Investigation of MIM Structures as Selector Devices for Crossbar Memory Arrays

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I. Motivation

- As memory continues to scale further and densities continue to increase, leakage current becomes a non-trivial concern
- A selector device limits the leakage current from memory elements so that the current passing through a selected device significantly exceeds the residual leakage
- A Metal-Insulator-Metal (MIM) device can be used in conjunction with a memory element to invoke non-linear I-V's
- Ni/TiO_2/Ni was chosen for multiple reasons: large non-linearity factor, high on/off current ratio, and bipolar switching

II. Project Objectives

Goal: To determine whether a Ni/TiO_2/Ni structure can function as a selector device for crossbar memory arrays

- Characterize MIM structure
- Determine the extent of non-linearity present in I-V's
- Compare against known criteria and determine whether Ni/TiO_2/Ni is suitable as a selector device

Parameter	Ideal Value
Current Density	$\geq 10 \frac{MA}{cm^2}$
On/Off Ratio	$\geq 10^6$
Operation Polarity	Bipolar
Scalability	Compatible with Memory Element

III. Crossbar Array

- Currently, the most common non-volatile memory choice is NAND flash, with utilizes the structure shown in figure 01

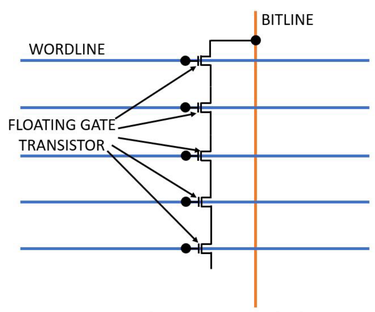


Figure 01: Simplistic NAND Flash memory structure

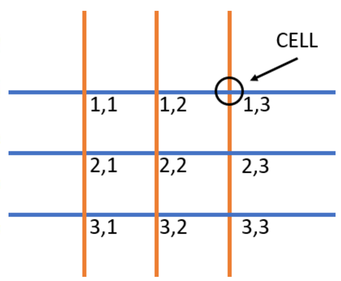


Figure 02: Crossbar memory array compatible with a selector device

- New non-volatile memories use crossbar arrays, as in figure 02
- This allows for the very simple integration of a selector device into a process for a bipolar operated crossbar memory device:

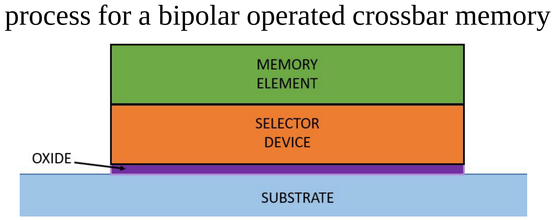


Figure 03: Cross-section of a crossbar array implemented with a selector device

IV. Functionality

- The electron affinity of TiO_2 varies widely with the degree of crystallinity of the film
- This in turn leads to variation in the work function difference between the electrode and the insulator, which makes it hard to predict exact device behavior
- Crystallization can potentially lead to better on/off current ratio in the oxide, but also decrease the functional voltage margin

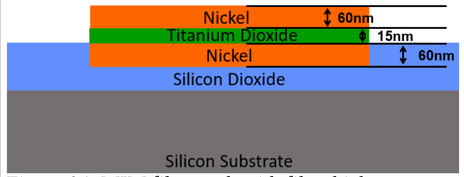


Figure 04: MIM film stack with film thicknesses

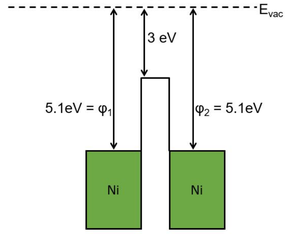


Figure 05: Band diagram for Ni/TiO_2/Ni

V. Mask & Process Design

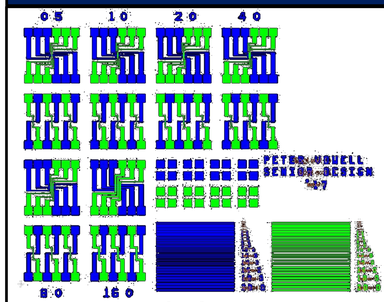


Figure 06: Test chip layout

- A test layout was created containing 3X3 crossbar arrays as well as individual cells
- Allows for testing the influence of neighbor cells by comparing results between isolated cells and cells included within an array
- Cell sizes vary from ½ square microns to 16 square microns

