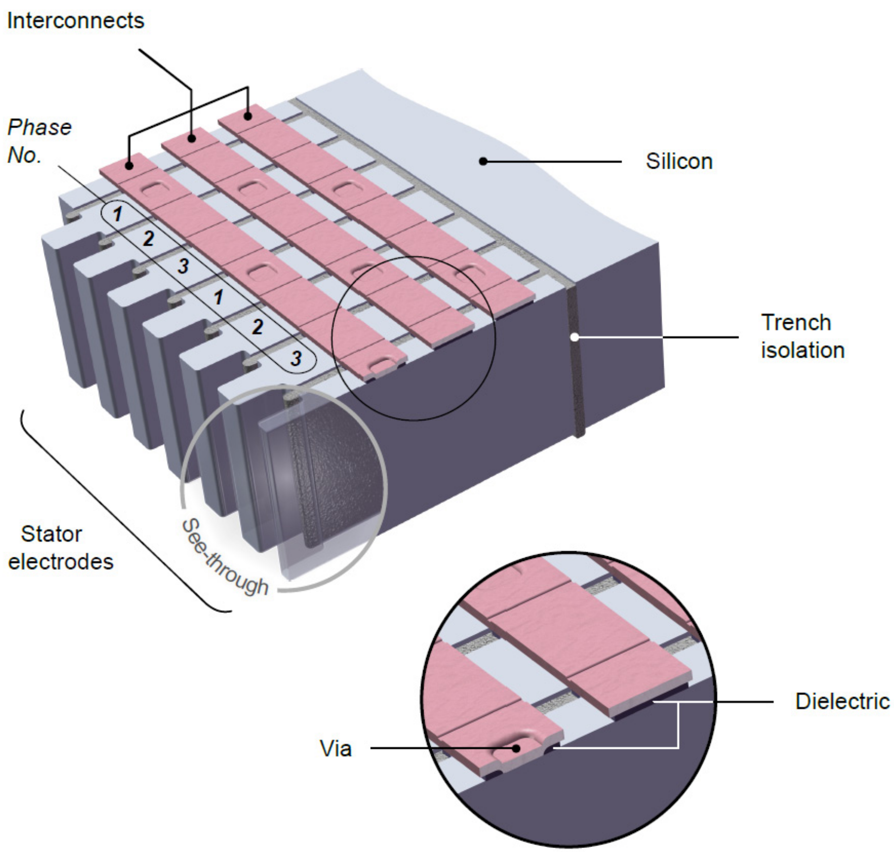
Off state

Flexural pivot bearing

- \+ No friction / No wear
- \+ Rotor electrically grounded
- \+ Flexures as mechanical support for the wiring
- \+ Initial position of the rotor
- – limited rotational range

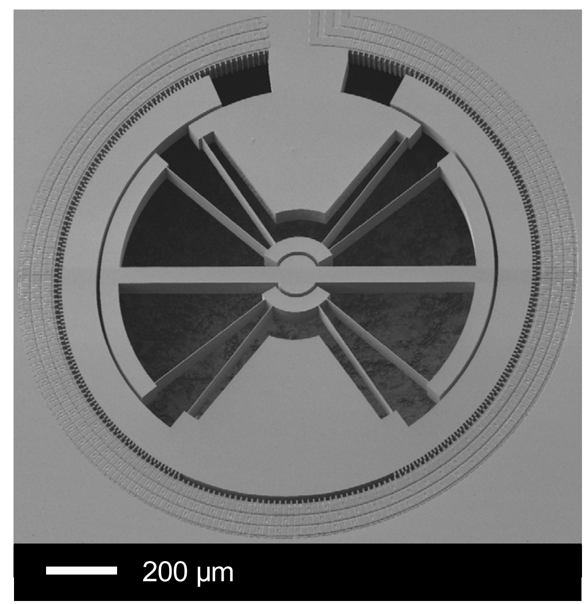
Previous results | Presented at MEMS 2009

Electrostatic Rotary Stepper Micromotor for Skew Angle Compensation in Hard Disk Drive
E. Sarajlic, C. Yamahata, M. Cordero & H. Fujita
Proc. 22nd IEEE Int. Conf. on MEMS, January 2009, pp. 1079-1082.



***5-masks** fabrication process*

Stator poles are connected in an alternating sequence with 3 distinct electrical phases.



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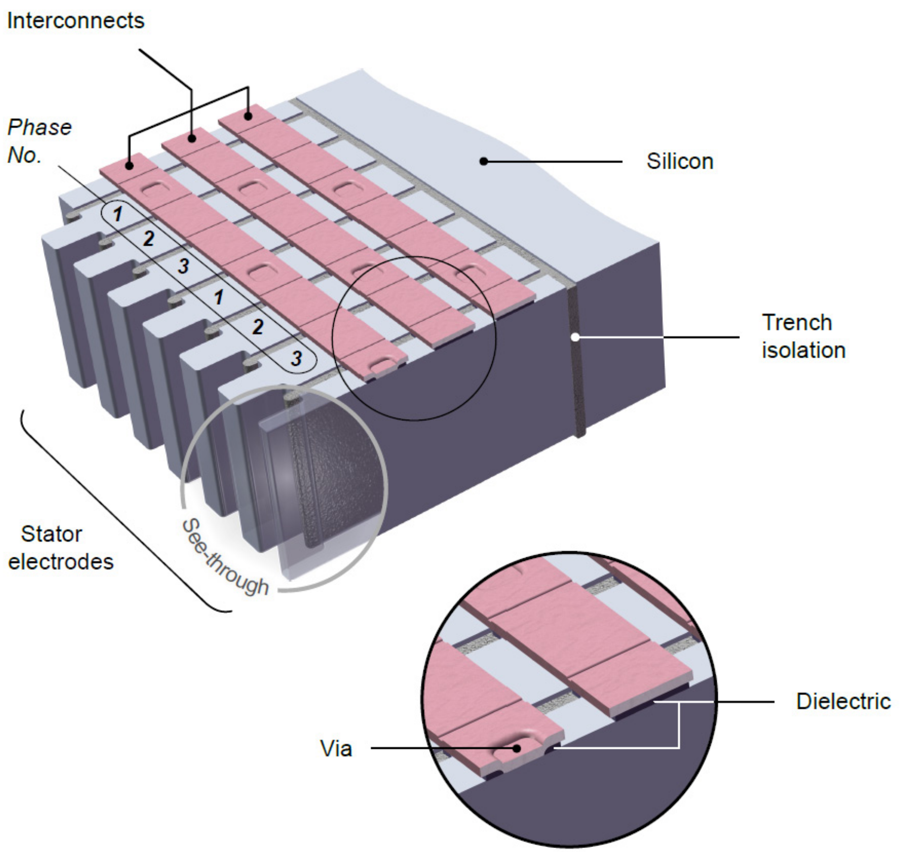

