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Different Behaviour Seen in Flexible Titanium Dioxide Sol-Gel Memristors Dependent on the Choice of Electrode Materials

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Motivation

The archetypal (Strukov) memristor was made via atomic deposition of TiO_2 between platinum electrodes [1]. The report of flexible solution-processed titanium dioxide memristor [2] was greeted with interest as it made it easier to fabricate working memristors. This device consisted of a spun-on sol-gel layer between two aluminium electrodes.

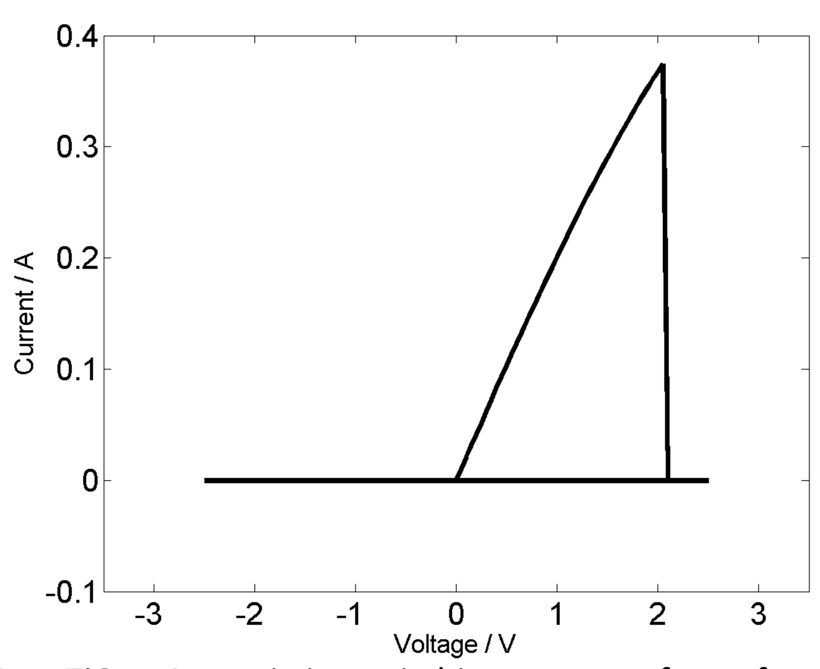
Despite several examples in the ReRAM literature of aluminium oxide playing an essential role in resistance switching [3], even when it was just via aluminium electrodes [4,5,6,7], reference [2] did not report a detailed test comparing aluminium electrodes to noble metal electrodes and instead simply stated that the switching was not attributable to the aluminium electrodes as the memristors still switched with noble metal (Au, Pt) contacts.

We have undertaken a study to elucidate the effect of changing the electrode metal on TiO_2 sol-gel memristors, prepared as in [2], to discover possible methods to control device characteristics.

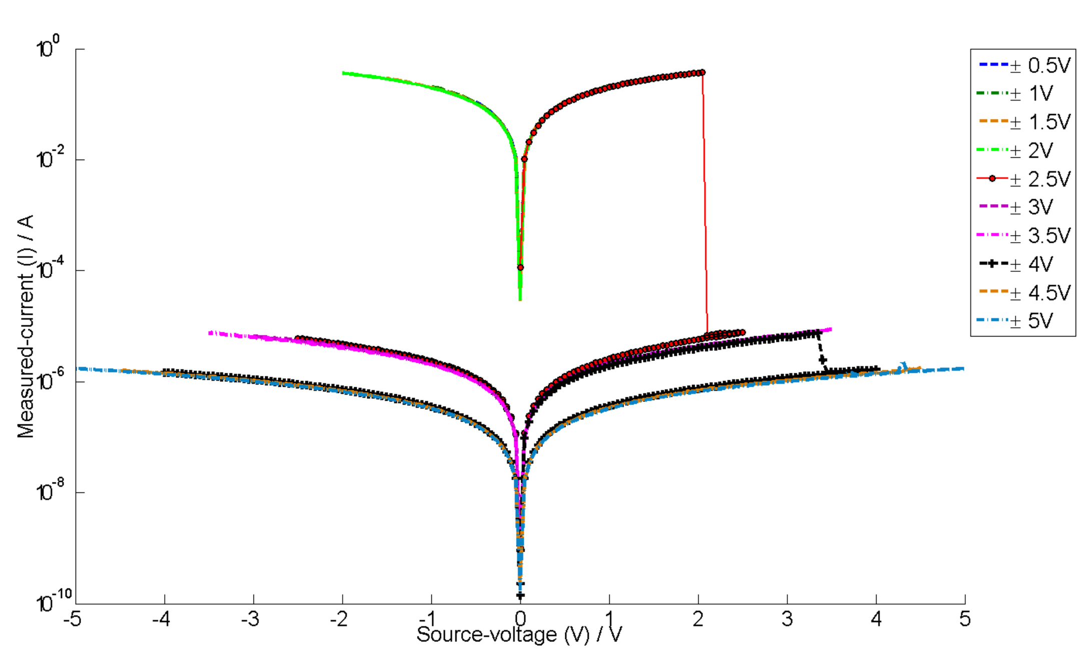
Au—TiO_2—Au sol-gel 'memristors'

