TU3D-3

High-Isolation BST-MEMS Switches

Yu Liu, Troy R. Taylor *, James S. Speck *, and Robert A. York

Electrical and Computer Engineering Department, * Materials Department, University of California, Santa Barbara, Santa Barbara, CA 93106

Abstract — **In this paper, emerging (Ba,Sr)TiO$_3$ thin film technology was investigated for enhancing RF-MEMS capacitive switches. Materials properties of high-permittivity BST thin films and fabrication issues are discussed. Prototype BST-MEMS switches for K/Ka band applications were fabricated and measured. This measured data is compared with measurements from conventional SiN-based MEMS switches, showing improved isolation at lower frequencies due to the higher down-state capacitance density.**

I. INTRODUCTION

Radio frequency Microelectromechanical Switches (MEMS) have many advantages over traditional semiconductor switches such as high power handling capability, high linearity, low power consumption and low fabrication cost. In recent years, many research groups are involved in works to optimize the physical structure and process flow of MEMS switches for high performance in a wide span of frequency range [1-4]. With the process development, both yield and durability of MEMS switches have been significantly improved. The actuation voltage can also be reduced to as low as 10-20volts.

One key factor of MEMS switches is input-output signal isolation in the down or "off" state. In the commonly used CPW shunt structure, in order to further improve the performance of MEMS switches, higher switch on/off capacitance ratio and thus larger down-state capacitance is required. Traditional approaches include large MEMS air bridge size and a thin dielectric layer, with silicon nitride frequently used because of its superior property and ease in fabrication.

In this work, we investigated on replacing traditional silicon nitride dielectric layer with (Ba,Sr)TiO$_3$ (BST) thin film in RF-MEMS capacitive switches. With the high dielectric constant of BST thin film (ε_r>200), higher isolation and smaller device size are anticipated. In the following sections, we first present the pertinent electrical properties of BST thin films, along with fabrication concerns when BST thin films are utilized in RF-MEMS switches. MEMS switches using both BST and silicon nitride dielectric layers were fabricated. Measurements of both devices were compared, followed by discussions on further improving the performance.

II. DESIGN AND FABRICATION

Figure 1 shows a CPW shunt capacitive MEMS switch in both up and down switch states. The switch is designed for a very low capacitance between top membrane and bottom central signal line in the switch-up position. When the top membrane is switched down by electrostatic forces, a larger metal-insulator-metal capacitor is formed. The capacitance in this down state must be sufficiently large to effectively short-circuit the RF signal flow to the ground pads. This down-state capacitance can be enhanced by the use of high-permittivity materials such as BST.

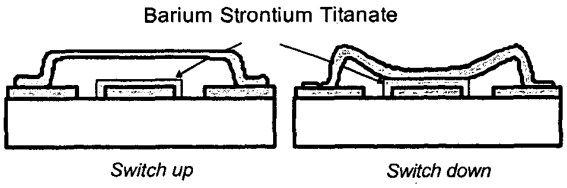


Fig. 1. RF MEMS shunt switch using BST thin film to replace conventional silicon nitride layer in both switch up and down states.

A. BST Thin Film Properties

The optimization and understanding of the materials properties of BST thin films are critical in this work. Thus far our efforts have been towards mapping out the parameter space of the RF magnetron sputter deposition system to correlate growth parameters with relevant device properties. In RF MEMS switches applications, high dielectric constant and low loss tangent are required for sputtered BST thin film. We have investigated various substrate materials and evaluated them based on RF performance and feasibility in process. Sapphire was chosen as a primary substrate due to its excellent insulating properties at microwave frequencies and its availability in optically polished surfaces at low cost. Thus far, platinum deposition has been optimized for use as a

0-7803-7239-5/02/$10.00 © 2002 IEEE

bottom electrode. Routine BST optimization is carried out using low frequency (1-100 MHz) device processing and measurements. Figure 2 shows the K (relative permittivity) and quality factor of the 100nm sputtered BST thin film. More detailed materials properties and deposition conditions of BST thin film can be found in related published paper. [5]

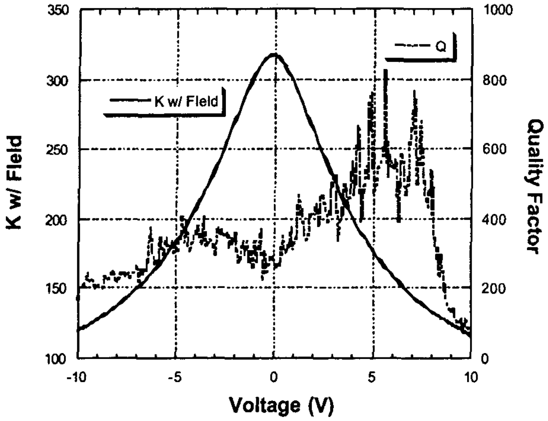


Fig. 2. Relative permittivity K and quality factor Q of the 100nm sputtered BST thin film.

