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# FABRICATION AND MODELLING OF TITANIUM DIOXIDE MEMRISTORS

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**Concept – Including Filamentary Conduction in the Mem-Con Theory of Memristance Improves the Model for ‘Triangular’ Memristors**

**Introduction:** Memristors are the novel 4<sup>th</sup> fundamental circuit element predicted to relate the magnetic flux,  $\phi$ , to charge,  $q$ , via  $d\phi = M(q) dq$ , where  $M$  is the memristance [1]. Memristors can act as artificial synapses in brain-like computer architectures. Our memristors are made of sputter-coated aluminium electrodes and 40nm thick layers of titanium dioxide sol-gels [2,3].

## Characterization

Two types of memristor were seen:

- 'Curved'-type which have off and on states in the same order of magnitude, see fig. 2A.
- 'Triangular'-type which have off and on states in different orders of magnitude, see fig. 2B.

- The **curved** switching is caused by bulk movement of oxygen ions creating volumes of doped  $TiO_{(2-x)}$
- It is believed that the **triangular** switching is caused by the fusing and breaking of filaments of very low resistance titanium dioxide.

## Theoretical Modelling

The mem-con theory [4] is a new model of memristance based on the chemistry of the device by describing the magnetic field associated with the flow of oxygen ions and relates memristance,  $M$ , and magnetic flux,  $\phi$ , to experimental measurables.

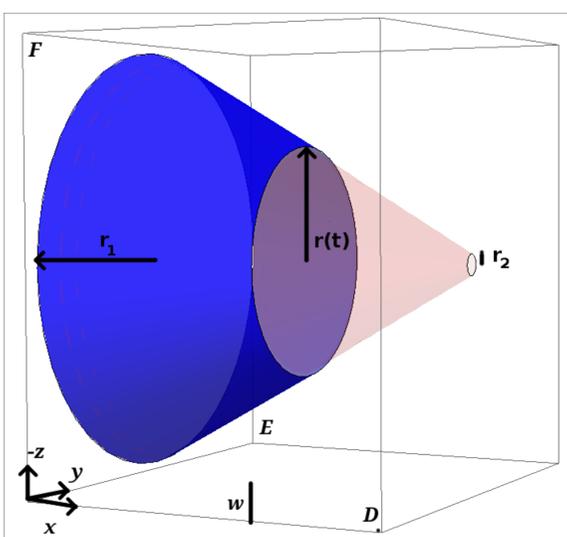


Figure 1. Schematic of conducting filament

## Results

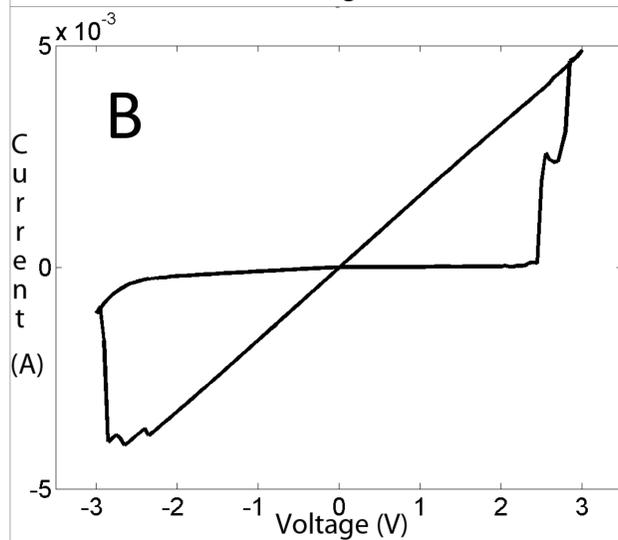
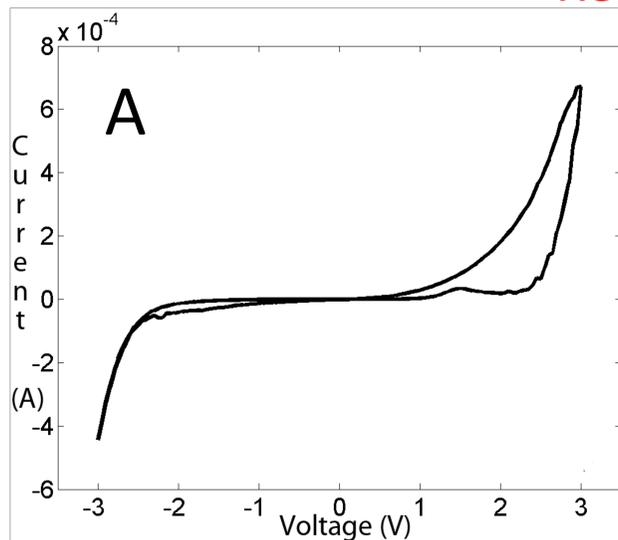


Figure 2. Experimentally measured I-V curves obtained from  $TiO_2$  sol-gel memristors. The 'curved' type, A, have  $R_{off}$  and  $R_{on}$  in the same order of magnitude, the 'triangular' type, B, has  $R_{off}$  and  $R_{on}$  separated by several orders of magnitude.