We found that Au – TiO_2 – Au memristors did still switch, but in a fundamentally different way. These devices switched in a fuse-like manner, but did not switch back the way that Al – TiO_2 – Al devices did (as reported in both [2] and right). The low resistance state, LRS, and first high resistance state, HRS, currents were ohmic and separated by 5 orders of magnitude, making these devices useful for WORM [Write-Once Read Many (times)] memory. There was also a second low resistance separated by an order of magnitude.

As all the resistance states in these devices piecewise linear rather than non-linear circuit elements, these devices are best described as resistance switching memory, RSM, rather than memristors.

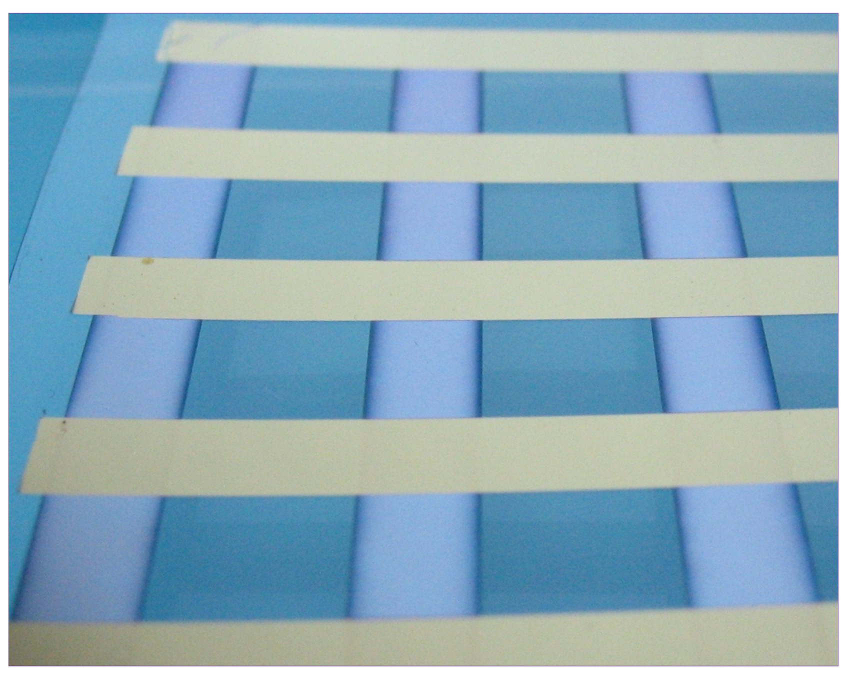


Au—TiO_2—Au resistive switching memory fuses from a low resistance state to higher ones.