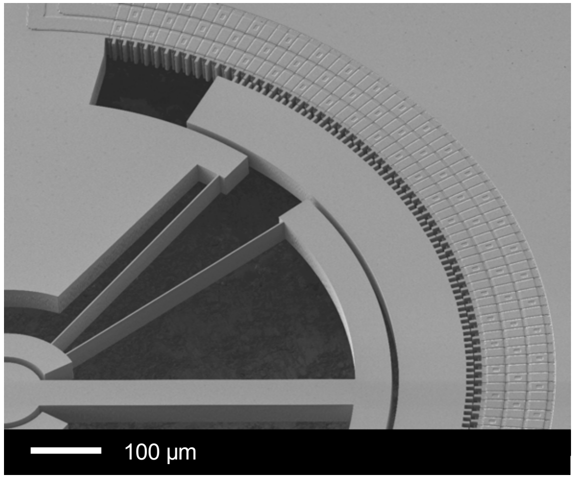

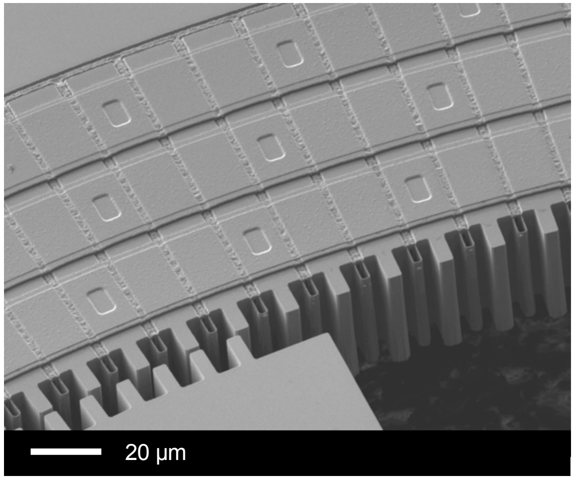

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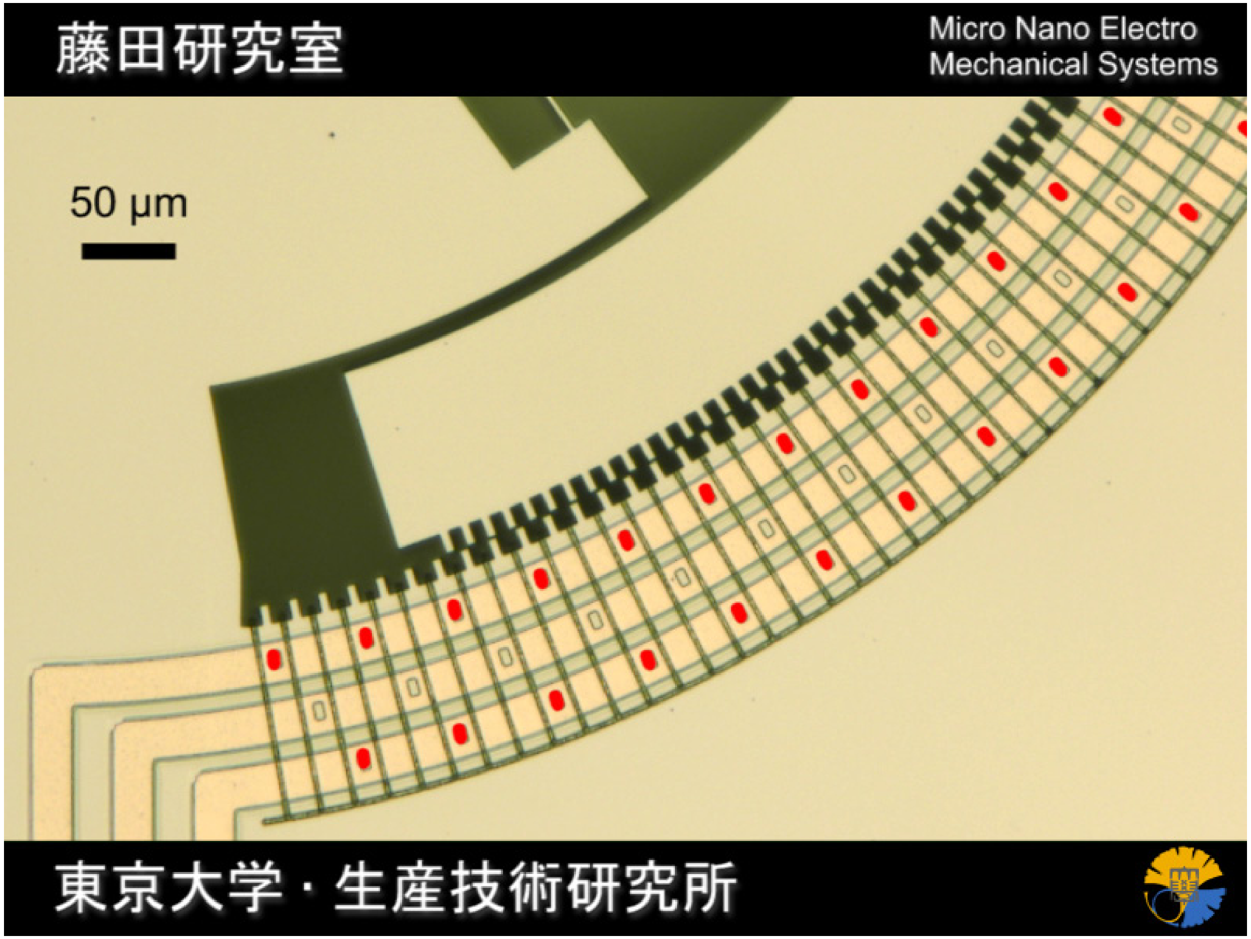
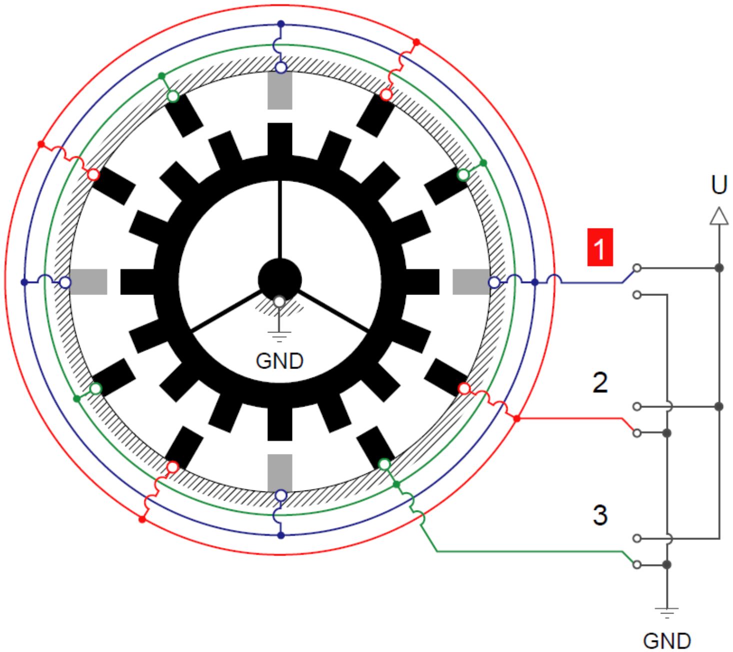