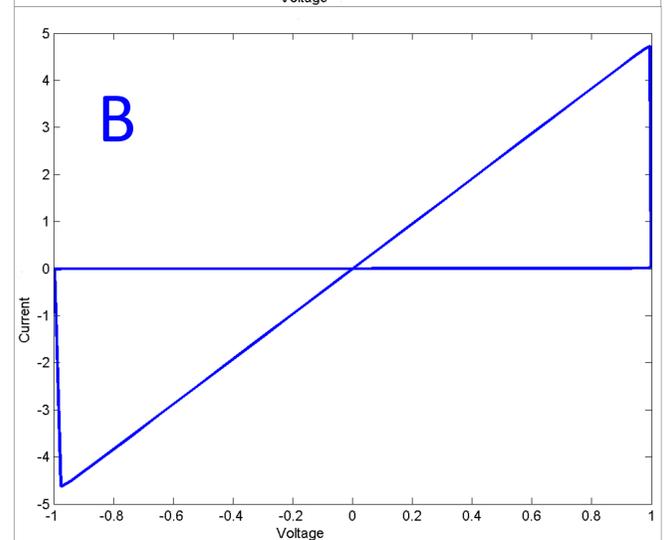
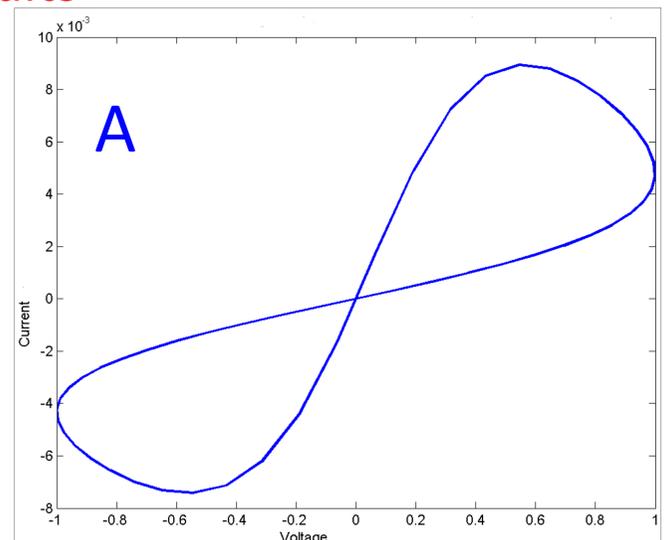


Figure 3. Simulated curves from the mem-con theory, A, and the filamentary extension to the mem-con theory, B.

## Filamentary Memristance

The filament is modelled as being in parallel with the bulk movement of oxygen ions within the conical frustum envelope seen in fig. 1. The total system memristance,  $R_{Tot}$ , is given by:

$$R_{Tot} = \frac{1}{\frac{1}{F_{Mem} + F_{Con}} + 2H(w-D)\frac{1}{R_{fil}}}$$

where  $F_{Mem}$  is the memory function,  $F_{Con}$  is the conservation function,  $R_{fil}$  is the resistance of the filament. The Heaviside function,  $H$ , is used to model the connection and rupture of the filament. The filament connects when the drifting ions reach  $D$ .

## Conclusions

- The 'bulk' Mem-Con model, fig. 3A describes the qualitative characteristics of the 'curved' memristor switching, fig 2A.
- The addition of a switching filament to the model, see fig. 3B, improves the description of triangular switching, see fig. 2B

This result adds to the evidence that triangular switching memristors operate via a filamentary mechanism. This extended theory provides us with a more physically relevant model for use in neuromorphic computing simulations to test and refine our experimental designs.

## References:

- L. Chua, "Memristor: The Missing Circuit Element," *Adv. Funct. Mater.*, **21**, 507-519 (1971)
- N. Gergel-Hackett et al, "A Flexible Solution Processed Memristor," *IEEE Elec. Dev. Lett.*, **30**, 706-708 (2009)
- E. Gale et al, "Aluminium Electrodes Effect the Operation of the Titanium Dioxide Sol-Gel Memristor," arXiv:1106.6293v1 [cond-mat.mtrl-sci]
- E. Gale, "The Missing Memristor Flux Found," arXiv:1106.3170v1 [cond-mat.mtrl-sci]