# Characterization of Back-end-of-line Nanoelectromechanical Reconfigurable Interconnects

Kelsey Horace-Herron[1], Urmita Sikder[2], and Tsu-Jae King Liu[2]
[1]Department of Computer Engineering, Jackson State University
[2]Department of Electrical Engineering and Computer Science, University of California Berkeley
[1]Email: j00803083@sutdents.jsums.edu

***Abstract*—Multiple metallic layers in the back-end-of-line (BEOL) process are used to implement nano-electro-mechanical (NEM) reconfigurable interconnects to increase the energy efficiency for reconfiguring the functions of a CMOS circuit. The optimized etch recipe for releasing the reconfigurable interconnects is determined by characterizing the interconnect performance using electrical tests and scanning electron microscopy (SEM).**

***Index Terms*—NEM, BEOL, Reconfigurable Interconnects**

## I. Introduction

As time progresses, integrated circuit devices are getting smaller and the functions in the circuits are becoming more complex. The smaller the device the more percentage of energy is lost via OFF-state leakage. NEMory-based LUT is projected to be 10x times faster and 100x times more energy efficient while achieving a higher density [1]. The implementation of nanoelectromechanical (NEM) switches on a Complementary Metal Oxide Semiconductor (CMOS) platform can help to reduce the energy consumption while the functions of the circuit are being reconfigured [2]. In order to achieve this, a smaller operating voltage and a compact footprint are required. This work aims to implement energy efficient NEM devices compatible with the CMOS technology. Back-end-of-line (BEOL) process provides an energy efficient strategy to reconfiguring the functions of integrated circuits [2].

Kwon *et al* had achieved a lower operating voltage in a device built in a single BEOL layer [3], but the problem of a large footprint still persisted. Muñoz-Gamarra *et al* used a lateral configuration but a small voltage was not achieved [4]. Riverola *et al* used a torsional beam but the switches were not very reliable [5]. This work implements a compact device with multiple layers so that a smaller voltage can be used to switch them. Moreover, the top BEOL layers have larger minimum spacing requirements leading to a larger operating voltage; so instead we use the bottom layers where the smallest gaps can be patterned.

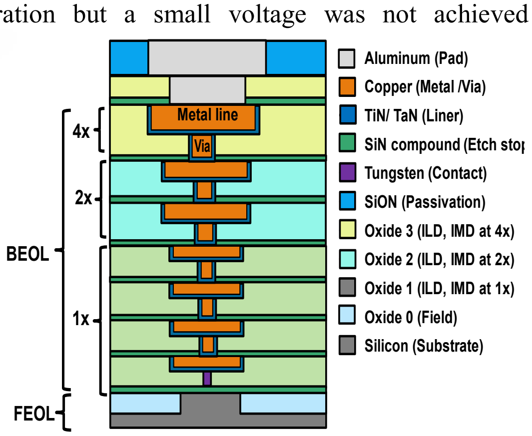



*Figure 1: BEOL Process Cross Section used to fabricate the NEM reconfigurable interconnects*

## II. Device Description

This work focuses on finding the characteristics of energy efficient NEM reconfigurable interconnect devices that demonstrate non-volatility and reconfigurability. The NEM device is made up of five components which are: the beam, two actuation electrodes, and two contact electrodes.The BEOL metal stack of a 65nm standard process is used fabricate the device. The front-end-of-line circuits (FEOL) are connected through the BEOL metal and via lines to the probe pads. The BEOLprocess uses three different stacks of dielectrics for different minimum spacing requirement, as shown in Figure 1. To have a large actuation the device needs to have small air gaps, so the bottom stack of copper metal and via lines are used to fabricate the interconnect. To program/reprogram the device a voltage will be applied to program electrode 0/1 to change into state “0”/”1”, which is demonstrated in Figure 2. A non-volatile state will be achieved when the restoring force, $F_k$ is less than the adhesion force, $F_{adh}$, which means the state will be retained in absence of any program voltage.