http://christophe.yamahata.fr/videos/RSM/

QuickTime video

Windows Media Player

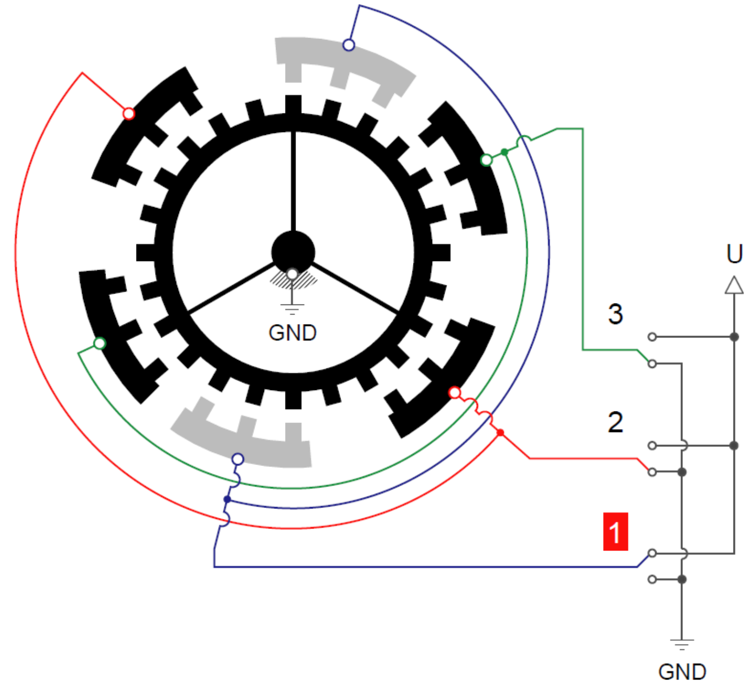
New design | Single mask 3-phase stepper motor



Previous design (MEMS '09)

Each stator electrode is electrically insulated from its neighbors.

Conductive interconnects were employed to connect the electrodes to a given electrical phase.

