Fabrication of Five-Terminal Laterally-Actuated Nano-Electro-Mechanical (NEM) Relays

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Abstract:

Nano-electro-mechanical (NEM) relays offer reliable alternative switches with low leakage current compared to MOSFETs. In a NEM relay, applying voltage to a gate electrode causes electrostatic force to mechanically actuate a beam, which makes contact between source and drain electrodes, allowing current to flow. One of the present drawbacks of NEM relays is that the pull-in voltage at which the switch actuates is extremely high (~20V). This project focused on a laterally-actuated (in the plane) cantilevered relay and investigated how parameters at different fabrication steps affected the relay's pull-in voltage. The body and electrodes of the relay were fabricated by first growing silicon dioxide on a silicon wafer, depositing polysilicon, and defining the physical features with electron-beam lithography. A layer of titanium nitride was then deposited and etched. Finally, the beam was released from the surface of the wafer by etching with hydrofluoric acid. Parameters such as deposition temperatures and etch times were varied in an effort to produce a durable, lower pull-in voltage relay. Lower pull-in voltages in NEM relays would be a step towards integrating the devices into ultra-low-power applications such as computing.

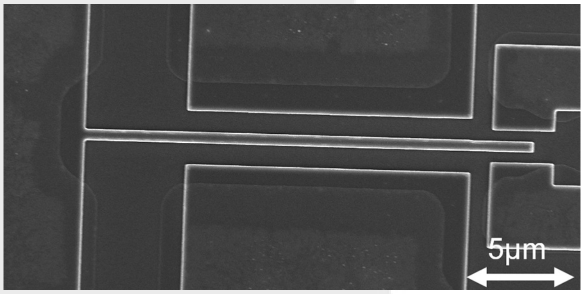

Figure 1: SEM image of a completed NEM relay. At the left is the device source, to which the beam is attached. Gates are in the middle top and bottom, and drains are at the right. Beam-to-gate gaps are 1000 nm and beam-to-drain gaps are 500 nm.

Introduction:

The most common form of logic switch today is metal-oxide-semiconductor field-effect transistors (MOSFETs). As MOSFETs are scaled down for faster computing, leakage current will flow through the device even in its "off" state. Nano-electro-mechanical (NEM) relays promise no leakage current and faster switching behavior than MOSFETs [1]. Similar to MOSFETs, a basic NEM relay requires three terminals: source, drain, and gate. Applying a sufficiently high pull-in voltage to the gate generates enough electrostatic force to move a beam, connected to the source, to contact the drain, allowing current to flow through the device. One of the present drawbacks of NEM relays is an extremely high pull-in voltage, approximately 20V in literature [2].

In this project, we demonstrated a five-terminal NEM relay with two drains and two gates. A finished device is shown in Figure 1. The laterally-actuated beam moved in the plane of the wafer on which the device was fabricated. The goal of this project was to investigate the effects of varying certain processing steps to create a device with a lower pull-in voltage and other properties favorable for ultra-low-power application.

Procedure:

Fabrication began by growing 400 nm of silicon dioxide (SiO_2) and depositing 400 nm of polycrystalline silicon (polysilicon). The polysilicon was then patterned using electron-beam lithography (EBL) and etched anisotropically with plasma. Next, 20 nm of titanium nitride (TiN) was deposited using atomic layer deposition (ALD). The TiN was patterned with another round of EBL and etched anisotropically with plasma. This anisotropic etch removed TiN from horizontal surfaces, exposing the underlying SiO_2, but left TiN on vertical sidewalls intact. Because we needed to determine a suitable etch recipe for TiN, we etched four separate samples for 60s, 90s, 120s, and 150s. Finally, the device was finished by etching the now-exposed oxide using 20:1 buffered oxide etch

(BOE) and drying the samples in a critical point dryer, releasing the beam. Finished devices were tested using a three-point probe measurement, with source voltage grounded, drain voltage held at 0.5V, and gate voltage varied between 0 and 25V. Devices were also imaged under a scanning electron microscope (SEM) after several fabrication steps. After examining and testing the four samples, an additional sample was prepared, with TiN etched for 150s.

Results and Discussion:

From SEM images, the 60s TiN etching samples seemed best etched, as shown in Figure 1. In contrast, the 90s, 120s, and 150s TiN etching samples (Figure 2) had unetched TiN remaining between the gates and drains. As seen in the tilted SEM image in Figure 3, underetching was apparent from tilted SEM images, but it was unclear whether the beams were fully suspended during HF etching. Measurements on the samples with 60s TiN etching revealed that current would always flow through the device. Our conclusion was that 60s was too short of an etch time, leaving a conductive layer of TiN all over the device. Measurements on the samples with 150s TiN etching were also inconclusive, as the leftover TiN between the gates and drains created a short circuit that left us unable to measure the current flowing between the source and drain. We concluded that the samples with 150s, 120s, and 90s TiN etching were unsuccessful due to problems in the TiN etching. Oddly, the second 150s TiN etch sample did not have leftover TiN for reasons yet undetermined.

Future Work:

Further investigation is needed to improve the TiN etching. Once working samples have been completed, we then need to measure pull-in voltages using the three-point probe measurement described above. Moving forward, we will further explore fabrication techniques to further decrease the pull-in voltage of these laterally-actuated NEM relays, such as varying device geometries (e.g., gaps between features, beam shape) and integrating with other technologies.

References:

[1] R. Parsa, “Nanoelectromechanical Relays for Low Power Applications,” Stanford University, dissertation, May 2011.

[2] R. Parsa, W. S. Lee, M. Shavezipur, J. Provine, R. Maboudian, S. Mitra, H.-S. P. Wong, and R.T. Howe, “Laterally Actuated Platinum-Coated Polysilicon NEM Relays,” in Journal of MEMS, Vol. 22, No. 3, June 2013.

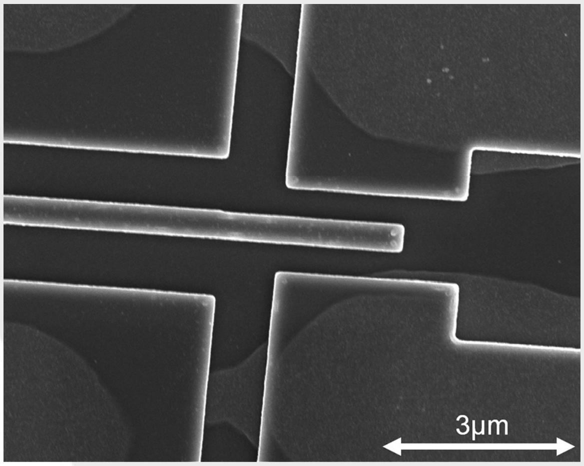

Figure 2: SEM image of a 120s TiN etching sample. TiN is visible in the lighter regions and on the reflective sidewalls. TiN remains on the surface between drains and gates.

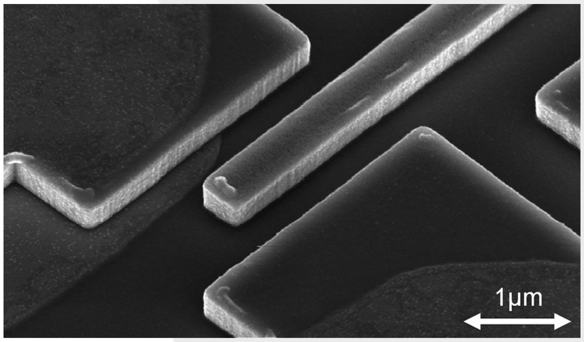

Figure 3: SEM of a 90s TiN etching sample, tilted 38°. Dark shadows under the features indicate some etching by HF.