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## Effectiveness of BaTiO<sub>3</sub> dielectric patches on YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> thin films for MEM switches

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**Abstract.** A micro-electro-mechanical (MEM) switch built on a superconducting microstrip filter will be utilized to investigate BaTiO<sub>3</sub> dielectric patches for functional switching points of contact. Actuation voltage resulting from the MEM switch provokes static friction between the bridge membrane and BaTiO<sub>3</sub> insulation layer. The dielectric patch crystal structure and roughness affect the ability of repetitively switching cycles and lifetime. A series of experiments have been performed using different deposition methods and RF magnetron sputtering was found to be the best deposition process for the BaTiO<sub>3</sub> layer. The effect examination of surface morphology will be presented using characterization techniques as x-ray diffraction, SEM and AFM for an optimum switching device. The thin film is made of YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> deposited on LaAlO<sub>3</sub> substrate by pulsed laser deposition. For this work, the dielectric material sputtering pressure is set at  $9.5 \times 10^{-6}$  Torr. The argon gas is released through a mass-flow controller to purge the system prior to deposition. RF power is 85 W at a distance of 9 cm. The behavior of Au membranes built on ultimate BaTiO<sub>3</sub> patches will be shown as part of the results. These novel surface patterns will in turn be used in modelling other RF MEM switch devices such as distributed-satellite communication system operating at cryogenic temperatures.

### 1. Introduction

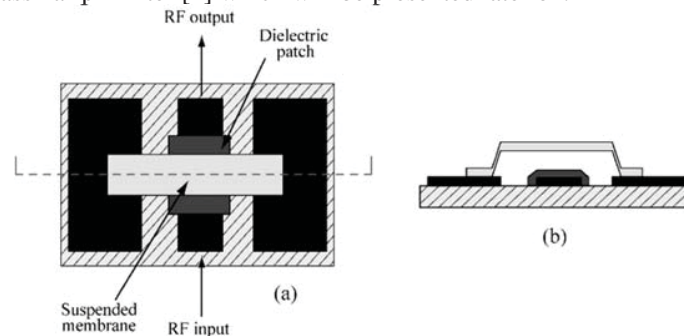
MEMS play an important role due to the benefits that MEM switches can offer over PIN-diode or FET counterpart in terms of fabrication, cost operation and functionality [1]. In this work, we will focus on the BaTiO<sub>3</sub> dielectric patches for functional switching points of contact and fabrication of BaTiO<sub>3</sub>/YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub>/LaAlO<sub>3</sub> substrates using laser ablation and RF magnetron sputtering deposition to build optimum MEM switches. Therefore, characterization process is a key to resolve the morphology of the die surface using techniques such as X-ray diffraction, SEM and AFM which will be presented. After the device characterization is done we will be set for the MEMS device layout patterning process. This device is designed to be switched operating at cryogenic temperatures.

### 2. Design

These switches execute switching by shunting the signal by the BaTiO<sub>3</sub> patch acting as capacitive contact to ground. Physically, the suspended membrane collapses when biased thus allowing the BaTiO<sub>3</sub> path



and transmission line to make electrical short to ground as shown in Figure 1. Force acting in between two metal electrodes has been used to actuate switching. A bias voltage of 36 V was enough to activate the switches in [2], it was only when it reached 80 V that a contact resistance of less than 1 ohm was measured. However, a high voltage severely impacts the switch lifetime by increasing the risk of a mechanical or dielectric failure [3]. After calculations it was determined that the line width of transmission line was 169  $\mu\text{m}$ , the length varies between 14.90 and 18.574 mm depending on the frequency, and  $\epsilon_{\text{eff}}$  equals to 14.7. Four MEM switches working in pairs were necessary to actuate and deactivate a bandpass hairpin filter [4] which will be presented later on.



**Figure 1.** Shunt MEMS switch on coplanar transmission line: (a) top view, (b) cross section.

### 3. Fabrication

The deposition of  $\text{YBa}_2\text{Cu}_3\text{O}_7$  on  $\text{LaAlO}_3$  using PLD of high-temperature superconductor materials provides high quality superconducting thin films because of the ability to stoichiometrically transfer the composition of the target to the deposited film [5].

