Design and Integration of 3-Terminal Back-End-Of-Line Nanoelectromechanical Oscillators

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It has recently been shown that systems of coupled oscillators will naturally find an optimal solution of the Ising problem, which can be mapped to solve nondeterministic polynomial (NP)-hard problems significantly faster and more efficiently than conventional computing frameworks. Monolithically integrated micro/nanoelectromechanical (M/NEM) switches implemented in IC Back-end-of-line (BEOL) metallization can be configured to create dense oscillator arrays monolithically integrated with leading-edge IC technology, enabling a low power single-chip solution.

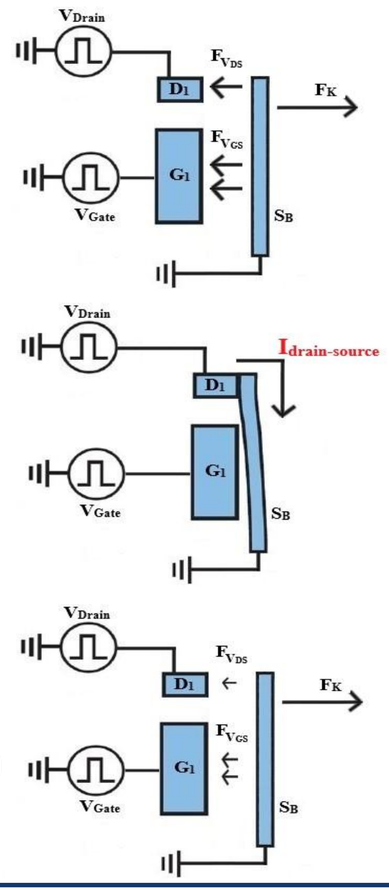
Introduction and Operation

The 7nm BEOL NEM relay is a three terminal vertical switching structure consisting of a gate node (G_1), drain node (D_1), and an actuating source beam (S_B) anchored on one end.

1) Both the gate-source (V_{GS}) and drain-source (V_{DS}) voltage biasing provide an attractive electrostatic force (F_{VDS} + F_{VGS}) on the actuating electrode beam S_B.

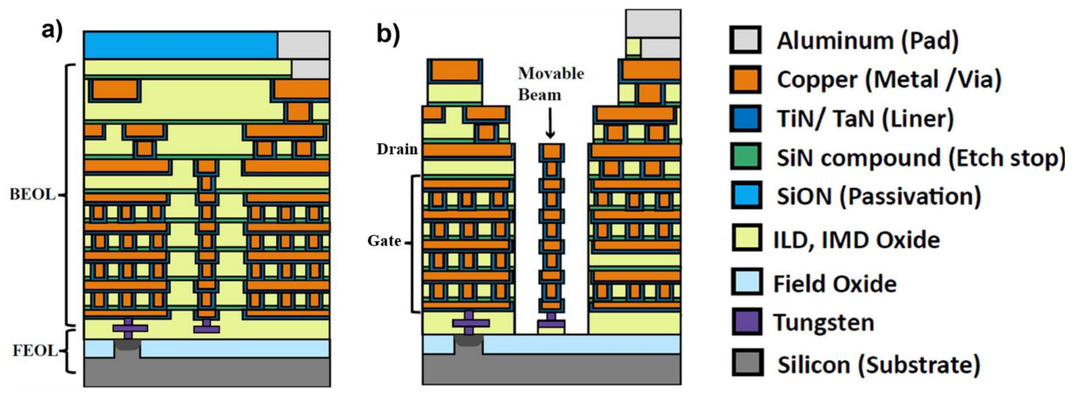
2) When the electrostatic force reaches a critical pull-in voltage (V_{PI}), the electrode beam snaps into contact with the drain node which discharges through the source.

3) V_{GS} and V_{DS} decrease until the electrostatic force is weaker than the beams equilibrating spring force (F_K) which causes the beam to return to its original position.



Device Design

- **A representative 7nm technology node BEOL NEM is created as a baseline device.**



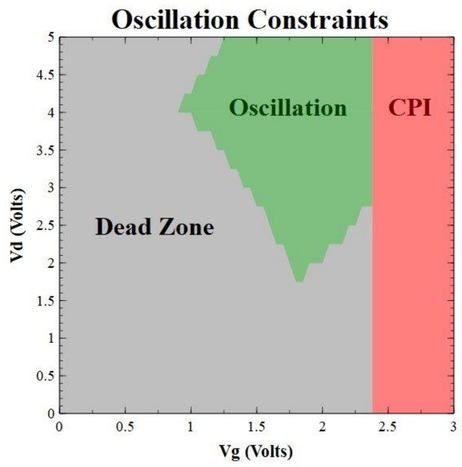
Schematic cross sections illustrating the BEOL layers in a conventional CMOS process (a) before and (b) after the release etch process.

