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

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Introduction

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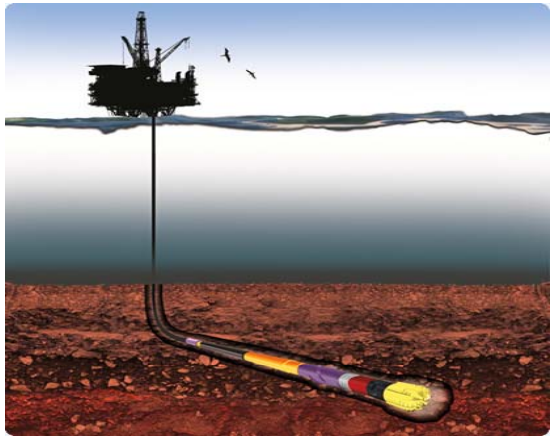
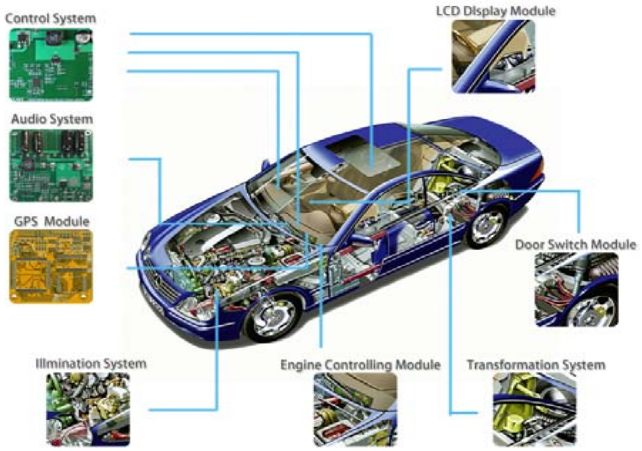
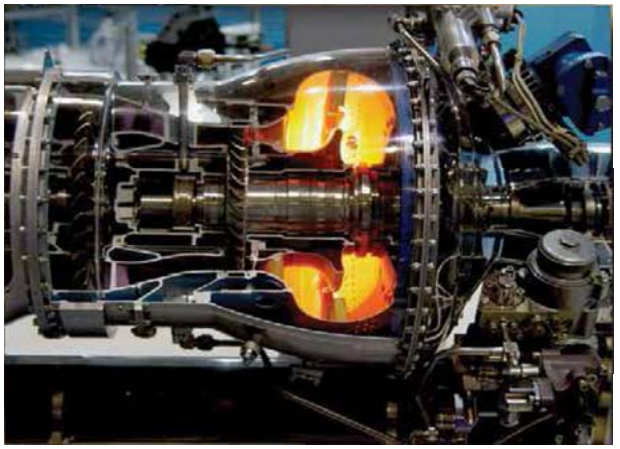


Oil Rig Industry

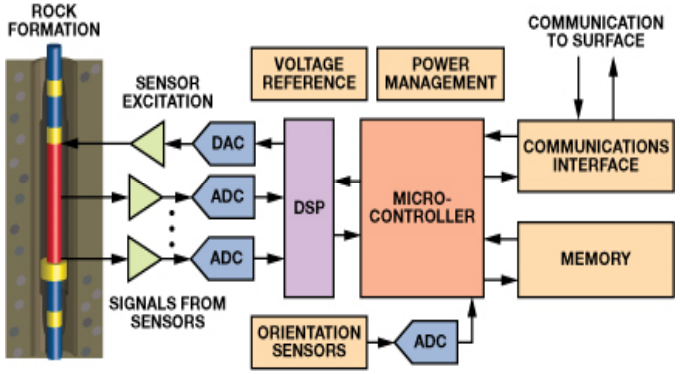


Automotive



Aviation

- **Memory device for data logging in harsh environment are highly demanded**
- **Market Available flash memory exhibits poor retention when exposed to high temperature(> 200ºC)**



