FABRICATION OF A MEMS COMB DRIVE ACTUATOR

Adam Banees
Advisor: Dr. Lynn Fuller
What are Comb Drive Actuators?

- Comb drive actuators are capacitive actuators that utilize electrostatic forces to **move or sense comb actuation**
- Used in many other MEMS applications
  - Examples: gyroscopes, resonators, accelerometers
- Used in applications of optical communication, wireless communication, and biomedical engineering

Example of Comb Drive Actuation
MEMS Comb Drive Operation

- Comb drive actuators mainly use two forces:
  - Electrostatic Force: the drive-in voltage applied to the combs that makes the device actuate due to the capacitance in the fingers
  - Mechanical Restoring Force: the spring structure that returns the movable comb to the original state

- The two forces are equated to obtain the force equilibrium equation to give a displacement of the movable combs vs. the drive-in voltage applied to the device
Comb Drive Force Theory

Electrostatic Force Equation

\[ F_e = \frac{n\varepsilon_0 h}{2g} V^2 \]

Mechanical Spring Force Equation

\[ F_s = k_x \cdot x = \frac{2Eb^3}{L^3} \cdot x \]

Force Equilibrium Equation

\[ x = \frac{n\varepsilon_0 L^3}{4Egb^3} V^2 \]

\( n \) = number of fingers
\( V \) = voltage
\( \varepsilon_0 \) = permittivity of free space
\( g \) = gap between the fingers
\( h \) = thickness of device
\( E \) = Young’s Modulus
\( b \) = device width
\( L \) = device length
\( x \) = displacement of combs
\( k_x \) = spring constant
\( F_e \) = Electrostatic Force
\( F_s \) = Mechanical Spring Force
Theoretical Results

Voltage vs. Electrostatic Force

Voltage vs. Lateral Displacement

Finger Gap
- 0.5 um
- 1.0 um
- 1.5 um
- 2.0 um

Target Displacement = 2 µm
Fabrication and Design Details

• Two process runs were done throughout the year: fall and spring

• Fall wafers were done with the MEMS Fabrication class
  • Two designs were used: 2 µm finger gaps and 1.5 µm finger gaps

• Spring wafers were done with some minor device design adjustments
  • Adjustments to mechanical spring structure and added 1 µm and 0.5 µm finger gap devices
Design A

- # of Fingers, $n$: 47
- Beam Length, $L$: 280 um
- Beam Width, $b$: 5 um
- Thickness, $h$: 2 um
- Finger Gap, $g$: 1.5 um
- Drive Voltage to Move 2 um, $V$: 52.2 V

Design B

- # of Fingers, $n$: 41
- Beam Length, $L$: 200 um
- Beam Width, $b$: 5 um
- Thickness, $h$: 2 um
- Finger Gap, $g$: 2 um
- Drive Voltage to Move 2 um, $V$: 92.7 V
Fall Design A

2 μm

1.5 μm

10 μm

Anchor

Movable Combs

Fixed Combs

L

b
Spring Designs

Design C

Design D
Fabrication Process

• The RIT Surface MEMS Process contains 8 mask levels and 51 process steps[3]

• The MEMS processing workload was shared with Mattias Herrfurth who also used this fabrication process but had a different MEMS device

Adam Banees: Development of a MEMS Comb Drive Actuator
Wafer Progress

• Fall wafers are at pre-release
  • Release layer is still under development

• Spring wafers are at metal
  • Challenges with metal etch
Results

- Analysis done with the exposure process on the mechanical poly layer [4]
- The mechanical poly layer is sensitive to focus and exposure
- A focus exposure test was done to find the optimal focus and dose:
  - Focus: -0.5 µm, Exposure Dose: 400 mJ/cm², NA: 0.6, σ: 0.7
Results (con’t)

- Issues with comb finger definition in the MEMS poly 2 etch
  - STS etcher is a deep reactive-ion etching (DRIE) tool that uses the Bosch process to give a very anisotropic etch. This tool was down during the time of the poly 2 etch.
  - Since there is no other tool in the SMFL uses the Bosch process, the Drytek Quad was used as the next best option.
  - Since the aspect ratio of the fingers were 1:1 (2um width : 2um thickness), the fingers were over-etched or destroyed completely.
  - Future MEMS projects will use the STS etcher for the mechanical poly layer
Conclusion and Future Work

- Comb drive actuators were designed and partially fabricated using the RIT Surface MEMS process
  - It was found that the anisotropy from the STS etcher is necessary to create combs for these specific devices
- Improvement to the lithography step for the mechanical poly layer
- Future work
  - Continue to improve and characterize Surface MEMS process
Acknowledgements

• Thanks to Dr. Fuller and Adam Wardas for their work on the RIT Surface MEMS process
• Thanks to Mattias Herrfurth, Chris O’Connell, and the SMFL Staff for helping with the fabrication of these devices
• Thanks to Dr. Pearson and Dr. Ewbank for advice throughout my senior design project
References


• [2] MEMS Mechanical Fundamentals, L. Fuller

• [3] Surface MEMS Fabrication Details, L. Fuller

• [4] MEMS Fabrication Blog 2015, L. Fuller