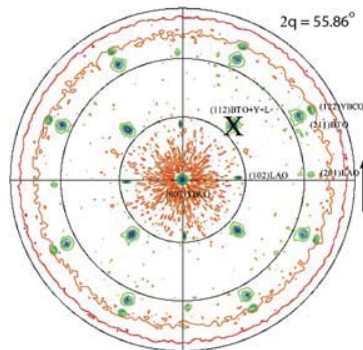
#### 3.1. Preparation of $\text{BaTiO}_3$ patches

**3.1.1. Lift off process.** This process involves two layers. The underlying layer is a polymer (PMGI SF15) to ensure proper undercut for an ideal liftoff. The top layer is a coat of thin photoresist AZ5214.

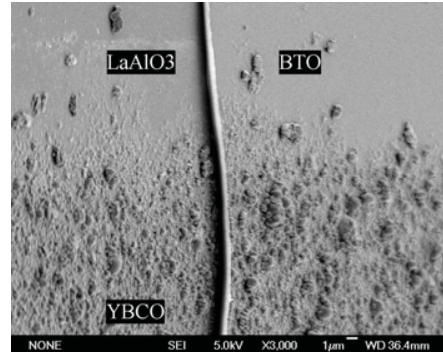
**3.1.2.  $\text{BaTiO}_3$  and gold bridge liftoff depositions.** Planar magnetron sputtering with RF potential on the surface enables the use of non-conducting materials as targets and allows reactive deposition of films as conventional RF sputtering. For this work the pressure is set at  $9.5 \times 10^{-6}$  Torr. RF power is 85 W at a distance of 9 cm. A double coated PMGISF15 is required to have an ideal suspended bridge support above the dielectric patches. The thickness of this layer is key for this process because it defines the height at which the gold bridge is suspended, and consequently controls the actuation voltage required to pull down the gold membrane. The gold bridge liftoff deposition process is very similar to the  $\text{BaTiO}_3$  dielectric mask but the difference is that AZP4620 thick photoresist is utilized. A resistively heated of a tungsten filament vacuum chamber is used. The gold film thickness is between 0.12 and 0.25  $\mu\text{m}$ .

### 4. Film characterization

The  $\text{BaTiO}_3$  dielectric patch crystal structure and roughness affect the ability of repetitively switching cycles and lifetime. A series of experiments have been performed using different deposition methods to examine the effects of surface morphology and RF magnetron sputtering was found to be the best deposition process for the  $\text{BaTiO}_3$  dielectric layer. Figure 2 is an X-ray diffraction pattern for a non-uniform epitaxial  $\text{BaTiO}_3$  growth using RF magnetron sputtering. This film was sputtered on and off axis at 36  $^\circ\text{C}$  in 260 mTorr of argon gas with 80 W RF power. The resulting film was slightly more than 0.2  $\mu\text{m}$  thick. As seen in Figure 3, a scanning electron microscope (SEM) micrograph confirmed a thickness of 0.3  $\mu\text{m}$ . and the roughness of the surface derived from the X-ray diffraction analysis.

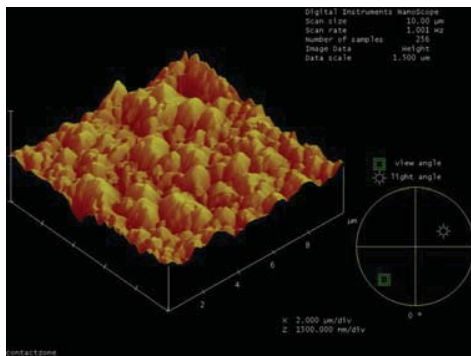


**Figure 2.** X ray diffraction using RF magnetron sputtering deposition.

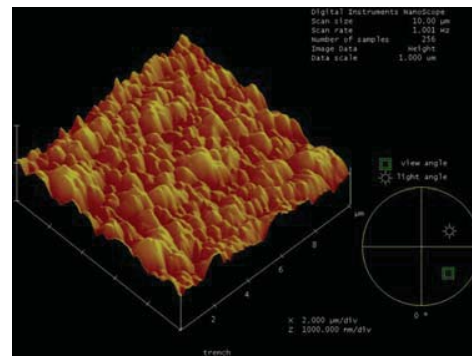


**Figure 3.** SEM of  $\text{YBa}_2\text{Cu}_3\text{O}_7$  on  $\text{LaAlO}_3$  substrate and sputtered  $\text{BaTiO}_3$ .

In Figure 4, the roughness of the substrate is consistent with the X-ray diffraction and the SEM results. The atomic force microscope (AFM) analysis shows the  $\text{BaTiO}_3$  film deposited by RF magnetron sputtering of the contact area when the suspended gold membrane is in the down position or “on” state. Figure 5 shows a 3-D analysis of the  $\text{BaTiO}_3$  film deposited by RF magnetron sputtering in the up position or “off” state. Notice that the surface in Figure 5 is smoother than the contact area analysis in Figure 4 due to the electro-mechanical contact between the gold and the dielectric material.