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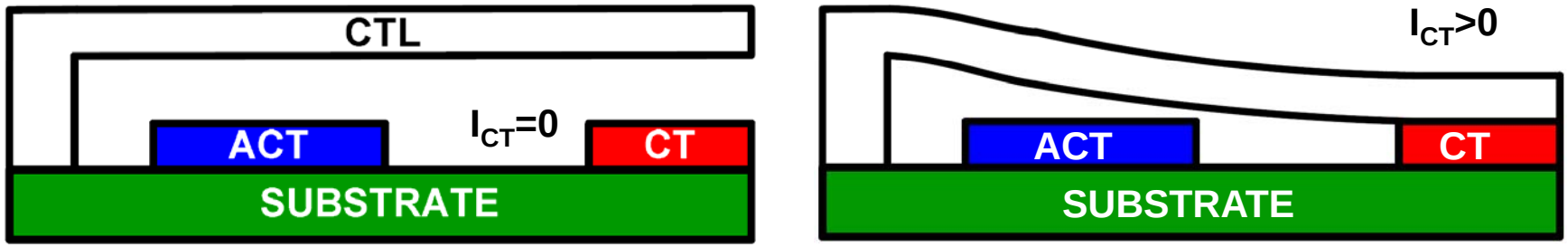
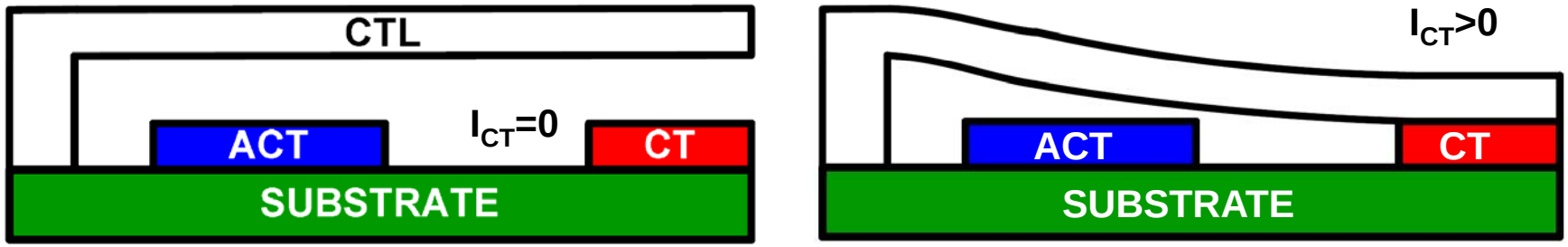
Anchored NEMS Memory Device



ACT: Actuator, CT: Contact, CTL: Cantilever

- **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 .**

Anchored NEMS Memory Device

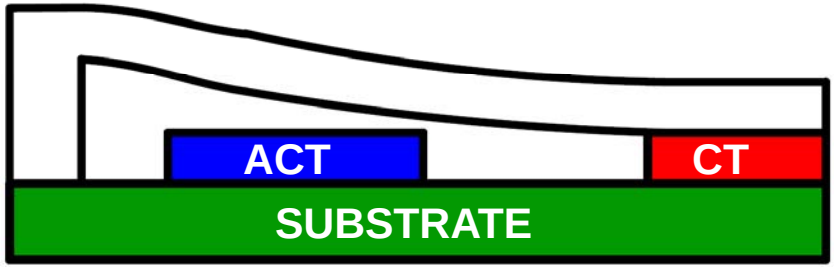


ACT: Actuator, CT: Contact, CTL: Cantilever

- **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

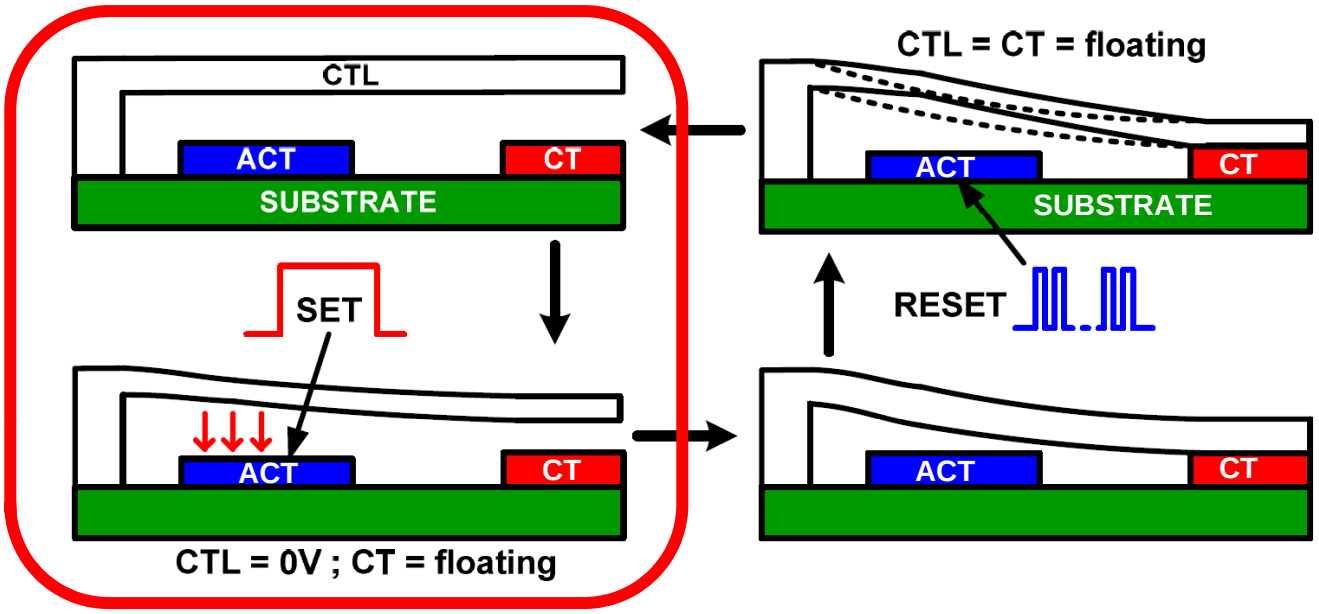
- Magnitude F_{ad} of the adhesive (Van Der Waals) force :



$$F_{ad} = \frac{A_{metal}}{12 \cdot \pi \cdot D_{rms}^2}$$

- A_{metal} : Hamaker constant of the metal, D_{rms} : Surface roughness
- F_{ad} increases with temperature, thus data retention improves at higher temperature.