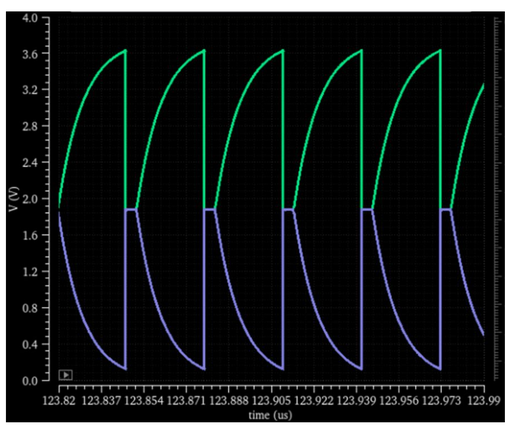
- **Device parameters are adapted from [1] and optimized for oscillatory performance.**

Design Parameter	Specification/Values
D_1 contact electrode length	**15nm**
G_1 actuation electrode length	**100nm**
Contact area	**660nm²**
Contact gap	**18nm**
Actuation gap	**20nm**
Adhesion force per unit area	**1500 nN/um²**
Metallic material & Young's Modulus	**Copper 128 GPa**
Metal layer used for D_1 electrode	**M6**
Metal layers used for G_1 electrode	**M1-M5**

[1] L. P. Tatum, U. Sikder, and T.-J. K. Liu, "Design technology co-optimization for back-end-of-line nonvolatile NEM switch arrays," IEEE Transactions on Electron Devices, vol. 68, no. 4, pp. 1471–1477, Apr. 2021, doi: 10.1109/TED.2021.3062251.

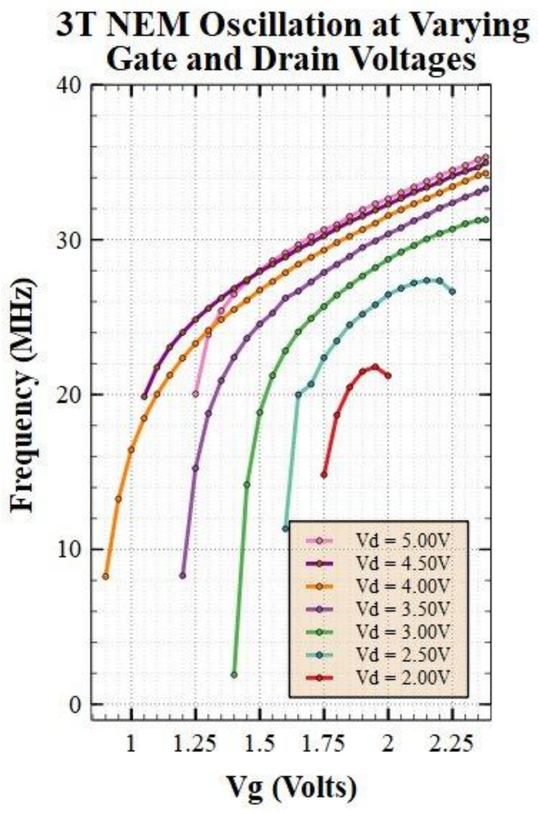
Waveform Analysis

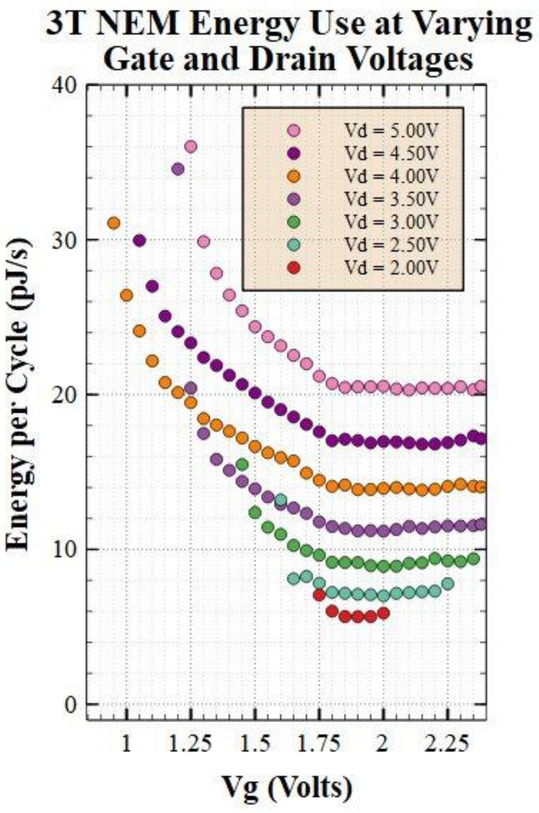




- V_G-V_D voltage combinations (left) and V_S, V_D transient waveform (right).

Results





Conclusion

- Simulation results show that three terminal vertical BEOL switches are able to oscillate at a variety of controllable frequencies.
- 32MHz peak frequency achieved during simulation suggests that higher oscillatory frequency is mechanically possible.

Acknowledgment

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