Unipolar Resistive Switching in 100 nm² Pt-NiO-Ni-Pt Cells

Matthew T. Hershberger
Physics, Bethel College, Kansas

NNIN iREU Site: Institut Für Bio- Und Nanosysteme (IBN), Forschungszentrum, Jülich, Germany
NNIN iREU Principal Investigator(s): Rainer Bruchhaus, Institut für Festkörperforschung (IFF), Forschungszentrum Jülich; Professor Rainer Waser, Institut für Festkörperforschung (IFF), Forschungszentrum Jülich and Electrical Engineering and Information Technology, RWTH Aachen
NNIN iREU Mentor(s): Robert Weng, Institut für Festkörperforschung (IFF), Forschungszentrum Jülich
Contact: matthew.hershberger@yahoo.com, r.bruchhaus@fz-juelich.de, r.weng@fz-juelich.de

NNIN iREU Program

Abstract:

We investigated the effects of a nickel adhesion layer in the resistive switching of nickel oxide (NiO) using platinum electrodes. Resistive switching has applications in making resistive random access memory (RRAM) devices. The nickel adhesion layers tested were five nanometers and ten nanometers thick. We concluded that varying the thickness of the nickel adhesion layer may affect the voltage required for forming.

Introduction:

In the ever continuing quest for Moore's Law and its accomplices, scalability is largely desirable. The dominant form of nonvolatile memory is silicon (Si)-based flash memory, but the low endurance, low write speed, and physical limits in scaling are significant disadvantages [1]. One future candidate to succeed flash memory is RRAM. In this form of memory the 0 and 1 states are represented by different resistive states [2].

There are several types of RRAM including electrochemical metallization, thermochemical memory, and phase change memory, but the exact physical models for these systems is unknown [1]. Each type of RRAM has a mechanism that allows it to be set from a high resistance state (HRS) to a low resistance state (LRS) and reset from the LRS to the HRS. This is achieved by applying a large enough voltage or current to trigger a physical or chemical change resulting in a change in resistance. The resistance state of the cell can be read by applying a small voltage which does not change the cell [2].

The first set operation of a cell is known as forming due to a distinctly higher voltage and current needed. The I-V curves for a form and a reset are shown in Figure 1. The numbers one through four are the set and five through seven are the reset. Note that the current compliance for the forming process is a resistor due to the forming process being faster than the current compliance of the equipment.

The different types of RRAM also may be categorized as bi-polar or uni-polar. In bi-polar switching the set and reset voltages have opposite signs. Uni-polar switching is completed with voltages of the same sign [1]. NiO belongs to the category of uni-polar switching materials. NiO is of particular interest because industry has experience working with Ni and its compounds.

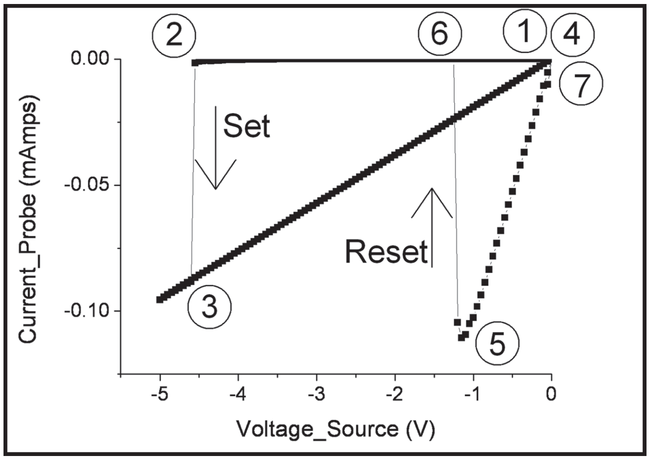

Figure 1: I-V curve of set and reset.

Procedure:

The four inch Si wafer was baked in the oxidation chamber until the silicon dioxide was 400 nm thick. Next, 5 nm of titanium was sputtered for an adhesion layer, and then 30 nm platinum (Pt) was sputtered for the bottom electrode. NanoNex NX2010 imprint resist was spun on at 3000 rpm. A UV imprint stamp was used to form the bottom electrode structures. The imprint resist was etched using a reactive ion beam etch (RIBE) with carbon tetrafluoride until the stamp formation was opened. The Pt was then etched using argon RIBE, leaving behind the bottom pads and electrodes. The imprint resist was removed using oxygen plasma ashing. At this point the wafer was diced into chips using a dicing saw.

Each chip had 25 nm NiO deposited by argon sputtering. A tri-layer electron beam resist of two layers of AllResist

AR-P 617 and one layer of AR-P 679 was used to form a large undercut for the 100 nm structures. Ni was evaporated as an adhesion layer for the 50 nm upper Pt electrode. The final step used MicroChemicals AZ 5214E photoresist and an argon RIBE to remove the NiO from the bottom pads.