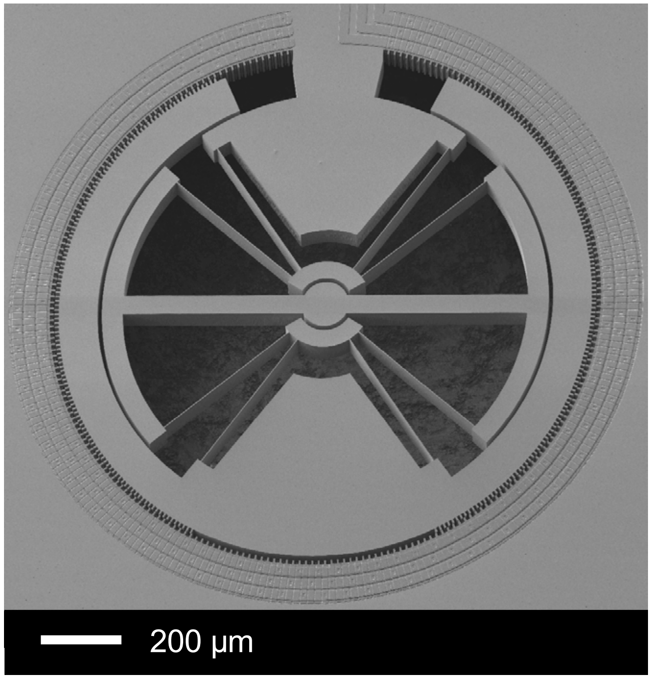


Current design

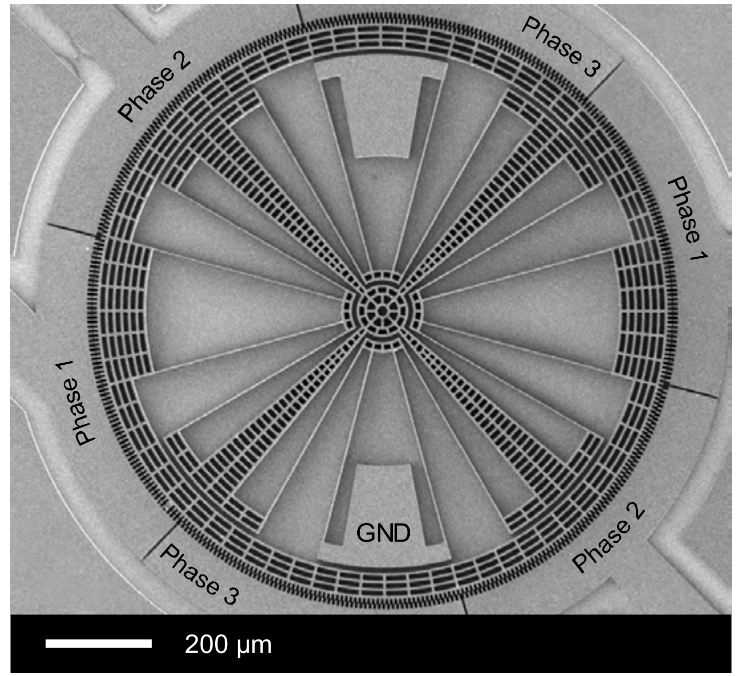
Stator electrodes are arranged into six groups.

Each group is connected to the driving electronics.

New design | Single mask 3-phase stepper motor



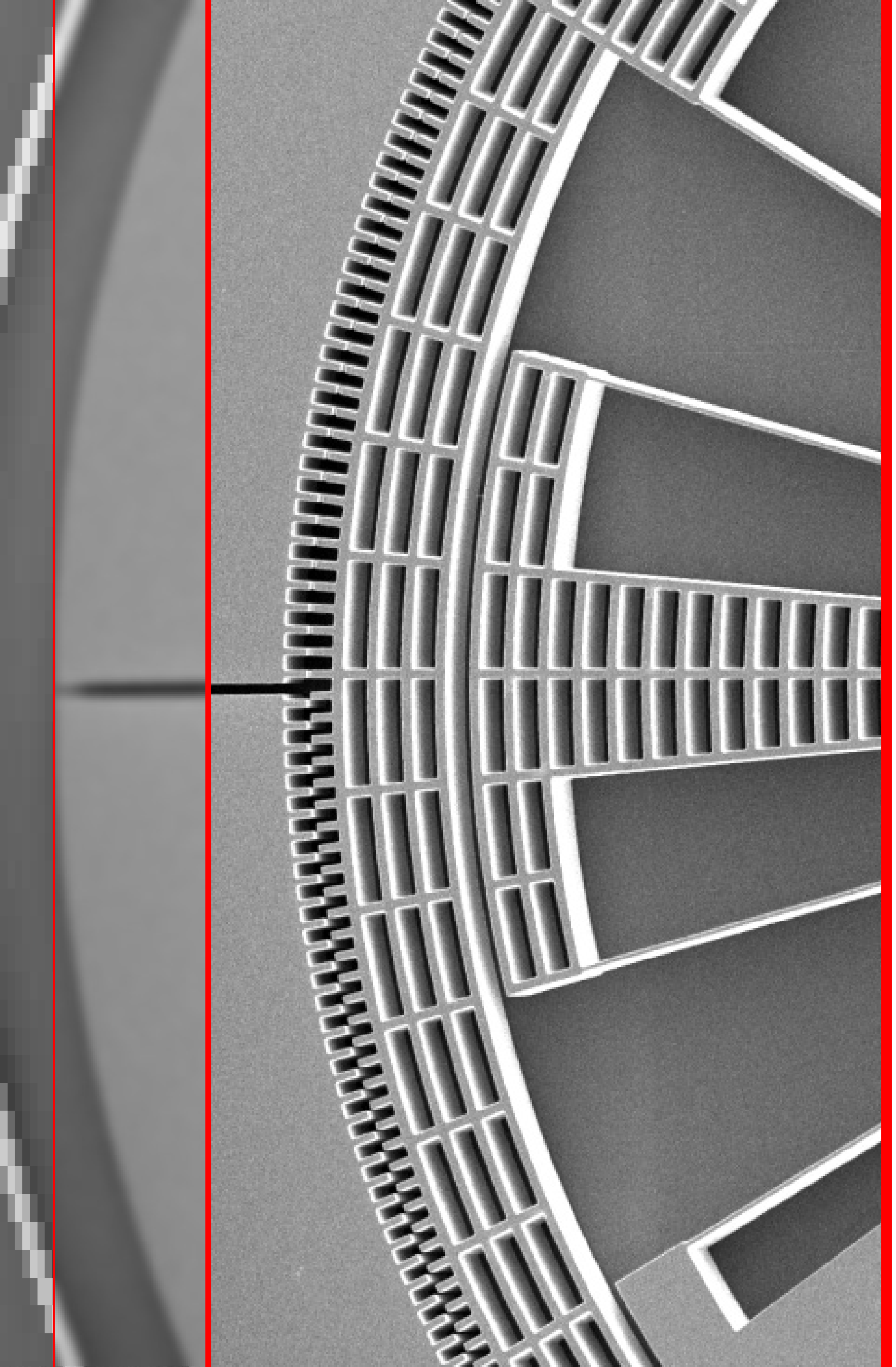
Previous design (MEMS '09)