Actuation Principle



ACT: Actuator, CT: Contact, CTL: Cantilever

- **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.**

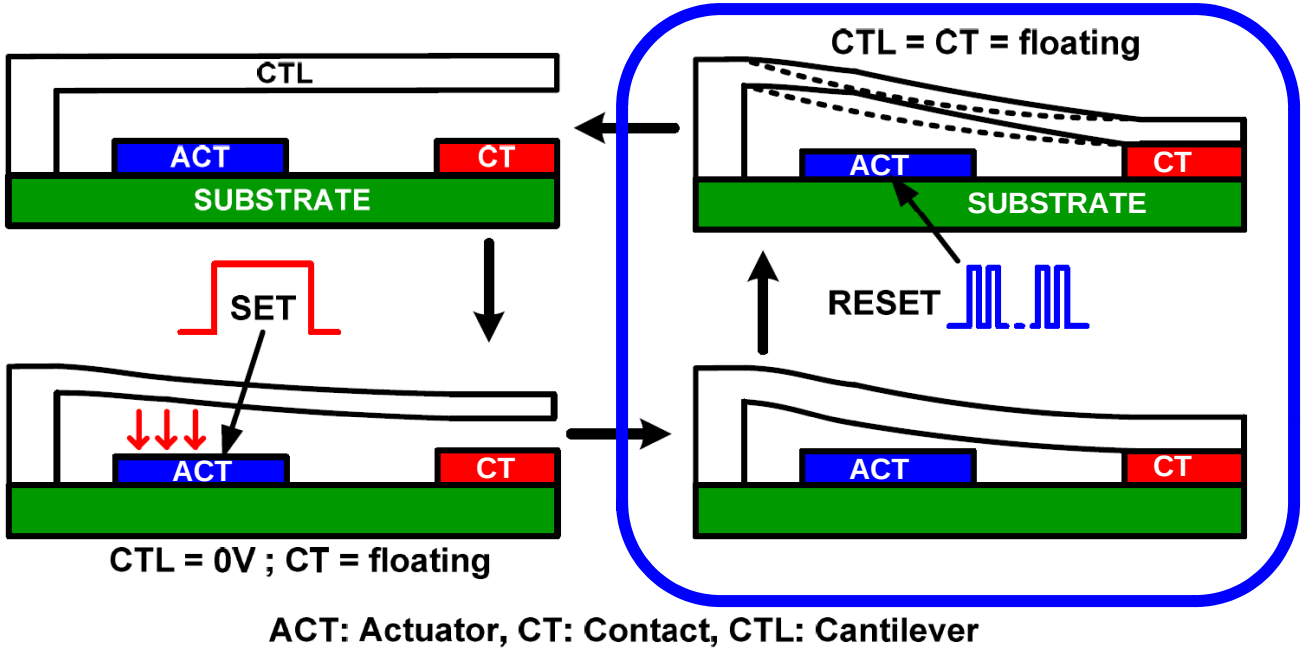
Actuation Principle

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

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

- 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

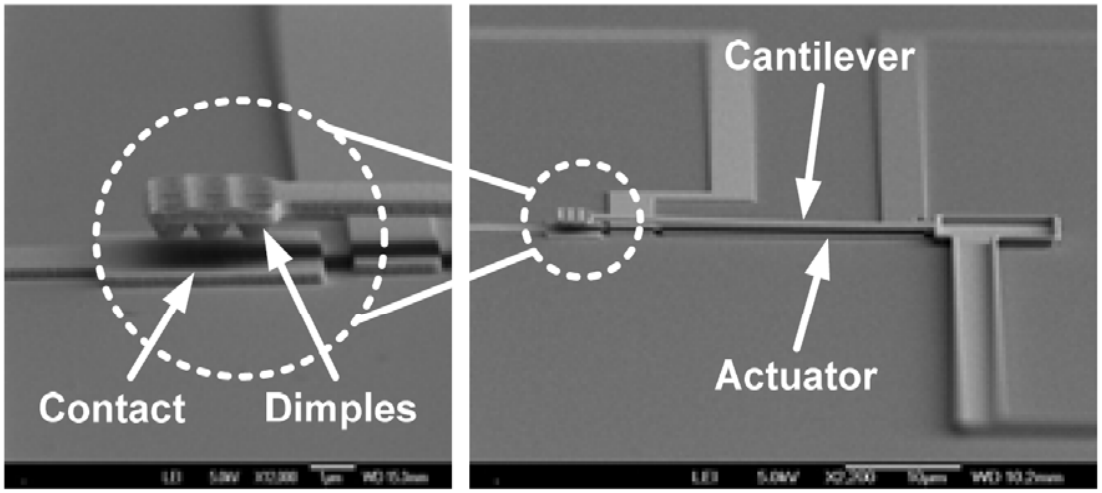
De-actuation Principle



ACT: Actuator, CT: Contact, CTL: Cantilever

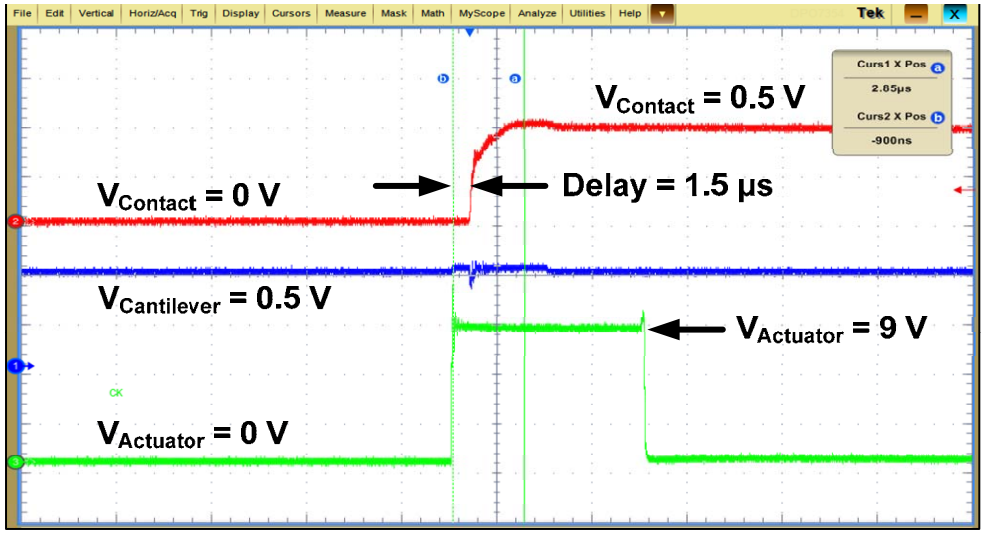
- **RESET** is carried out by applying **a train of short pulses** to the actuator.