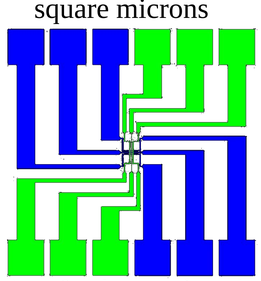
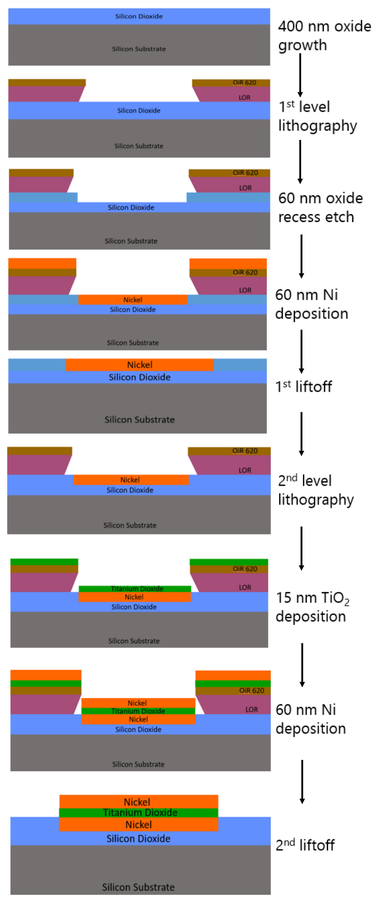


Figure 07: close-up of crossbar array



- Custom process flow was designed and implemented
- All depositions performed with electron beam evaporation

VI. I-V Characteristics

- Current densities of 10kA/cm^2 achieved with ½ micron features
- Asymmetric current response likely due to oxidation of the bottom nickel electrode

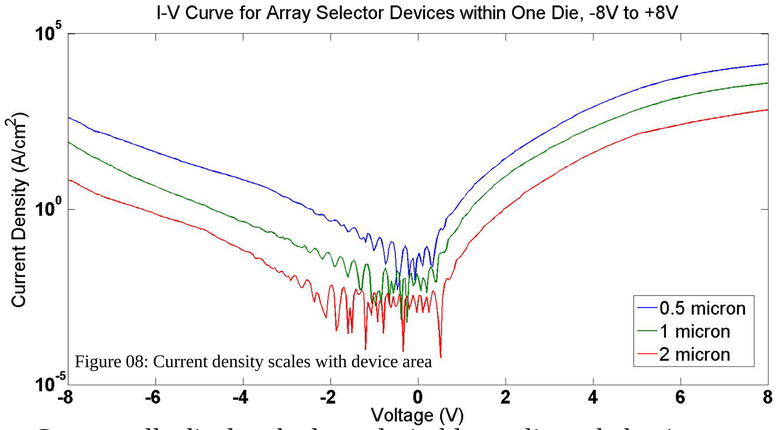


Figure 08: Current density scales with device area

- Corner cells display the least desirable nonlinear behavior, while center cells display the largest nonlinearity observed

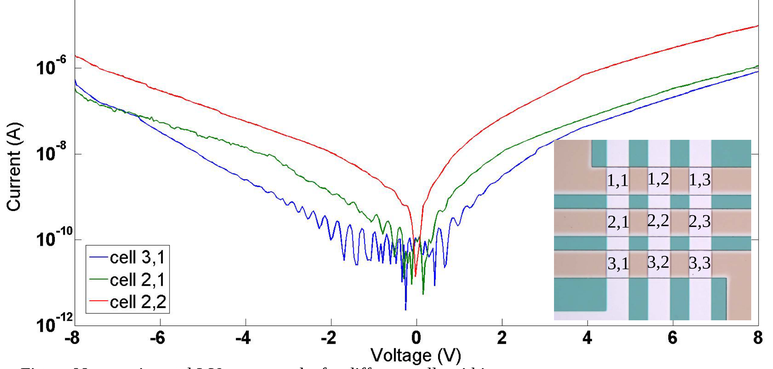


Figure 09: experimental I-V curve results for different cells within an array

VII. Observations

- As cell density increases, device characteristics improve
  - Suspect this is a processing phenomena linked to stress that is induced while performing liftoff
- An on/off ratio of six orders of magnitude was observed, and current density increases with device scaling

Future Work

- In-depth testing & results verification
- Investigate solution for asymmetric work functions
- Implementation of larger crossbar arrays containing both a selector device and a memory element

VIII. Acknowledgements

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