Current design

+ *Simpler fabrication*
+ *Larger number of poles*

– *Reduced efficiency*
– *Contact pads inside*

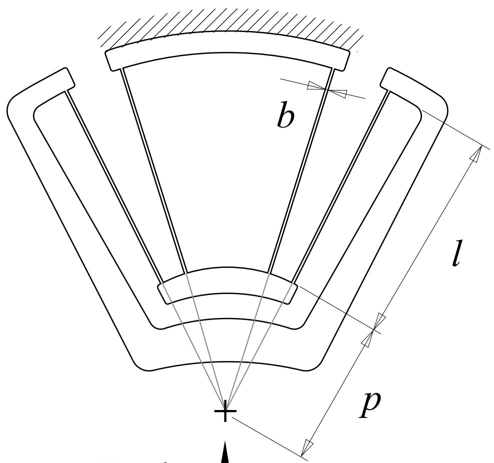


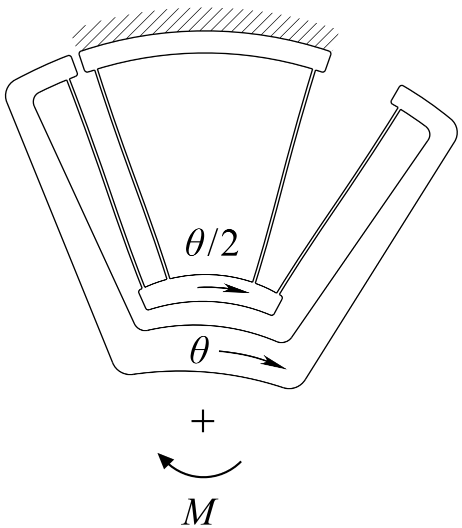
Modeling and Characterization

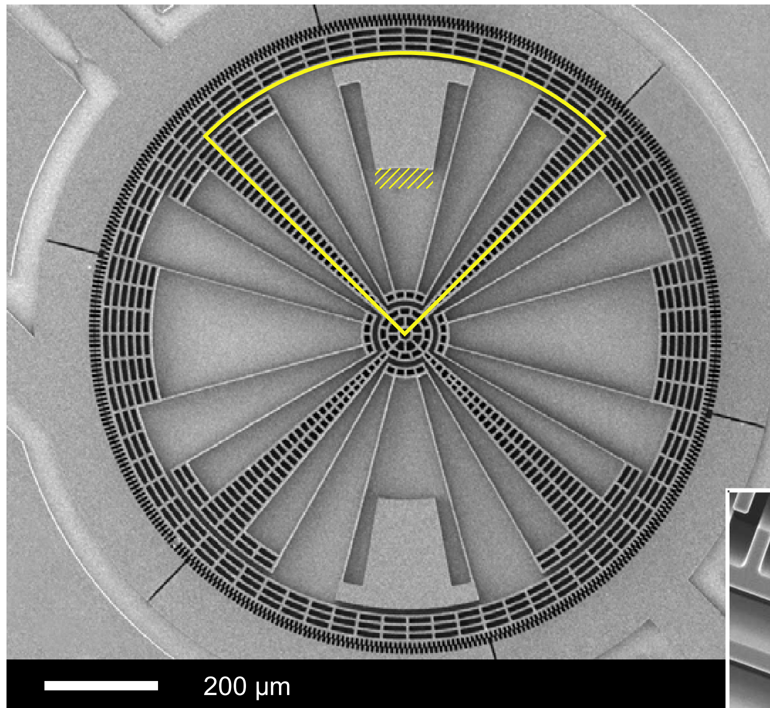
- Modeling
- FFT measurement method
- Experimental characterization

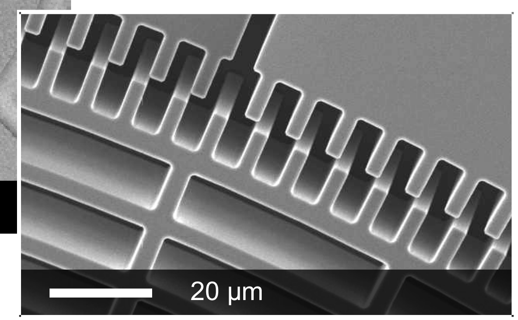
Modeling | Flexural pivot stiffness / Electrostatic torque

Flexural pivot









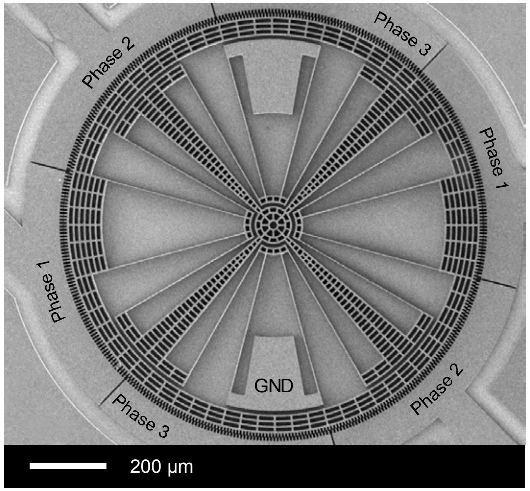
Flexural pivot stiffness

$$K_{\theta} = \frac{4\,EI}{l}\left(1 + 3\frac{p}{l} + 3\frac{p^2}{l^2}\right)$$

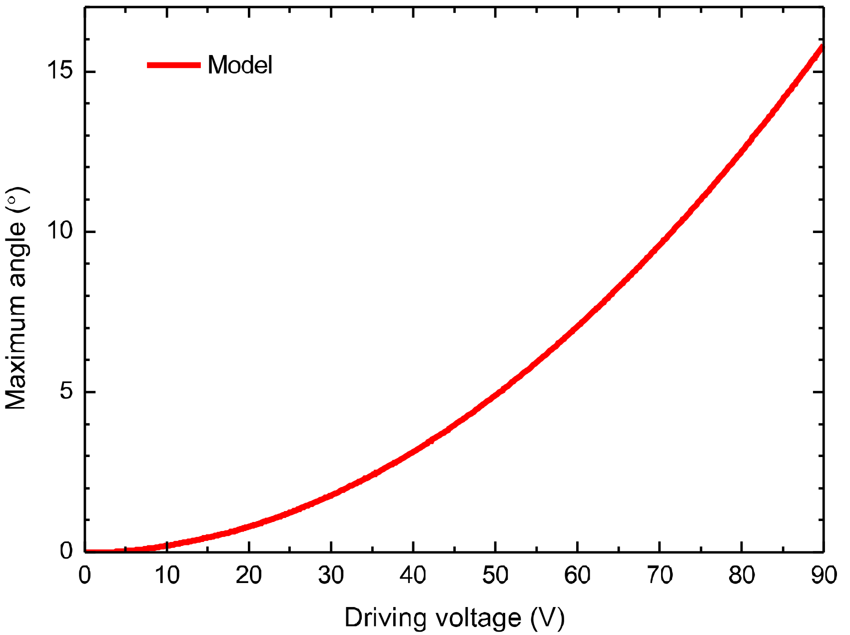
Electrostatic torque

$$M = F \cdot r = n\,\frac{1}{2}\,\frac{\epsilon_o h U^2}{g}\,r$$

Modeling | Performance characteristics (theoretical model)