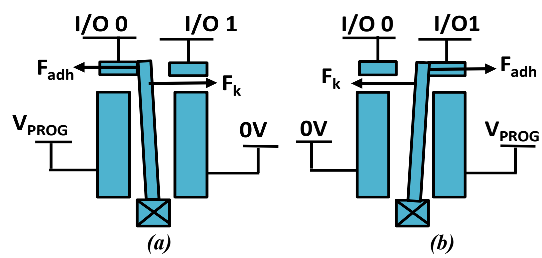



*Figure 2: Schematic of NEM reconfigurable interconnect when (a) programmed to state “0” and (b) reprogrammed to state “1”*

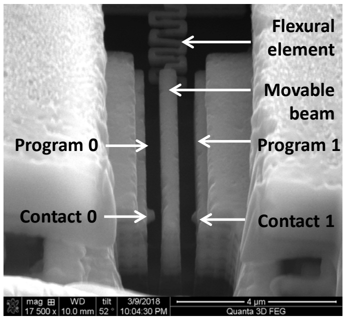



**Figure 3: Cross section SEM of NEM device**

## III. Device Characterization

To release the movable beam, the standard 65nm node chip with the fabricated devices goes through the sacrificial release etch process. For this work, reactive ion etching with $SF_6$and $O_2$capacitively coupled plasma was used to remove the dielectric stacks. An anisotropic etch process is used because of the high aspect ratio of the device cross-section. An isotropicetch process would release the fixed electrodes along with the movable beam. While the device is being etched the plasma power is adjusted accordingly to achieve the required undercut.Moreover, the device is dipped and sonicated in acetone in the middle of the etch process to remove any debris that has formed.SEM image of the cross-section of a released device is shown in Figure 3.Next the devices are tested at a vacuum probe station. The voltage applied to the actuation electrodes of the devices are varied and the currents through various terminals are found, while beam stays biased at 0V and contact electrodes have a fixed positive voltage. The current-voltageplots are analyzed to find device properties and etch processes are adjusted accordinglyResults and discussion

Many challenges occurred during the project. One of the problems faced was by-product build up this occurs when higher percentage of$O_2$ is used in the plasma, as shown in Figure 4. By-product build up consist of $SiO_xF_y$. The structural materials, i.e. Cu and TiN can diffuse into the by-product compound, making it conductive, which resulted in unwanted short-circuit between the electrodes. Another problem is catastrophic pull-in, i.e. when the movable beam and program electrodes make contact, as demonstrated in Figure 5.It happens when the device is being reprogrammed, usually for more compliant beam designs. Figure 6 shows the reprogramming of a three-terminal NEM interconnect from state "0" to state "1',

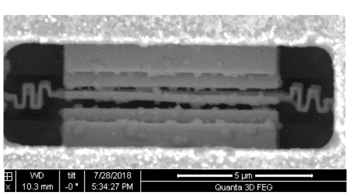
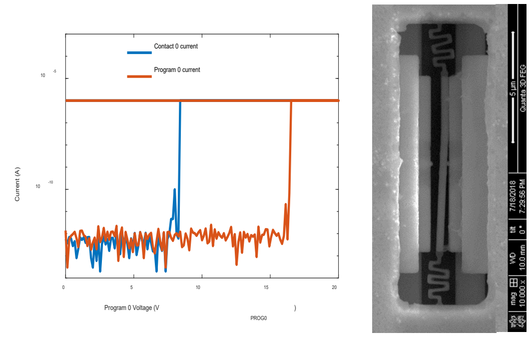


**Figure 4:** ***SEM of NEM interconnect with etch by-product on sidewalls***

which was accomplished for 2 cycles. Both states were non-volatile, however, the contact resistance seemed to be very high.




***(a) (b)***

***Figure 5: Catastrophic pull-in: (a) current-voltage characteristicsand (b) SEM image***

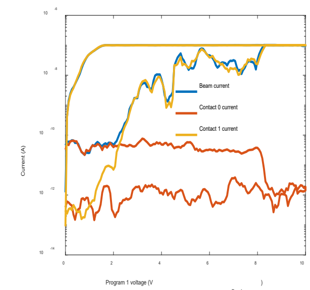



***Figure 6: Current-voltage characteristics showing reprograming for the NEM interconnect***

## IV. Conclusion

The experimental data concludes that an optimized etching process has been accomplished to release the movable beam successfully. The device still needs better isolation between the contact and actuation electrodes, which can be accomplished using a better wet clean for etch residue. Moreover, the movable beam needs to be stiffer to stop catastrophic pull-in.

## Acknowledgements

The author would like to thank the University of California Berkeley, all the participants and staff of the UCB-HBCU REU program for supporting this work.

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