B. Fabrication Concerns

Due to the high growth temperature of BST, platinum electrodes are typically used as the bottom electrode in BST thin film deposition. But platinum has much lower conductivity than gold, resulting in higher loss in signal transmission. To circumvent this problem, we tried a multi-layer deposition of Ti/Au/Pt (100Å/1000Å/1000Å) as bottom electrode on sapphire substrate. BST thin film is then sputtered on this multi-metal-layer bottom electrode. The measured materials properties of BST thin film turn out to be comparable to that of previous measured films. The surface roughness of the dielectric layer is within the range of 100Å.

Figure 3 shows the SEM photograph of the fabricated BST-MEMS switches for K/Ka band applications. The switches are fabricated on a 300 μm-thick sapphire substrate. From previous low-frequency measurements, the estimated breakdown voltage for BST thin film is about 10~12 volts per 1000Å deposition. Considering the pull-down voltage is in the range of 20~30 volts, we sputtered 3000Å BST to avoid voltage breakdown in operation. BST layer was patterned by etching in a buffered HF solvent with an etching rate of 150Å per minute. The CPW lines have 200 μm signal line width, and 280 μm ground-to-ground spacing. They were fabricated using a 3000 Å-thick gold layer. A 2.5 μm-thick PMGI photoresist layer was spun and patterned as the sacrificial layer. The MEMS air bridge length is 240 μm with a width of 60 μm. The air bridge is fabricated using a 1 μm-thick layer of Ebeam evaporated gold in a deposition rate of 7Å/second. In the last step, the sacrificial layer was released by using a critical point drier system. The measured pull-down voltage was 35 volts, and no breakdown through BST dielectric occurred in these measurements.

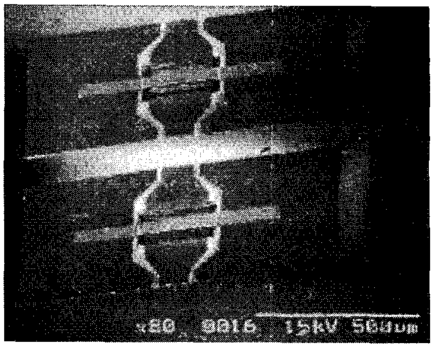
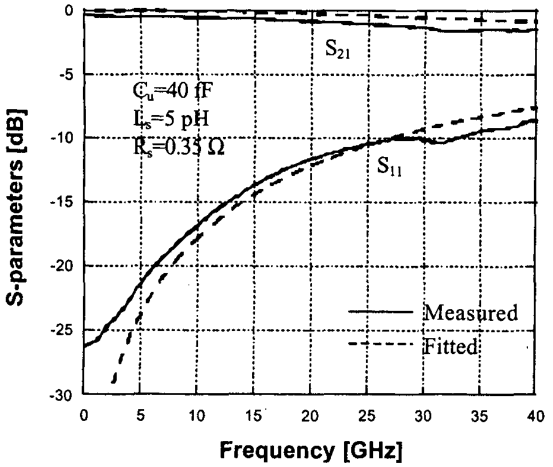


Fig. 3. The SEM picture of the fabricated BST-MEMS switches for K/Ka band applications.

III. MEASUREMENTS AND DISCUSSIONS

Figure 4 presents RF measurements for the fabricated BST-MEMS switch in both up and down-state positions. The insertion loss in the up-state is –0.88dB at 20GHz and –1.51dB at 40GHz. The reflection coefficient in the up-state is less than –10dB from DC up to 30GHz. Insertion loss is high because the CPW lines are only 3000Å thick. Much lower loss can be achieved by increasing the thickness of the CPW lines. An equivalent LCR circuit was used to fit the measured data. The fitted up-state capacitance is 40fF. Series inductance and series resistance of the switch are 5pH and 0.35Ω, respectively.

In the down-state position, more than 20 dB signal isolation is achieved at 10GHz, and the maximum isolation is 36dB at 26GHz. The fitted down-state capacitance and series inductance are 7pF and 5pH respectively, resulting in a down-state resonance at around 26GHz. Thus an excellent isolation of more than 30dB is obtained in a wide frequency range from 16GHz to 36GHz. The corresponding parallel plate capacitance for 3000 Å-thick BST thin film at near breakdown voltage bias is around 40pF, which is much larger than measured down-state capacitance of 7pF. This is partly due to the surface roughness of the MEMS air bridge and the BST layer. In addition, switch-down voltage was not applied beyond 35 volts in order to avoid breakdown in BST layer. The MEMS air bridge and the BST layer are not in full contact, which also results in much lower down-state capacitance. Despite of all these factors, the measured C_d/C_u ratio is 175:1, compared with 20~30:1 C_d/C_u ratio of SiN-MEMS switch.



