

# Resistive Switching of Iron-Doped $\text{SrTiO}_3$

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## Abstract:

We report on the resistive switching behavior of iron-doped strontium titanate ( $\text{SrTiO}_3$  or STO), particularly related to electroforming. Epitaxial iron:STO (Fe:STO) thin films were deposited on a single crystalline niobium:STO (Nb:STO) substrate with pulsed laser deposition (PLD). Large defect structures were located on the film using scanning electron microscopy (SEM). Platinum electrodes were placed over areas both with and without these defects; electroforming and switching behavior were characterized. Results indicated that defect structures have significantly different electroforming behavior than other areas of the film.

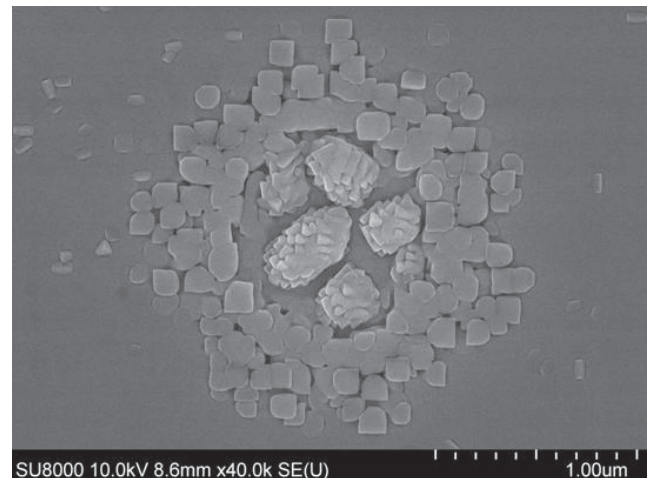
## Introduction:

As the scalability limits of transistor-based memory approach, it is becoming increasingly necessary to find alternatives to modern flash memory. One such alternative is to utilize resistive switching effects to create resistive random access memory (RRAM). Resistive switching is the phenomena in which certain materials can be switched between high and low resistance states, which at as binary “ON” and “OFF” states in memory. In resistive switching devices, a typically insulating layer, generally an oxide, is deposited between two conducting layers. The application of voltage switches the device between high and low resistance states. In some cases, an electroforming step is needed to activate the switching.

In this case, the one-time application of voltage changes the switching device from its initial virgin state and enables resistive switching. STO is often used as a model material for resistive switching. However, there lacks a clear consensus and understanding for the underlying physicochemical processes involved in resistive switching, particularly those for electroformation [1].

## Experimental Procedure:

To begin the fabrication process, 0.5 wt.% Nb-doped STO substrates were annealed for three hours to ensure a terrace step topography, which was then verified with atomic force microscopy. These substrates also act as the bottom electrode of the switching device. Epitaxial 5 at.% Fe-doped STO thin films were deposited using PLD, of thickness either 20 nm or 100 nm. On some samples, a 30 nm platinum thin film



*Figure 1: A defect structure located on the surface of an Fe:STO thin film.*

was then sputtered, patterned with photolithography, and etched using reactive ion etching (RIE) to create arrays of  $200 \mu\text{m}$  by  $200 \mu\text{m}$  top electrodes.

On a 100 nm Fe:STO thin film sample, a layer of poly(methyl methacrylate) (PMMA) was spun on top of the Fe:STO thin film, marker structures were patterned with e-beam lithography and etched with RIE prior to the sputtering of the 30 nm platinum film. The PMMA was then removed, leaving behind platinum marker structures on the Fe:STO thin film. Then, using SEM, the film was examined and large defect structures were located relative to the marker

structures. Figure 1 is an SEM image of one such defect structure located on a different Fe:STO film. Another layer of PMMA was spun, patterned, and etched using the same process to create wells for the top electrode pads. Subsequently, 30 nm of platinum was sputtered on top. The PMMA was then removed, leaving behind square platinum electrodes of side length 3  $\mu\text{m}$ , 5  $\mu\text{m}$ , or 10  $\mu\text{m}$ . These electrodes were placed over areas that defect structures as well as areas that were free of noticeable surface defects.

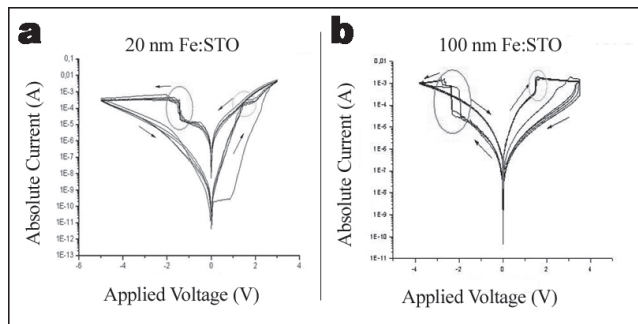


Figure 2: Current plotted as a function of applied voltage for 20 nm thin film Fe:STO sample (a) and 100 nm thin film sample (b).

### Results and Conclusions:

For the 20 nm and 100 nm thin film samples, the switching behavior of the 200  $\mu\text{m}$  side length pads was characterized by measuring current as a function of voltage. Figure 2 shows the plots of absolute value of current versus applied voltage for an electrode pad on the 20 nm thin film sample (left) and on the 100 nm thin film sample (right). The 20 nm sample displays an eightwise switching behavior whereas the 100 nm sample shows countereightwise switching. All measurements on the 20 nm sample displayed this switching pattern, whereas some 100 nm pads displayed eightwise switching. Literature suggests that this indicates that both filamentary and homogenous switching mechanisms are present in these samples [2].

In one 100 nm thin film sample, a significant difference was observed between areas free of large defects and areas that had such defects. For areas without defects, it was not possible to electroform the devices even for large voltages, 10 or 12 V, held for over an hour. Figure 3 shows the voltage versus time for a 5  $\mu\text{m}$  pad free of large defects. However, the samples with large defects formed rapidly. Figure 4 shows the current-voltage plot for one such pad that formed in  $\sim 1.8$  s at 10V. It displayed counter-eightwise switching, but other large defect structures had eightwise switching behavior. The extreme difference in formation time between areas with and without large defect structures suggests that these structures play a significant role in the electroforming process.

### Future Work:

To generalize these results, a greater range of iron concentrations should be examined in the STO thin films. Furthermore, other defect structures should be tested, including surface defects smaller than the defect structures tested in this experiment. Finally, more tests are required to increase confidence bounds on electroforming statistics.

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### References:

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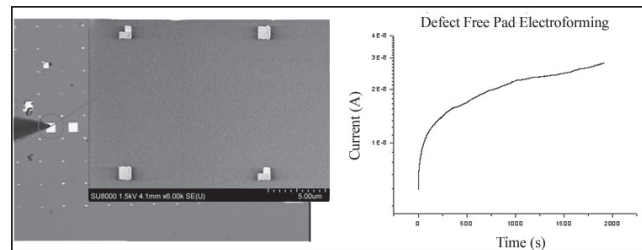


Figure 3, above: A sample area free of large defects (left) and its current versus time curve at 12 V electroforming (right).

Figure 4, below: Current-voltage plot after electroforming (right) for an area with a large defect structure (left).