Parameter	Symbol	Value
Motor radius	r	575 µm
Electrode width	w	4 µm
Electrode height	h_p	25 µm
Gap (rotor/stator)	g	1.5 µm
No. stator electrodes per phase	n	132
Pitch of rotor poles		0.9°
Flexure length	l	390 µm
Flexure width	b	3 µm
Flexure height	h	25 µm
Distance to virtual pivot center	p	80 µm

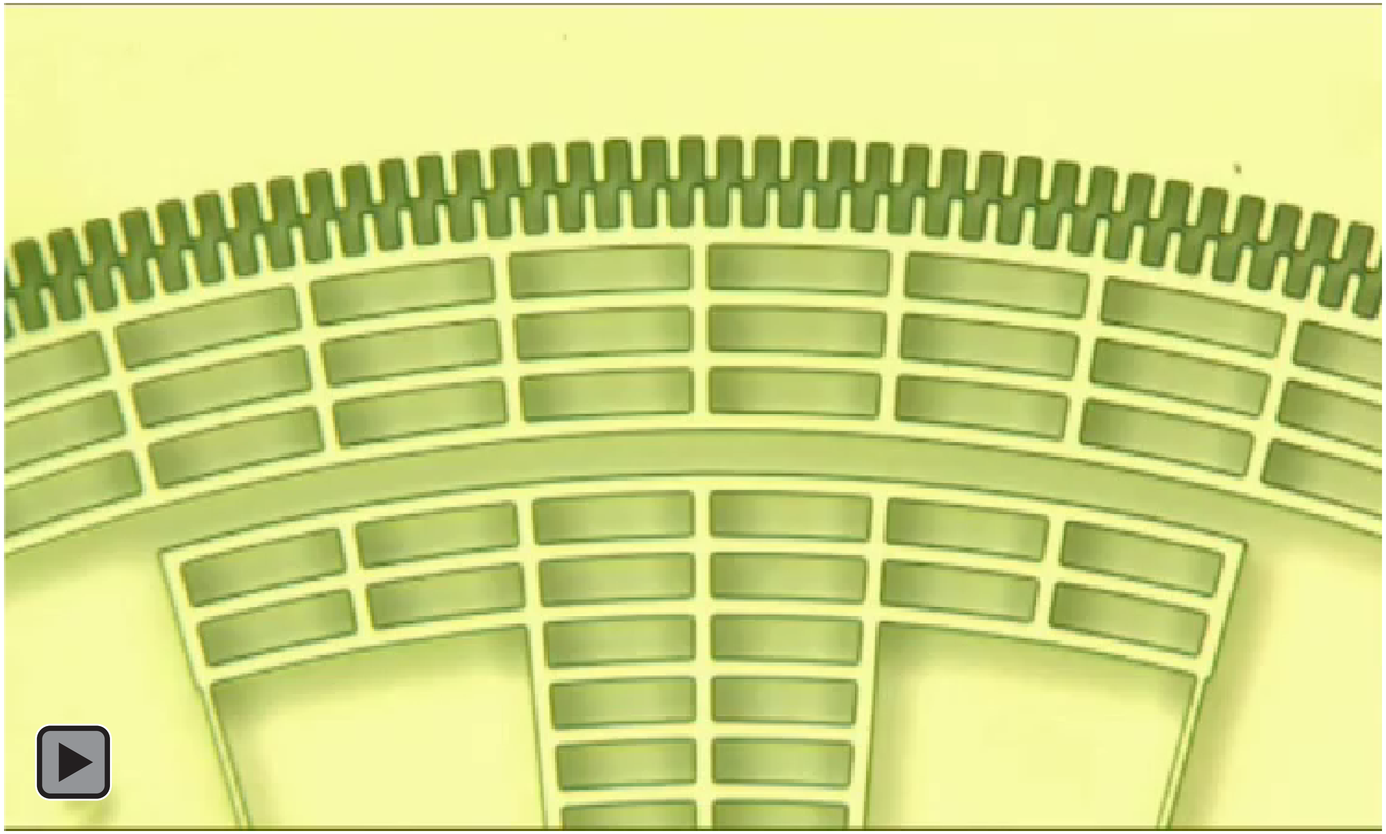


↑ Rotational range of the single-mask 3-phase rotary stepper motor.

The results are for one direction only. (The angular range is double.)

Video recording of the single mask stepper motor

Video frames are extracted for FFT calculations in MATLAB.