- Cantilever starts vibrate if the pulse frequency matches the **resonant frequency** of Cantilever.

Fabricated Device



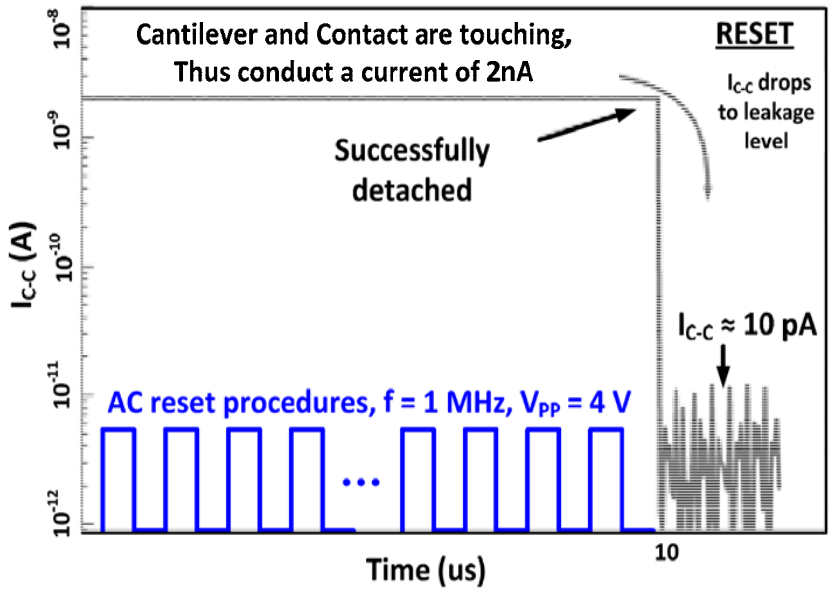
- **The head of the Cantilever beam has array of dimples. (500 nm × 500 nm).**
- **The number of dimples is of crucial as it decides the adhesion force between Cantilever and Contact.**

Measurement Results-Set



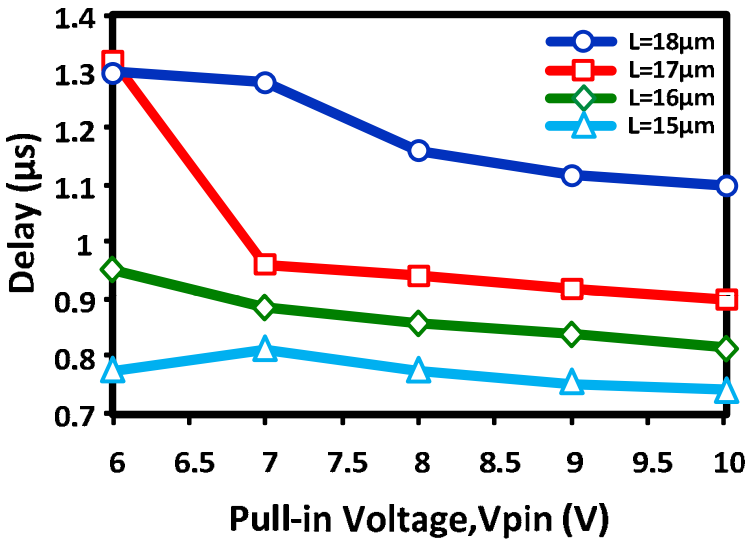
- **A long single pulse is applied for SET.**
- **The contact follows the cantilever voltage (0.5V) when SET is achieved.**
- **Read delay of 1.5 µs was measured at 9V.**

