A Cantilever-based Non-volatile Memory Utilizing Vibrational Reset for High Temperature Operation

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Contents

• Introduction
• Actuation and De-actuation Principle
• Measurement Results
• Performance Evaluation
• Proposed NEMS-based Anchored Memory, Read/Write Control Scheme
• Conclusion
• Memory device for data logging in harsh environment are highly demanded
• Market Available flash memory exhibits poor retention when exposed to high temperature (＞200°C)
Anchored NEMS Memory Device

- The proposed device has three terminals (CTL: Cantilever, ACT: Actuator, CT: Contact).
- Cantilever is actuated by Actuator with bias voltage.
- Actuation is performed by electrostatic force between Actuator and Cantilever.
Data retention is realized by Van der Waals force.

No memory operation is obtained when Van der Waals force is small.

Data read-out is carried out by sensing the current between Cantilever and Contact terminals.
Data Retention Principle

- Magnitude $F_{ad}$ of the adhesive (Van Der Waals) force:
  \[
  F_{ad} = \frac{A_{metal}}{12 \cdot \pi \cdot D_{rms}^2}
  \]

- $A_{metal}$: Hamaker constant of the metal, $D_{rms}$: Surface roughness
- $F_{ad}$ increases with temperature, thus data retention improves at higher temperature.
• **SET pulse** is applied to Actuator (CTL = GND) to create electrostatic force.

• Cantilever is pulled down and remains in contact by Van der Waals force.
Actuation Principle

- \( F_r \) - magnitude of restoring force, \( F_{ad} \) - magnitude of adhesion force

\[
F_r = \frac{EWt^3g}{4L^3} \quad F_{ad} = \frac{A_{metal}}{12\pi D_{rms}^2}
\]

- For adhesion: \( F_{ad} > F_r \)
- The adhesion force can be made larger by carefully engineering the smoothness, the size of the Contact and Cantilever and number of dimples
• **RESET** is carried out by applying a *train of short pulses* to the actuator.

• Cantilever starts vibrate if the pulse frequency matches the *resonant frequency* of Cantilever.
The head of the Cantilever beam has array of **dimples**. (500 nm × 500 nm).

The number of dimples is of crucial as it decides the adhesion force between Cantilever and Contact.
Measurement Results - Set

- A long single pulse is applied for SET.
- The contact follows the cantilever voltage (0.5V) when SET is achieved.
- Read delay of 1.5 µs was measured at 9V.
Measurement Results - Reset

- A train of short pulses is applied for RESET.
- The measured Cantilever-Contact current falls to 10pA when RESET is achieved. (Max. current is limited by external equipment for device protection.)
Performance Evaluation – “SET”

- Delay can be reduced by decreasing Cantilever length and increasing pull-in voltage.
- Delay decreases by lowering Cantilever voltage below GND.
Performance Evaluation – “SET”

- The variation in delay w.r.t pull-in voltage is less when the temperature increases.
- The trend is same for both low and high temperature. (shows working of device at high temperature)
Performance Evaluation – “RESET”

- Number of pulse required for de-actuation reduces as the pulse voltage increases.
- As the length increases the number of pulse reduces due to less stiffness.
Performance Evaluation – “RESET”

- The number of pulse required increases with temperature, due to increase in adhesion force.
- At high temperature, increase in cantilever length decreases number of pulses as at low temperature.
Proposed array organization

- Array structure has:
  - 1NEMS-1T memory cell
  - Two horizontal lines (WL<sub>i</sub> and AL<sub>i</sub>) per row, two vertical lines (DL<sub>i</sub> and BL<sub>i</sub>)
  - DL<sub>i</sub> connected to Cantilever
  - AL<sub>i</sub> connected to Actuator
  - Contact connected to access device (N<sub>A</sub>)
Proposed Read Operation

- BLs are pre-charged to $V_{DD}$ by PMOS (P1) devices.
- If Cantilever is at contact (i.e. Data = “1”), BL follows DL through access devices (N$_A$).
Proposed Write Operation

- Write data pattern is “01011….1”.
- DL₀ is raised to 4V to avoid writing to first cell as the datum to first cell is “0”.

\[ V_{p-in\ min} = 7V \]
Proposed Write Operation

- Write “1” or “0” can be done by flipping the stored data.
- **RESET** is performed before every write operation.
- A Level Shifter is used to supply the $V_{p-min}$ for the actuation of cantilever.
Conclusion

• A novel NEM memory device is proposed using Van-der-Waals force.
• A memory array structure is proposed.
• We propose a read/write scheme:
  – 1 NEMS–1 T bit cell
  – Vibrational RESET which eliminates the need for another terminal
  – Variation tolerance with temperature is addressed