Center for Energy Efficient Electronics Science

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Characterization of Contact Adhesion in MEM Relays

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Abstract:

Power consumption limits the range of applications for computing devices today. In the future, electronic switches that operate with superior energy efficiency to the metal-oxide-semiconductor field-effect transistor (MOSFET) will be needed to enable the Internet of Everything.

Micro/Nano-Electro-Mechanical (M/NEM) switches (relays) are promising in this regard, because they can be operated with voltages less than 10 mV, whereas MOSFETs today are operated with ~1 V. In order for integrated systems of mechanical switches to operate reliably, however, contact adhesion must be minimized in a controllable manner. Toward this goal, the influence of relay operating conditions on contact adhesion is experimentally studied.

Motivation

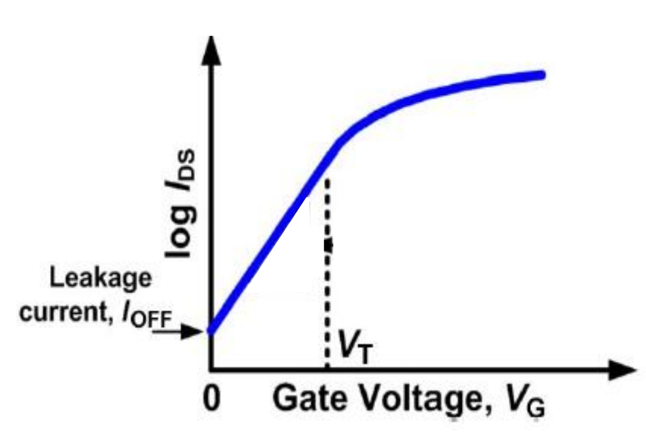
The Problem:

- The energy consumed per digital logic operation by MOSFET-based integrated circuits is many orders of magnitude greater than the fundamental minimum energy required for computation.

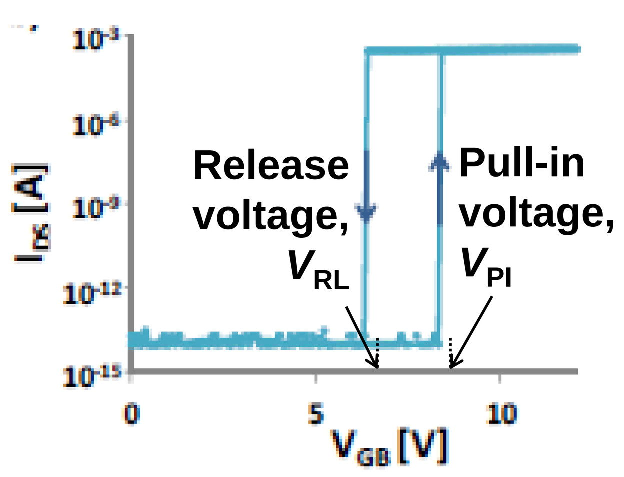
M/NEM relays can be operated with much lower voltage than MOSFETs

- Physical separation of electrodes provides for zero current in the off state
- Current (*I*) is switched abruptly between off state and on state.
- Switching with low gate voltage (V_G) is possible with body bias (V_B).