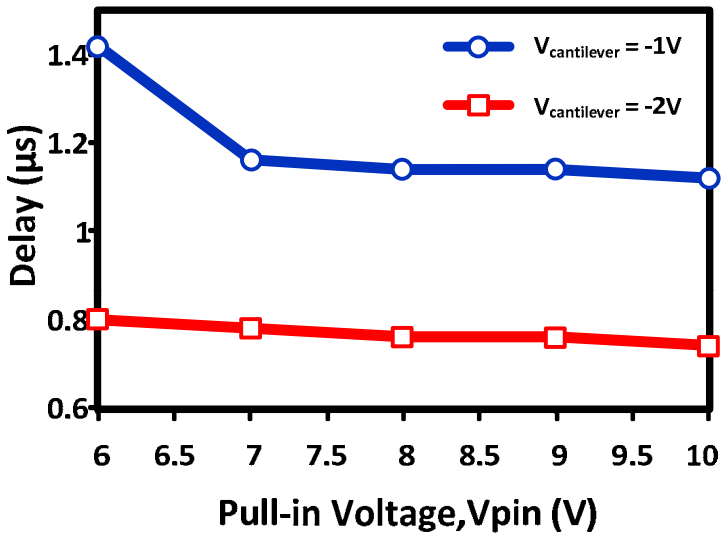
Measurement Results-Reset



- 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.)

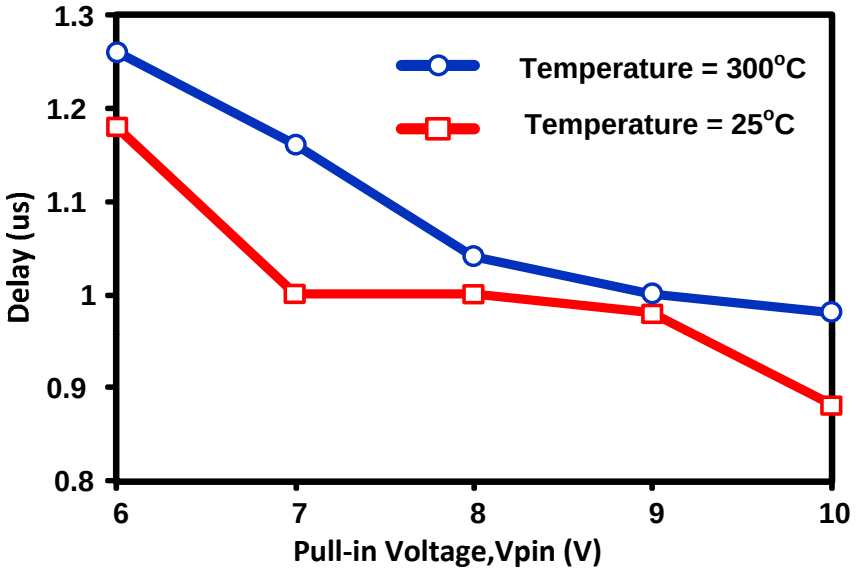
Performance Evaluation – "SET"





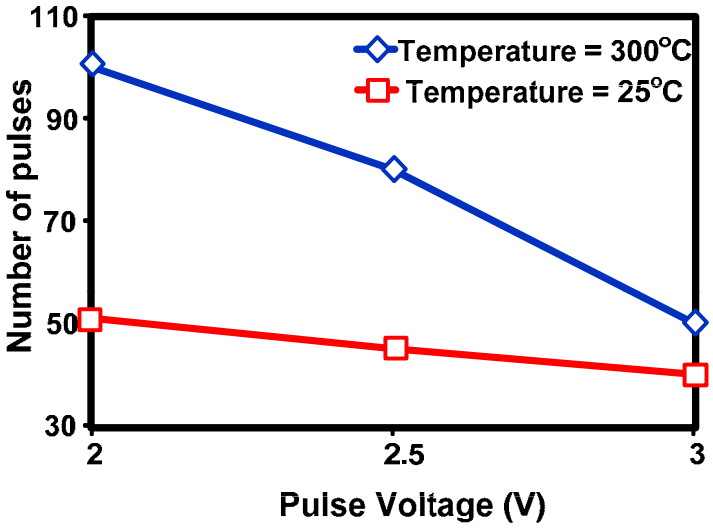
- **Delay can be reduced by decreasing Cantilever length and increasing pull-in voltage.**
- **Delay decreases by lowering Cantilever voltage below GND.**