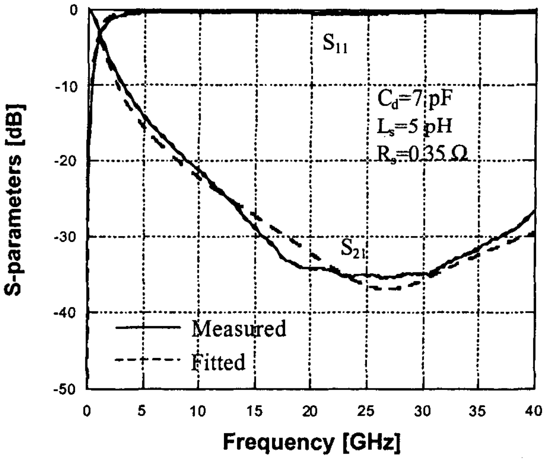


Fig. 4. Measured S-parameters of BST-MEMS switch: (top) in the up-state position and, (bottom) in the down-state position.

To better understand the performance of BST-MEMS switches, devices of the same physical structure and size but using silicon nitride as the isolation dielectric layer were also fabricated and measured. Figure 5 shows the down-state isolations of both BST-MEMS and SiN-MEMS switches. From the comparison we can see that BST-MEMS shunt switches result in much higher signal isolation than SiN-MEMS switches. For frequency bands lower than the down-state LC resonant frequency of the MEMS switches, the larger the down-state capacitance, the more signal isolation can be obtained when the device is switched off. In this case, higher isolation is expected by increasing the down-state capacitance, which requires more analysis on materials properties of BST thin film and its deposition method. On the other hand, since the dielectric constant of BST thin film is a function of applied voltage, it's desirable to isolate the RF flow from DC bias so the maximum dielectric constant of BST film at zero bias can be utilized for better performance.

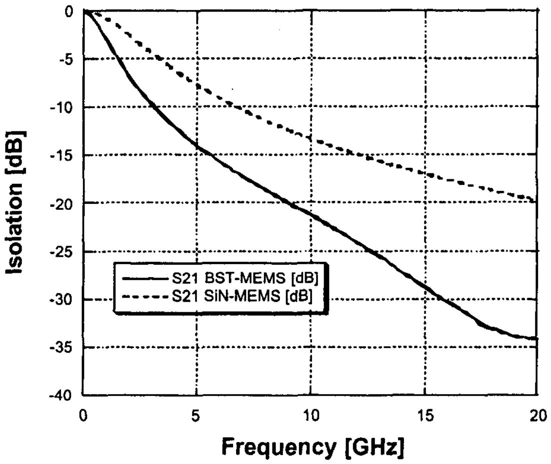


Fig. 5. Comparison between BST-MEMS switch and SiN-MEMS switch for down-state isolation performance.

V. CONCLUSION

In this work, we investigated on replacing traditional silicon nitride dielectric layer with emerging $(Ba,Sr)TiO_3$ (BST) thin film in MEMS switches. Materials properties of BST thin film and some fabrication concerns are addressed. The high dielectric constant of BST thin film results in both higher isolation and smaller device size for MEMS switches. An excellent isolation of more than 30dB is obtained in a wide frequency range from 16GHz to 36GHz. These BST-MEMS devices can be applied to microwave systems requiring for high-isolation switches. Performance of BST-MEMS switches can be further improved with the development of BST thin film technology in the future.

ACKNOWLEDGEMENT

This research has been supported in part by the U.S. Army Research Office under grant number DAAD19-01-1-0496, and DARPA through the Frequency Agile Materials for Electronics program (FAME) under Award No. DABT63-98-1-0006. The sputtering system fabrication was supported by the Army Research Office (ARO) through DURIP equipment award (DAAD19-99-1-0060).

REFERENCES

[1] C. Goldsmith, T.H. Lin, B. Powers, W.R. Wu, B. Norvell, "Micromechanical Membrane Switches for Microwave Applications," 1995 *IEEE MTT-S Digest*, pp. 91-94.

[2] Z.J. Yao, S. Chen, S. Eshelman, D. Denniston and C. Goldsmith, "Micromachined Low-Loss Microwave Switches" IEEE Journal of Microelectromechanical Sytems, vol. 8, no. 2, pp. 129-134, June 1999.

[3] J.B. Muldavin, G.M. Rebeiz, "High Isolation CPW MEMS Shunt Switches Part 1: Modeling," *IEEE Trans. Microwave Theory and Tech.*, vol.48, (no.6), IEEE, June 2000. pp.1045-52.

[4] J.B. Muldavin, G.M. Rebeiz, "High Isolation CPW MEMS Shunt Switches Part 1: Design," *IEEE Trans. Microwave Theory and Tech.*, vol.48, (no.6), IEEE, June 2000. pp.1053-6.

[5] T.R. Taylor, P. Padmini, R. Seidel, J.S. Speck and R.A. York, "RF sputtered high tunability Barium Strontium Titanate (BST) thin films for high frequency applications", presented at *ISIF 2000 Conference*, Aachen, Germany, March, 2000.