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Abstract
The design of a single-pole/double-throw (SPDT) nano-electro mechanical (NEM) switch implemented using the metal interconnect layers available in a standard 65 nm CMOS back-end-of-line (BEOL) process is investigated for non-volatile NEM memory (NEMory) applications. The Coventorware MEMS+ finite element analysis (FEA) software tool is used to study design trade-offs. The device geometry and dimensions are optimized to minimize the switching energy, mechanical delay and settling time.

Introduction
Hybrid CMOS/NEM technology recently has been proposed to enable faster and more energy-efficient data searching as compared with CMOS technology [1]. This work investigates the design of a non-volatile SPDT NEM switch implemented using a standard 65 nm CMOS BEOL process, to elucidate trade-offs between performance and energy efficiency.

NEMory Cell Design

![NEMory cell structure](Image)

- NEMory cell comprises a vertically oriented beam, programmed to touch either data line: DL0 ("0" state) or DL1 ("1" state)
- To program the cell, a voltage (Vprog) is applied to either AL0 or AL1, bit line (BL) is pulsed low, and word line (WL) is pulsed high.
- By implementing the NEM switch in BEOL layers, low-cost integration with CMOS and small cell area (footprint) can be achieved.
- In this work, multiple 1X metal layers, with minimum feature size and spacing of 100 nm, are used to implement the NEM switch.
- The vertically oriented beam is released by anisotropic and isotropic etching of the surrounding inter-metal dielectric material.

BEOL NEM Switch Design Trade-Offs

![BEOL NEM switch structure](Image)

- Reduction in spring stiffness provides for lower pull-in voltage (Vpl), but increases the likelihood of catastrophic pull-in to AL0/AL1.
- The actuation plate should be stiffer to reduce the possibility of catastrophic pull-in, but this increases the mass, resulting in slower switching speed.
- A larger actuation gap for the bottom AL layers results in reduced oscillation upon contact, but at the trade-off of increased Vpl.

Design Optimization Approach

![Design Optimization Approach](Image)

- For non-volatile operation, contact adhesive force (Fadh) must be greater than the beam’s spring restoring force (Fspring).
- For reprogramming capability, the electrostatic force (Felec) must be greater than Fadh – Fspring. To minimize Felec and hence the switching energy, Fspring ≈ Fadh.
- To reduce the possibility of catastrophic pull-in:
  - Add vias between actuation plate layers to reduce torsional motion
  - Make actuation plate thicker in M3 and M6 layers

Results and Discussion

![Results and Discussion](Image)

- Beam oscillation must cease before Vprog is removed for successful reprogramming.
- Larger overdrive (higher contact velocity) results in stronger oscillation.
- To reduce oscillation upon contact:
  - Make actuation plate narrower in M4 and M5 layers
  - Use larger actuation gaps at bottom (M3)

Summary

- Design guidelines for SPDT NEM switch design to achieve non-volatile operation with minimum energy × delay are developed.
- A stiffer actuation plate is advantageous for avoiding catastrophic pull-in, at a tradeoff of longer switching delay.

Reference:

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