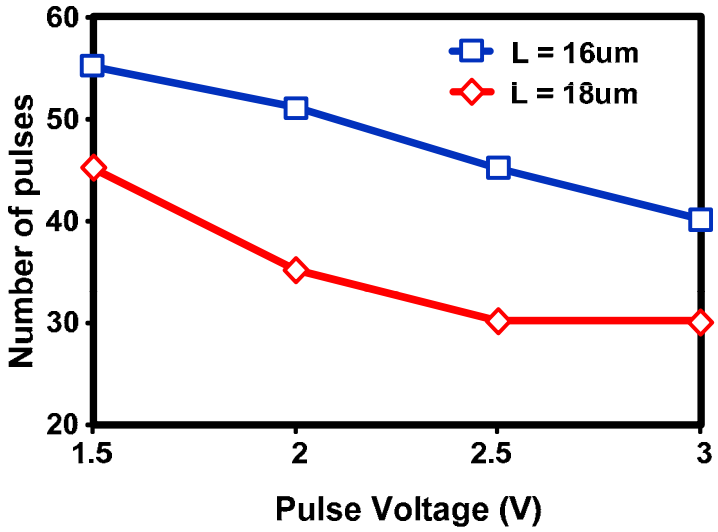
Performance Evaluation – "SET"



- 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)

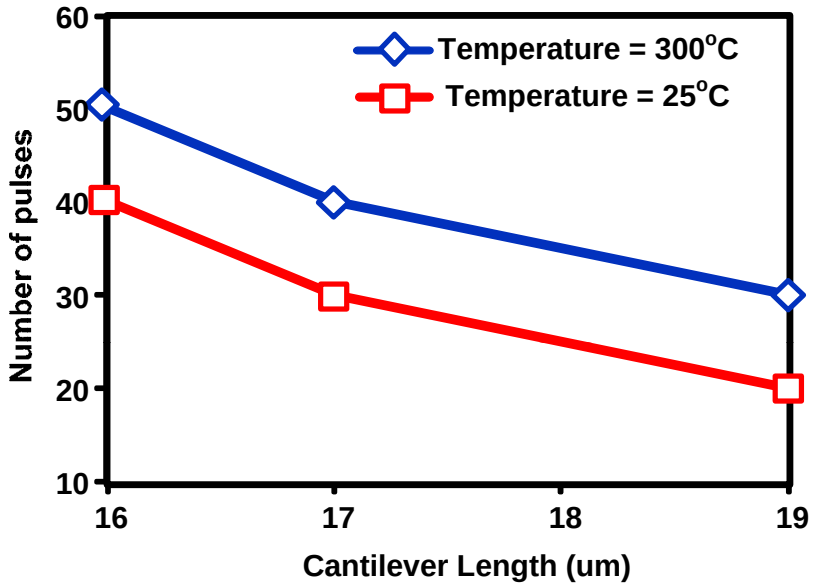
Performance Evaluation – "RESET"





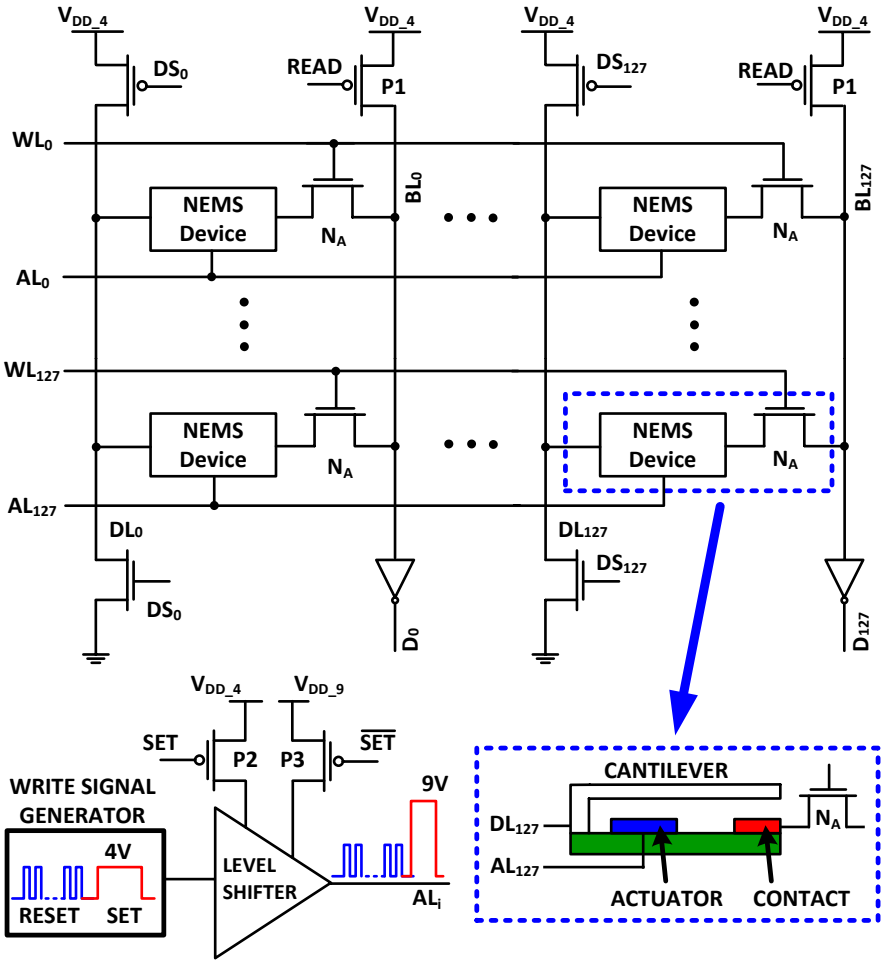
- **Number of pulses required for de-actuation reduces as the pulse voltage increases.**
- **As the length increases the number of pulse reduces due to less stiffness.**