***I-V* curve of a MOSFET**[1]

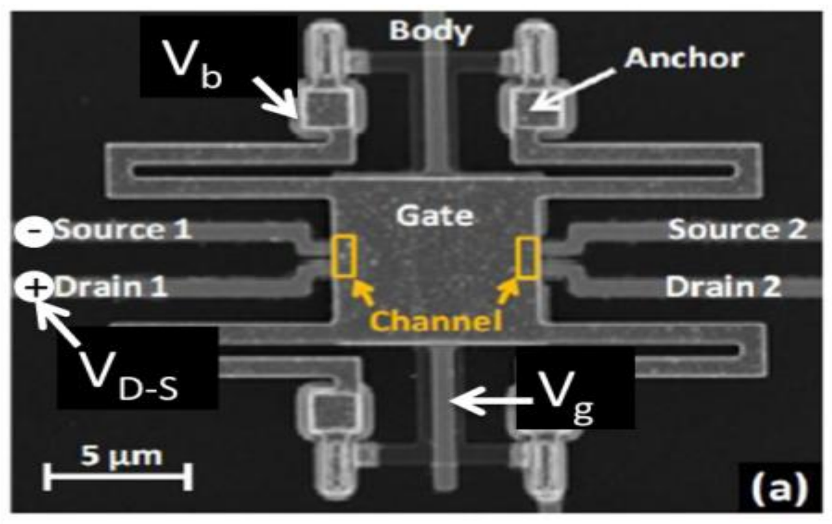


***I-V* curve of a MEM relay**[2]

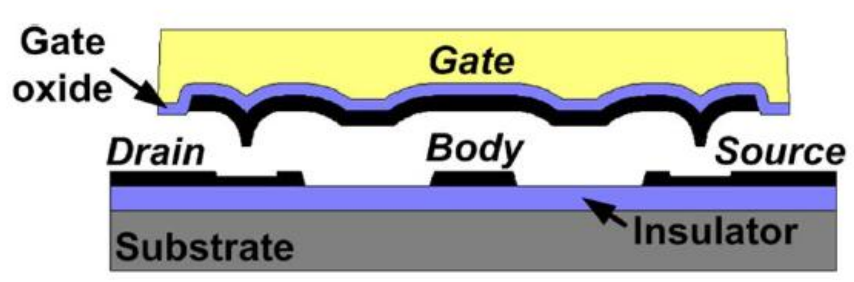


Relay Structure and Operation

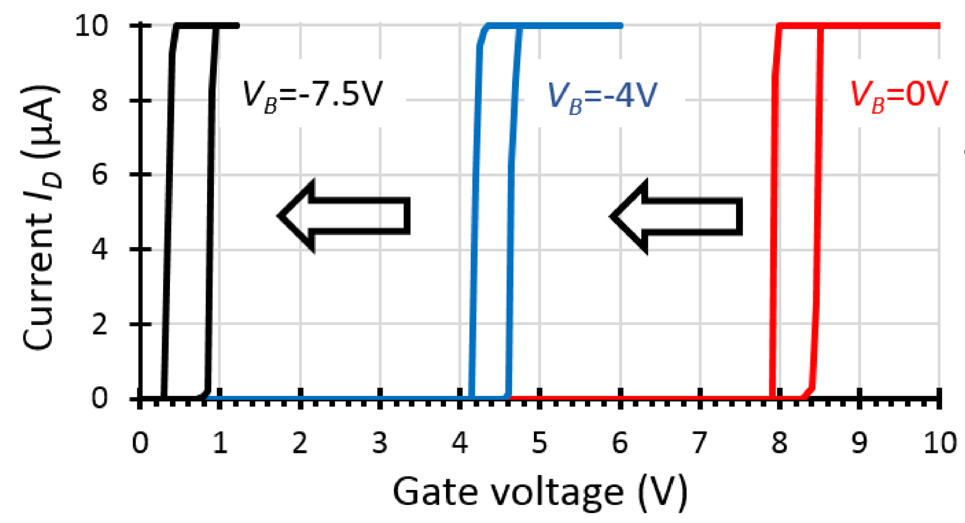
Plan-view Scanning Electron Micrograph[2]



Schematic Cross-Section[3]

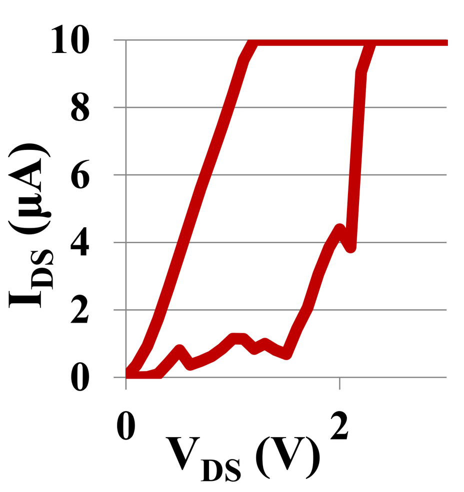


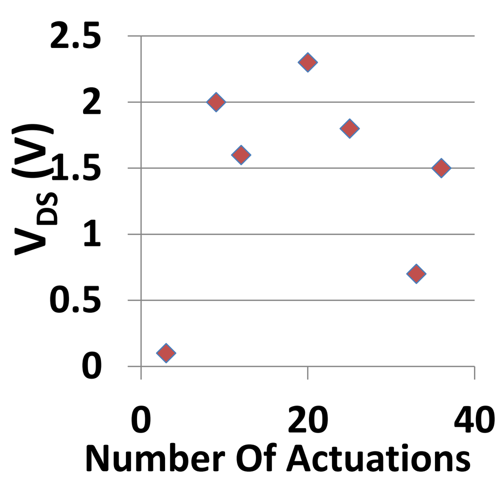
- Movable body electrode suspended by folded-flexure beams over the gate electrode.
- Conductive channels (metal strips) attached to body underside, with an intermediary insulating oxide layer to prevent body current.
- 2 pairs of source/drain electrodes → 2 electrical switches (Only one source/drain pair was used in this work.)
- Electrostatic force induced by gate-body voltage difference actuates body downward, causing the channel to contact source/drain.
  - Hysteresis ($V_{PI} - V_{RL}$) is exacerbated by contact adhesive force.