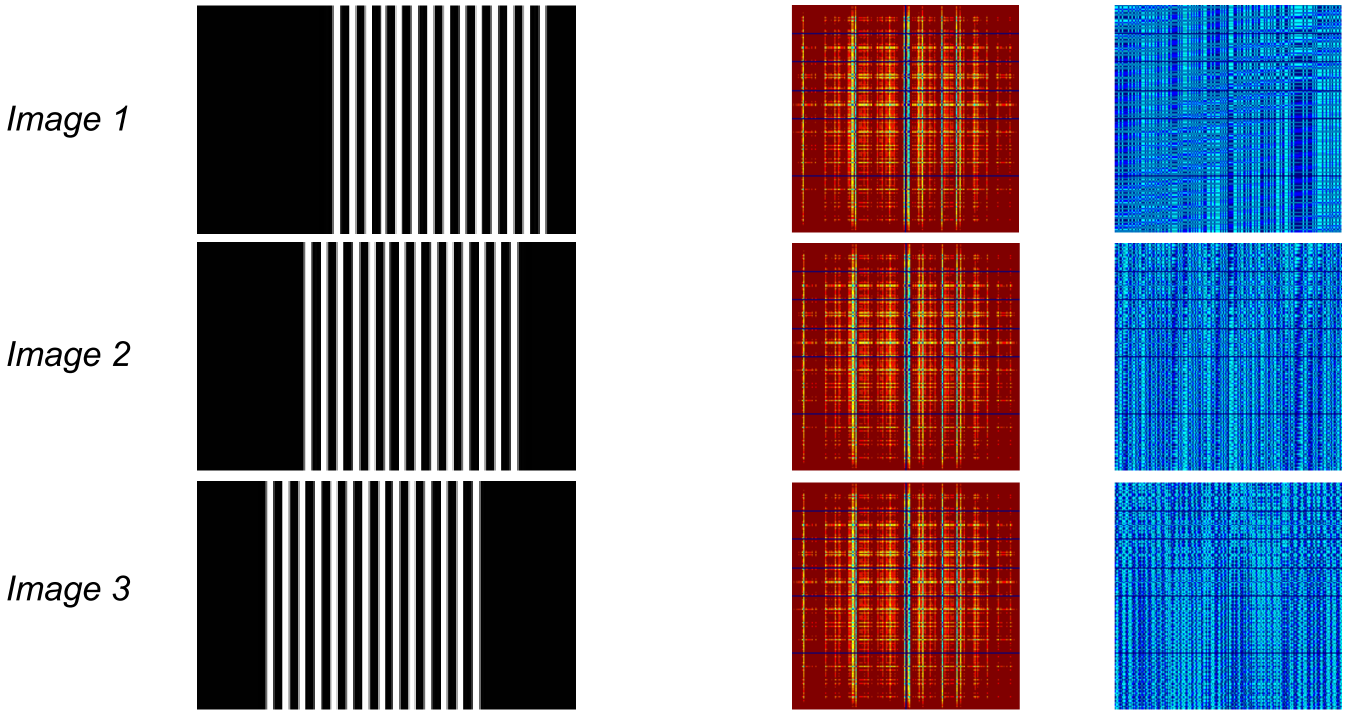


Displacement measurement by Fourier transform analysis

The Fourier transform can be applied to **images** (2D function).

Example: Fast Fourier Transforms of images

$$f(x) \overset{F}{\Leftrightarrow} \left|F(\omega)\right| \quad \Phi(\omega)$$



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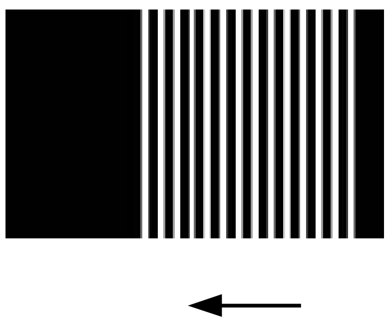
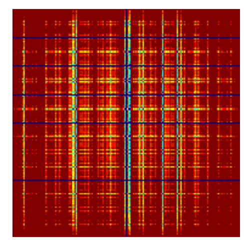
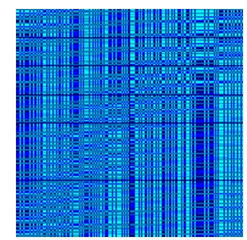