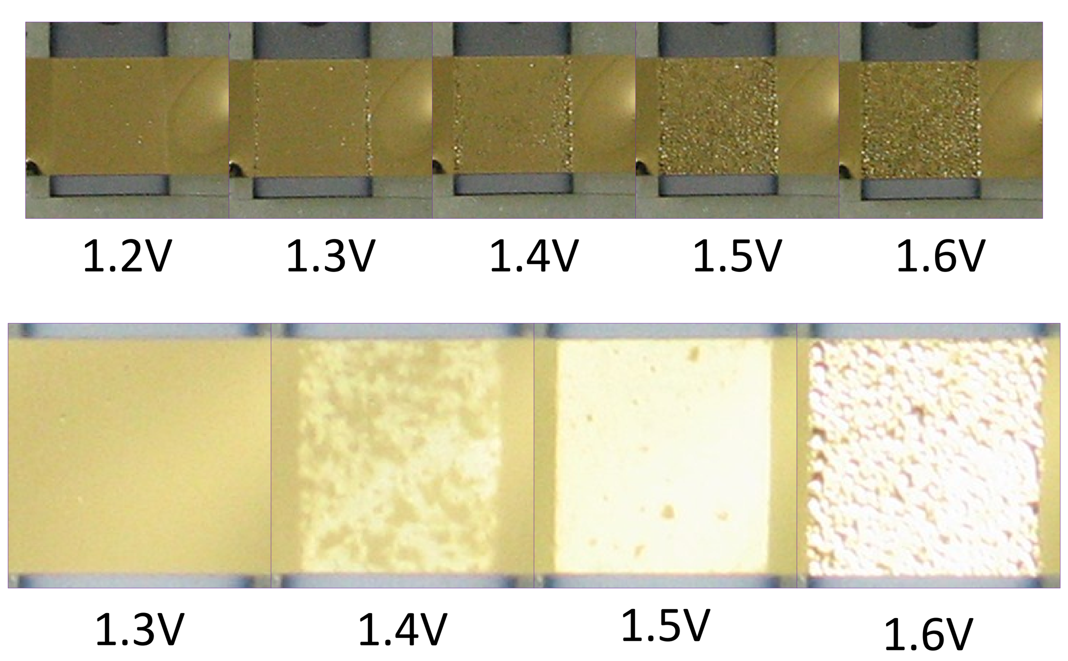
Au—TiO_2—Au Resistive Switching Memory has more than one state and these are separated by at least one order of magnitude.

Al — TiO_2—Au sol-gel (half-) memristors

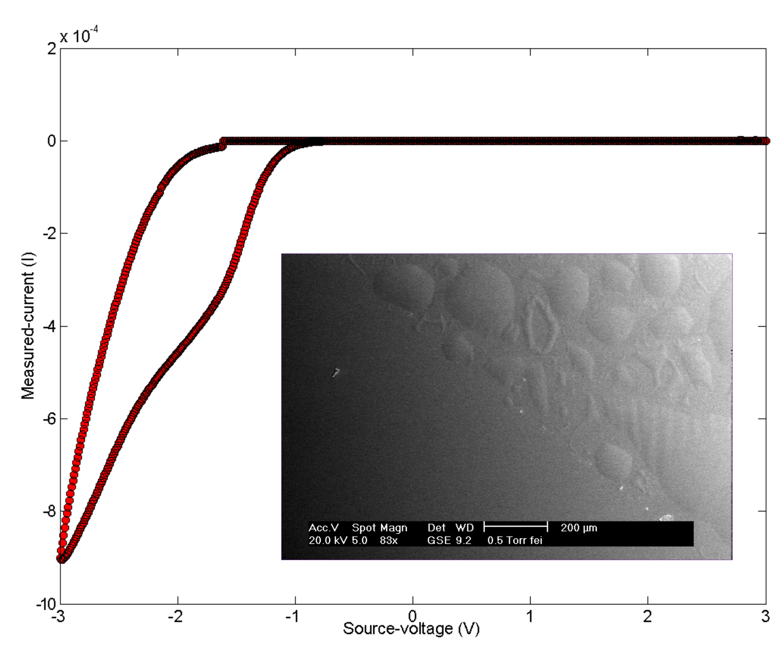


Al—TiO_2—Au sol-gel electrodes. Gold is the top electrode, aluminium is the bottom.

Mixed electrode devices only showed memristor behaviour when the Al electrode was negative with respect to the Au electrode. When the Au electrode was negative, there was oxygen evolution from the TiO_2 gel layer that led to significant deformation of the top electrode. We expect this happened because gold is blocking and cannot accept oxygen ions, but the Aluminium electrode can.