- **The gate voltage required to operate the relay is reduced with body biasing.**

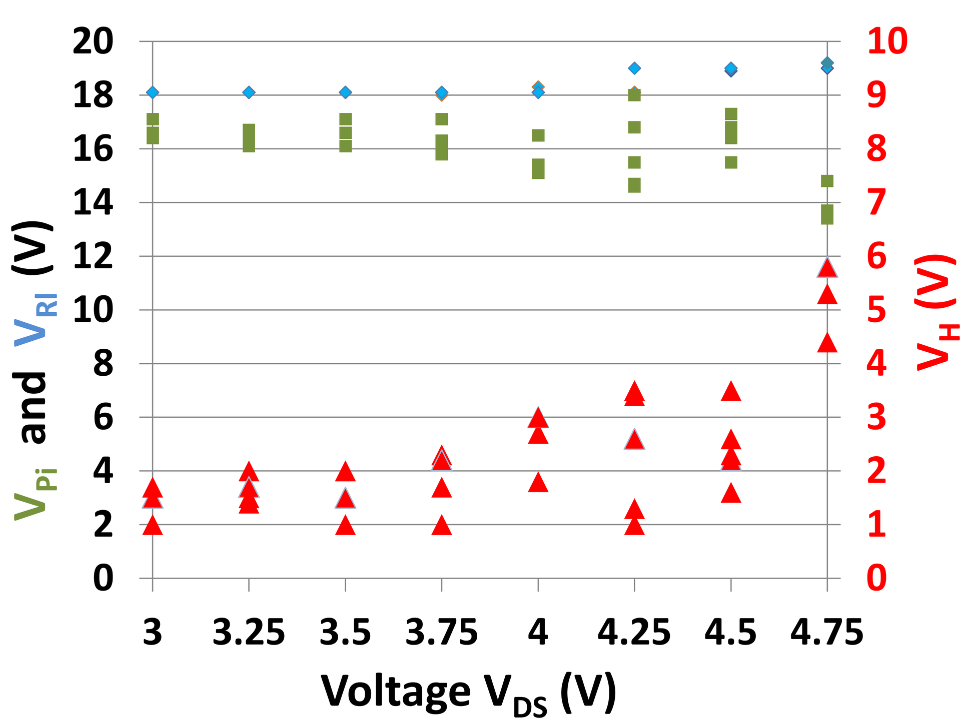
Results and Analysis





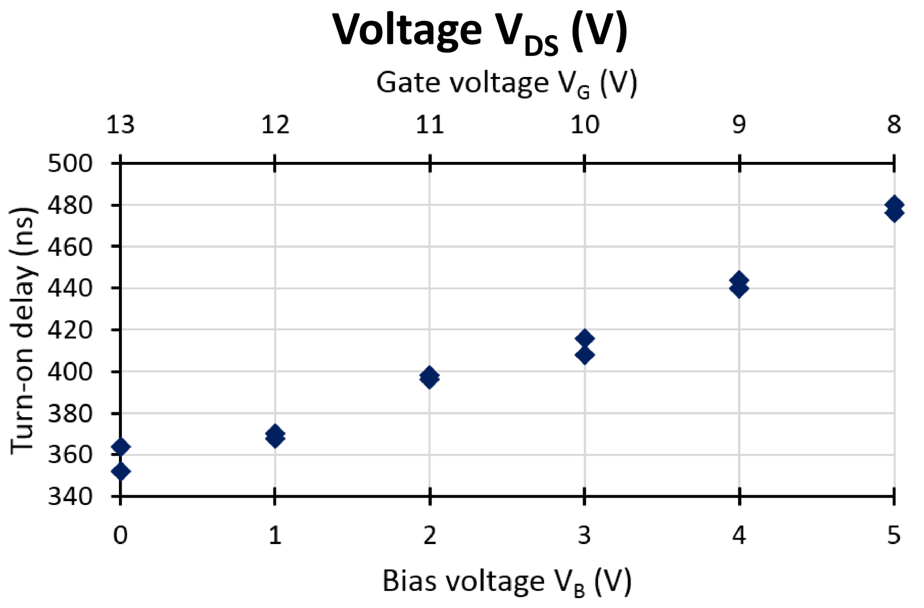
- Gate voltage was held constant at 17 V (on state)
- Drain voltage was swept from 0 to 4 V
- Erratic current flow for drain voltage (V_{DS}) below 2.5 V

→ V_{DS} values greater than 2.5 V were used for V_{PI} and V_{RL} measurements.