We made several chips with varying thicknesses of the Ni adhesion layer. The chip RW9901 had 5 nm of Ni, and the chip RW9902 had 10 nm of Ni. The chip RW9901 had no Ni adhesion layer, and the top electrodes were destroyed during liftoff as were all other chips with no Ni adhesion layer.

Figure 2 shows a scanning electron microscope (SEM) image of a completed cell. The left pad is the bottom pad and the right pad is the top pad. The vertical line going across the bottom pad is the edge of the NiO. The actual cell is at the intersection of the two needles in the middle of the SEM image and is approximately 100 nm by 100 nm. Electrical characterization and switching were done on a Keithley 2611 System Sourcemeter.

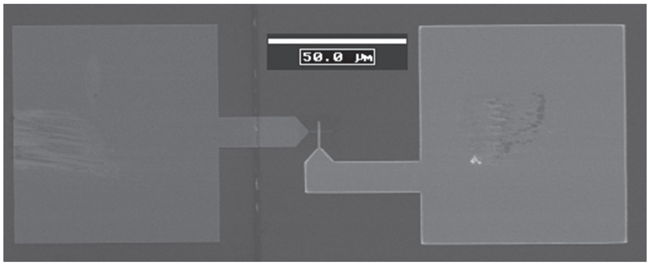

Figure 2: SEM image of single cell.

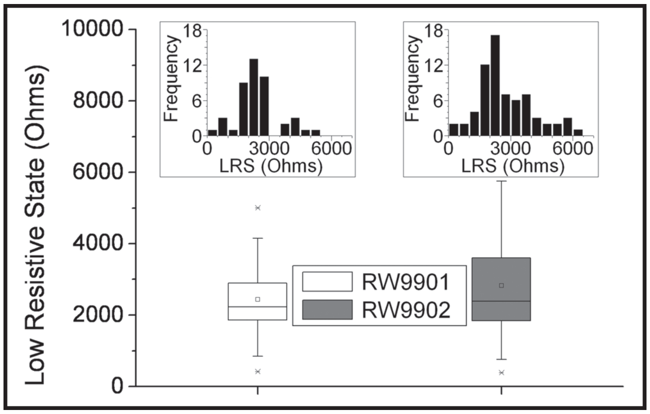

Figure 3: Boxplots of low resistive state by chip with histograms.

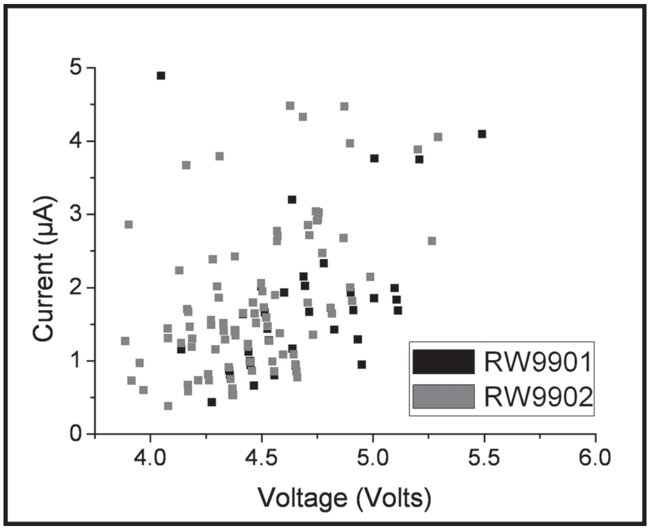

Figure 4: Scatterplot of voltage and current at forming.

Results and Conclusions:

We investigated the effects of the thickness of a nickel adhesion layer in the resistive switching of nickel oxide using platinum electrodes. Since the exact mechanism of resistive switching in NiO is unknown, there was concern that adding a layer of Ni could affect the resistive switching process.

Figure 3 shows the LRS for the chips RW9901 and RW9902 were similar in distribution and shape with a Student's T-Test P-value (STTPV) of 0.09. Figure 4 shows a scatterplot of the voltage and current at the point immediately before forming. Note that the voltage and current for each cell was nearly normal (histograms not shown). Comparing the current of the two chips resulted in an STTPV of 0.32. Comparing the voltage resulted in an STTPV of 0.0008.

We concluded that there may be a difference in the voltage required for forming as a result of the different nickel adhesion layer thicknesses, but more thicknesses would need to be examined.

Acknowledgements:

I would like to thank Professor Rainer Waser, Rainer Bruchhaus, Robert Weng, Marcel Gerst, Tobias Reuter, and the IFF-6 group. All SEM pictures were taken on the IFF Hitachi SEM. Funding was provided by the Forschungszentrum Jülich, the NNIN iREU Program, and the National Science Foundation.

References:

[1] R. Waser, R Dittmann, G. Staikov, K Szot, Adv. Mater. 2009, 21, 2632-2663.

[2] C. Kügeler, R. Weng, H. Schroeder, R. Symanczyk, P. Majewski, K.-D. Ufert, R.Waser, M. Kund, Thin Solid Films 2010, 518, 2258-2260.