Pattern shift:
displacement to the left

Only the phase
changes

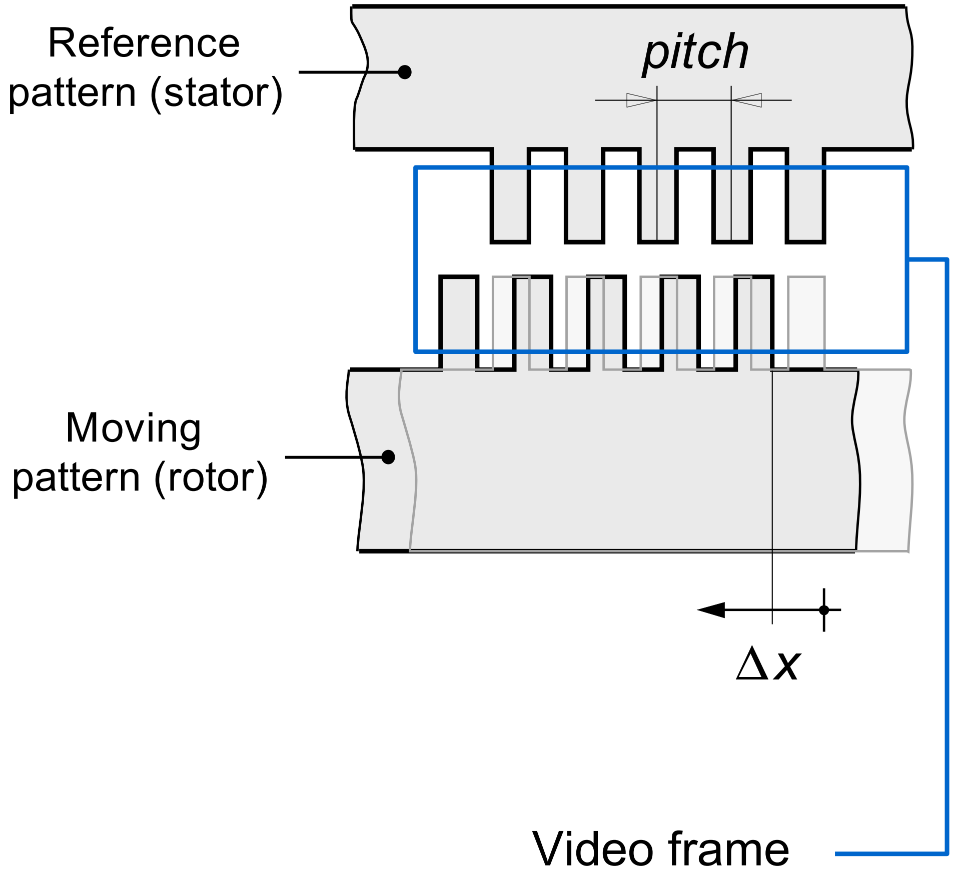
Image 1

Image 2

Image 3

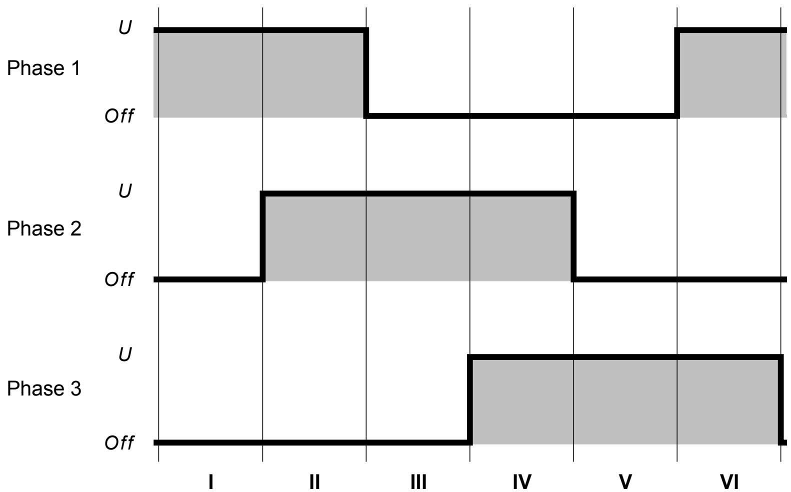
Measurement method | Fourier transform image analysis

Displacement measurement by Fourier transform analysis

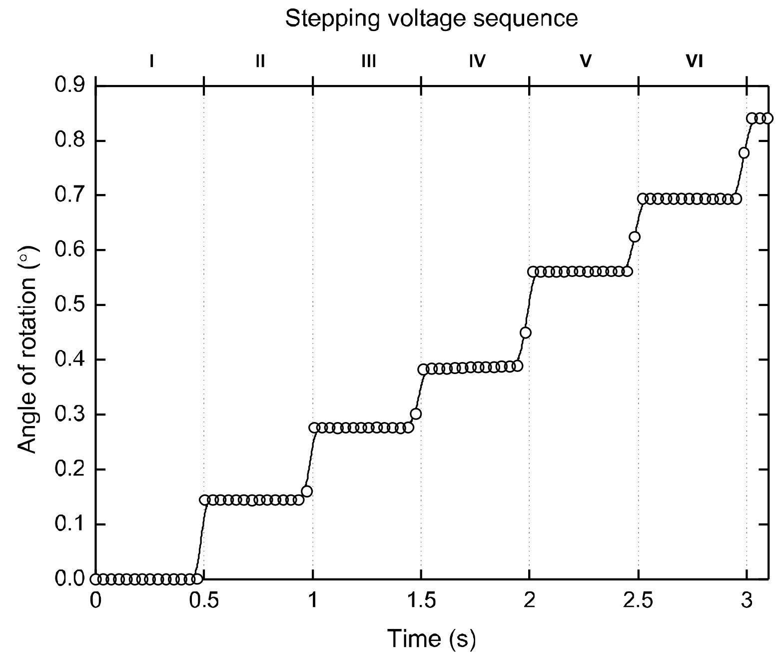


Experimental results | Stepwise actuation

Half stepping actuation of the micromotor

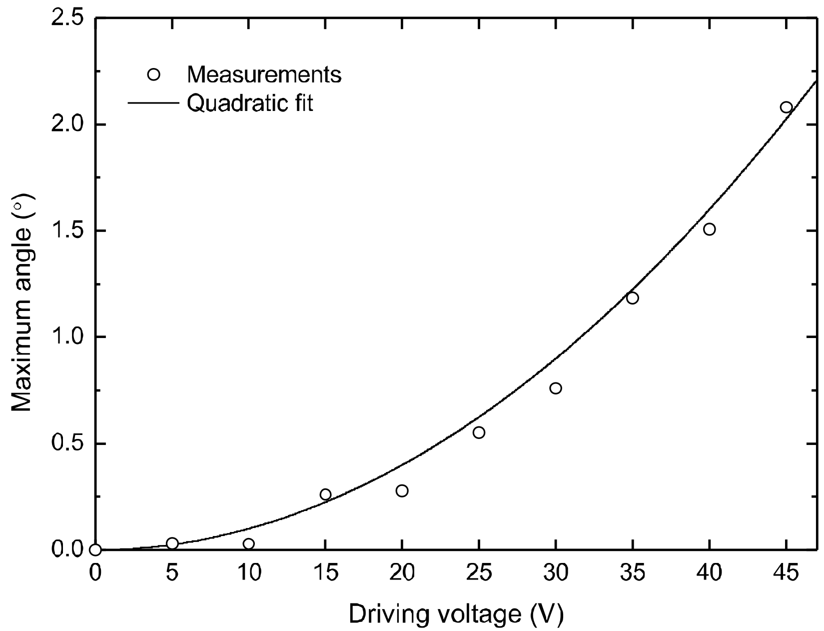


🡑 Half stepping actuation sequence.



🡑 Rotational displacement measured with an image processing technique based on FFT.

Experimental results | Rotational range



↑ Maximum rotational range of the single-mask 3-phase rotary stepper motor as a function of the driving voltage.

The measurements are for one direction only. The angular range is double.

We have observed stiction of the rotor. Probably due to charge build-up in a low-conductivity device layer.

Conclusion

Conclusion

- We have devised, fabricated and tested a 3-phase rotary stepper micromotor using a single mask fabrication process based on **SOI micromachining**;
- Performance characteristics of the motor were limited due to stiction of the rotor caused by charge build-up (low conductivity device layer);
- Significant improvement in performance and reliability of the motor expected when fabricated on a highly conductive SOI wafer.