Performance Evaluation – "RESET"



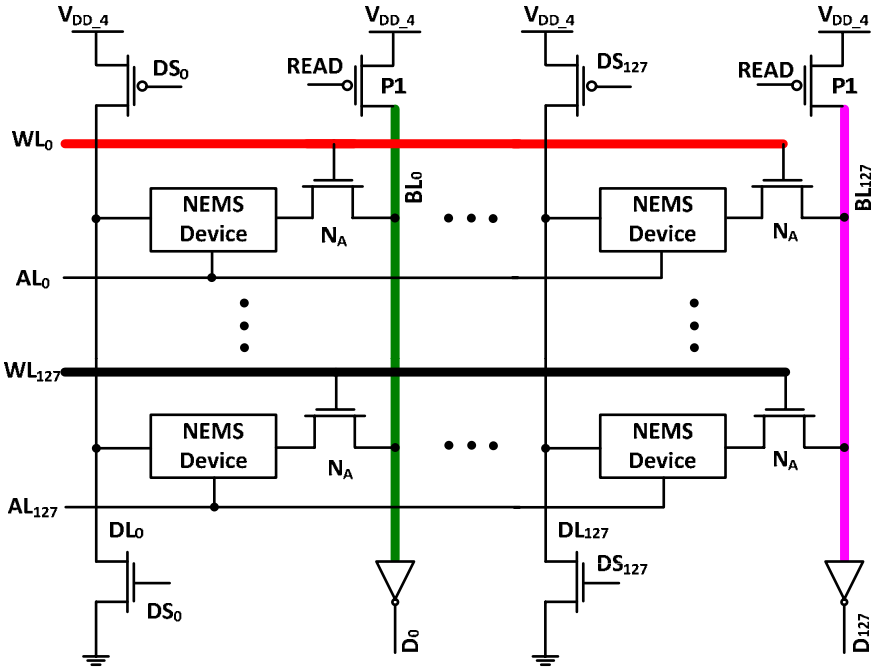
- The number of pulses required increases with temperature, due to increase in adhesion force.
- At high temperature, increase in cantilever length decreases number of pulses as at low temperature.

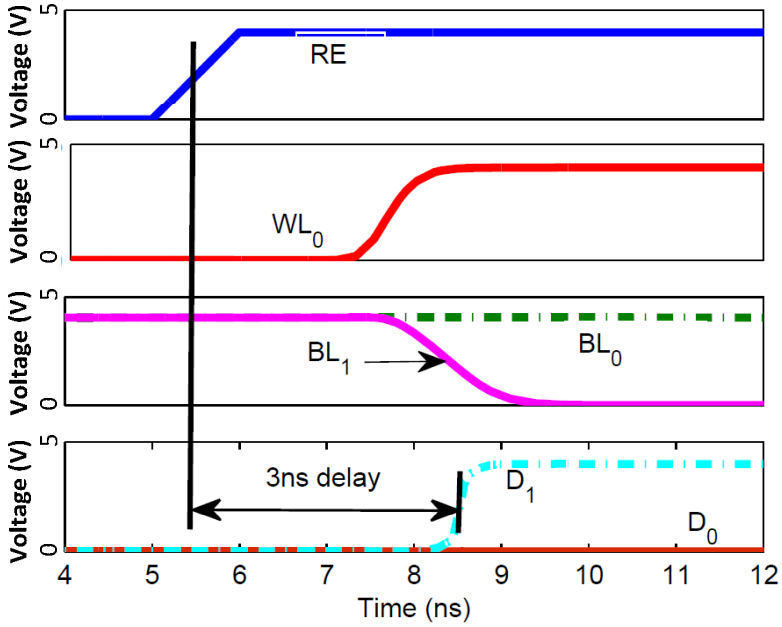
Proposed array organization



- **Array structure has:**
  - **1NEMS-1T memory cell**
  - **Two horizontal lines (WL_i and AL_i) per row, two vertical lines (DL_i and BL_i)**
  - **DL_i is connected to Cantilever**
  - **AL_i is connected to Actuator**
  - **Contact is connected to access device (N_A)**