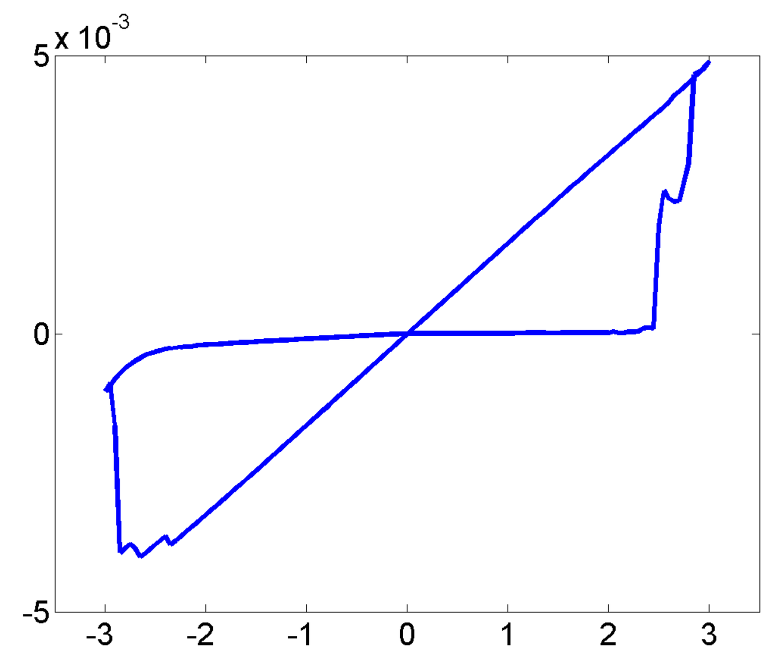
Surface deformation caused by oxygen evolution



Half of 'curved' memristance switching seen. Inset scanning tunelling micrograph shows the sharp boundary between the deformed top electrode over the active area above the bottom electrode

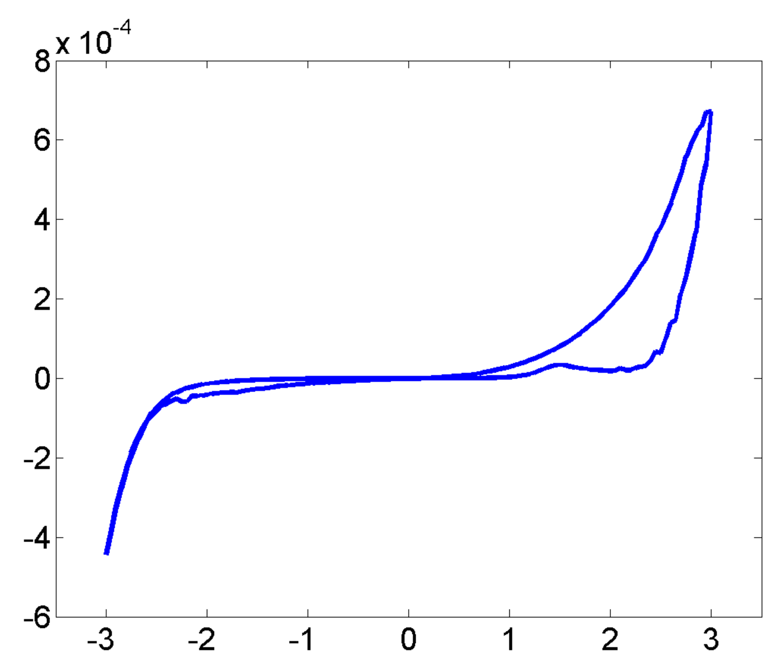
Al — TiO_2—Al sol-gel memristors

Some Al – TiO_2 – Al memristors had high current triangular memristor profiles that resembled those reported in [2]. The LRS was ohmic and in the mA range and never reached the 10^{-2}A range which the LRS of the Au – TiO_2 – Au memristor did (in a comparison of virgin runs of the device between ±3V). These devices had a non-linear HRS in the same range as the curved bipolar switching below.



Triangular memristive switching is seen in the Al—TiO_2—Al memristor

We also found non-linear memristor I-V curves in these devices which resembled both Chua's memristor theory [8] and also ReRAM bipolar resistance switching. Devices with this mode of operation were higher resistance, (most in the 10^{-6} to 10^{-4}A range over the voltage range tested) and very reproducible. Those with triangular memristor profiles were less reproducible, they had the same behaviour, but the switching voltage was not constant.



Curved memristive switching is seen in the Al—TiO_2—Al memristor

Conclusion

- The aluminium electrodes are an essential part of the operation of the TiO_2 sol-gel memristor

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