**Figure 4.** AFM of  $\text{BaTiO}_3$  film of the contact area in the “on” state.

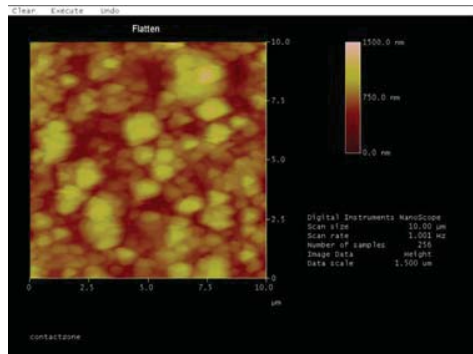


**Figure 5.** AFM of  $\text{BaTiO}_3$  film of the contact area in the “off” state.

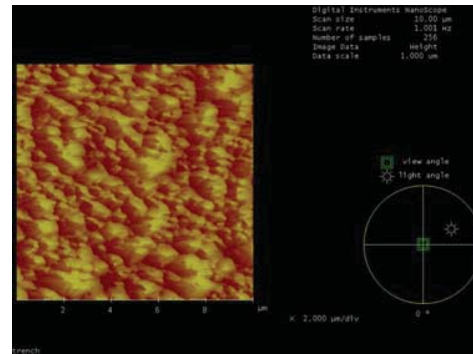
In Figure 6, the flatted area of gold (Au) membrane in contact with  $\text{BaTiO}_3$  film has bigger chunks of the dielectric compared to the sputtered deposition in Figure 7. The bigger the chunks present in a film the more irregular and inconsistent is its surface. These chunks or large particle sizes increase stiction forces upon the gold membrane as it collapses on them creating irregularities in its surface. Stiction occurs when drying the substrate after dissolving the sacrificial material or after the fabrication is finished. In some cases, capillary forces of the rinsing liquid pull the released structures together while drying and cause them to join. These forces are predominantly due to the liquid’s surface tension [4]. In this work, a second PMGI or sacrificial layer as stated in chapter four was found to smooth out irregularities and improve the gold suspended membrane’s profile thus reducing film stress and lowering the required actuation voltage.

## 5. Conclusions

A chebyshev bandpass filter is presented to illustrate the effectiveness of  $\text{BaTiO}_3$  patches as shown in Figure 8. The 2.1 GHz bandpass filter (dotted-curve 1) switched at 68 V at 40 K while the 2.6 GHz filter

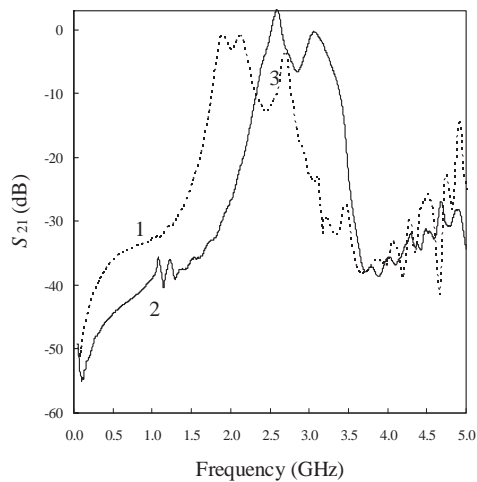


**Figure 6.** Flatted area of Au membrane in contact with BaTiO<sub>3</sub> film.



**Figure 7.** Figure 7: Flatted area of BaTiO<sub>3</sub> patch before switching.

(solid-curve 2) switched at 75 V at 30 K and a surface mode resonance (3) caused by cross coupling from the other filter. The use of a BaTiO<sub>3</sub> dielectric layer as an insulator under the suspended gold membrane has shown suitable and reliable switching cycles. The sacrificial layer was essential to form a proper undercut for the fabrication of the bridge. LaAlO<sub>3</sub> is a suitable microwave substrate for use with high T<sub>c</sub> superconductors. Results have demonstrated the feasibility of connecting superconductive MEMS switches with bandpass filters.



**Figure 8.** Experimental response (dotted curve 1) at 2.1GHz,  $T = 40$  K and experimental response (solid curve 2) at 2.6 GHz,  $T = 30$  K. Surface mode resonance (3).

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