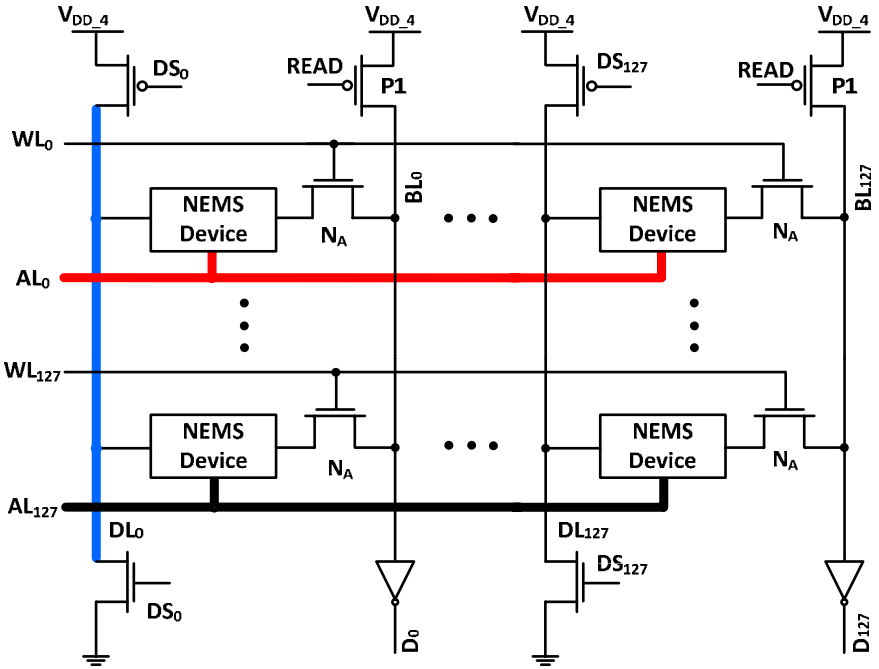
Proposed Read Operation

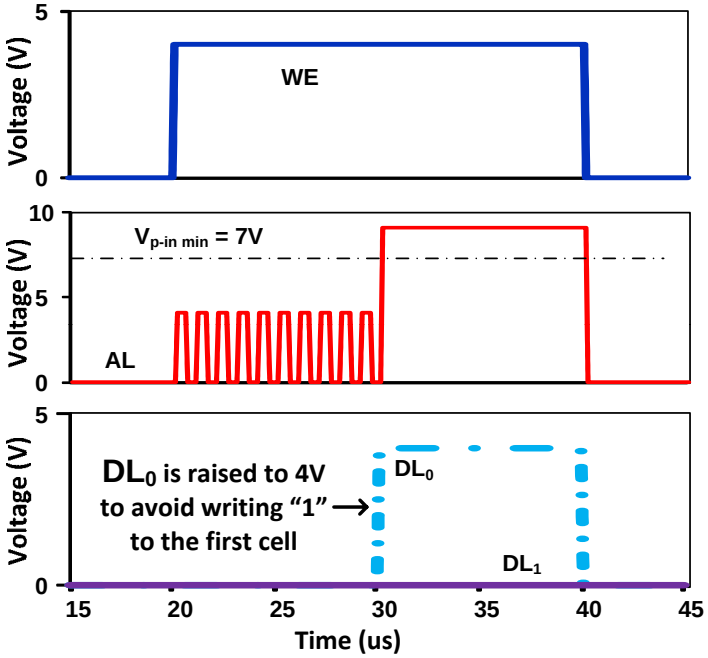




- **BLs are pre-charged to V_{DD} by PMOS (P1) devices.**
- **If Cantilever is at contact (i.e. Data = "1"), BL follows DL through access devices (N_A).**

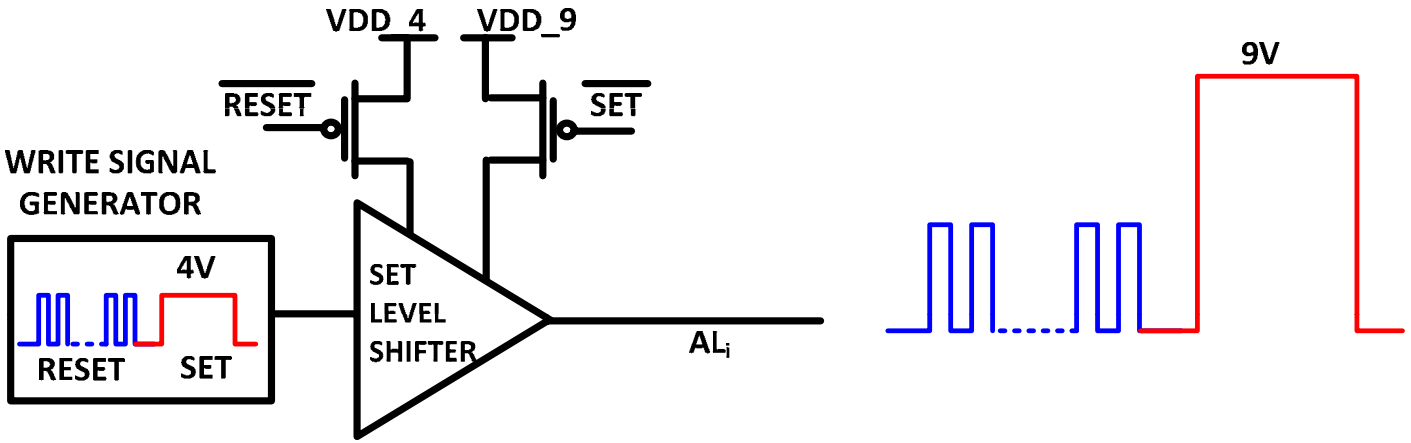
Proposed Write Operation





- **Write data pattern is "01011….1".**
- **DL_0 is raised to 4V to avoid writing to first cell as the datum to first cell is "0".**

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 $V_{p\text{-}min}$ 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