- V_{PI} and V_{RL} values were obtained by sweeping V_{GB} from 0 to 20 V and back down to 0 V, keeping V_{DS} fixed.
  - The effect of V_{DS} (in the range from 3 to 4.75 V) is studied.
- **Hysteresis voltage ($V_H \equiv V_{PI} - V_{RL}$) increases with increasing V_{DS}.**

→ **Contact adhesive force increases with drain/source voltage.**

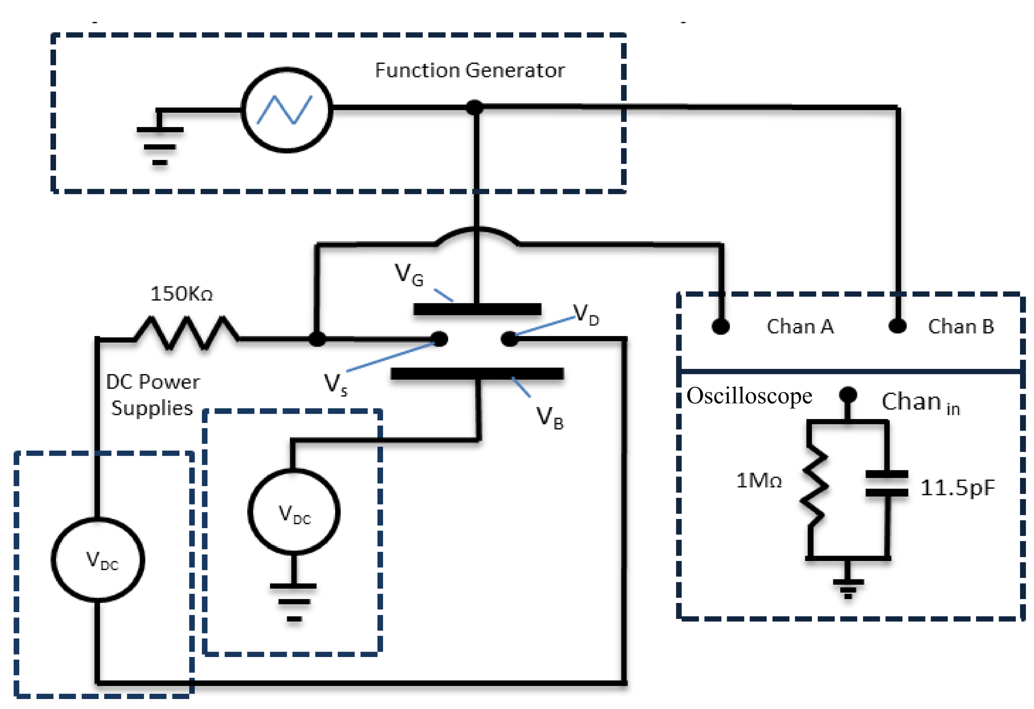


- Turn-on delay was studied as a function of the gate switching voltage, which can be reduced by increasing the body bias. (**V_{GB} is constant.**)

→ **Turn-on delay increases with decreasing switching voltage V_G.**

Experimental Approach

Schematic diagram of setup for dynamic testing



Equipment for static I-V measurements

- Semiconductor analyzer
- Similar set-up as for dynamic testing, without the oscilloscope.

Equipment for dynamic testing

- Function generator
- 2 DC power supplies
- Oscilloscope

Measurements

- Drain/source current was monitored as a function of gate voltage.
  - Voltage difference between drain & source electrodes was varied from 3 to 4.5 V in 0.25 V increments.
- Turn-on delay was measured as a function of gate & body-bias voltages.

Conclusion

- A minimum drain-source voltage difference is required for consistent current flow.
- Contact adhesive force increases with increasing drain-source voltage difference.
- Further work is needed to ascertain the effect of the body bias voltage on the contact adhesive force, and to study the effects of contact electrode surface oxidation.

References

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