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Switching Tantalum Oxide Films Created By IAD

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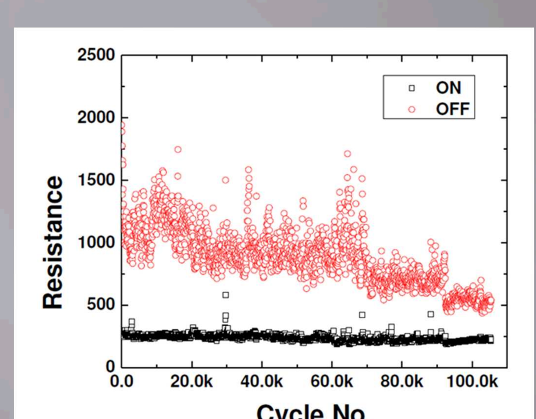
Abstract

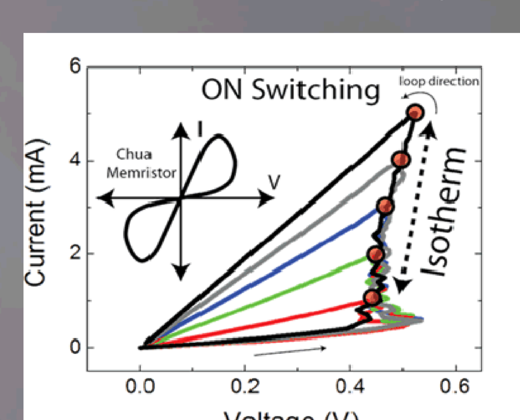
As super computers become larger, faster, and smarter, their energy consumption and heat load have also increased. Memory-resistors (Memristors) may be the solution to this problem. Memristors not only offer a solution for power requirements, they have the unique ability to create novel circuits similar to the [illegible] spent large amounts of time and money trying to create memristors using sputtering techniques. However, memristors are still difficult to create. Sputtering sub-stoichiometric metals have shown to have high cycle to cycle variability which can reduce the memristor's reliability and performance. Ion Assisted Deposition (IAD) shows promise to significantly reduce the variability and improve device performance. With the independent control of gas flow and metal deposition rate, the stoichiometry control has been excellent. The advantages IAD has over sputtering memristors films may usher in the next generation of memory and computing.

What is a Memristor?



A memory resistor, or memristor, is an electrical component that limits or regulates the flow of electrical current in a circuit and remembers the amount of charge that has previously flowed through it. Memristors are important because they are non-volatile memory.

Using only partial voltages causes partial changes. Similarly to synapses in the brain, as current passes, it becomes easier for more current to pass. Instead of a 1 or 0 state a novel circuit can use an intermediate state for example 1.2.

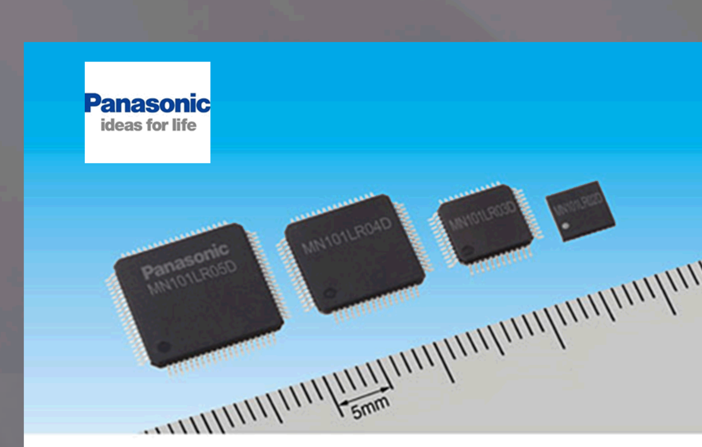


Why Memristors?

Tianhe-2, the world's fastest super computer consumes 4.04 MW of electricity annually. This equates to $4 million a year.

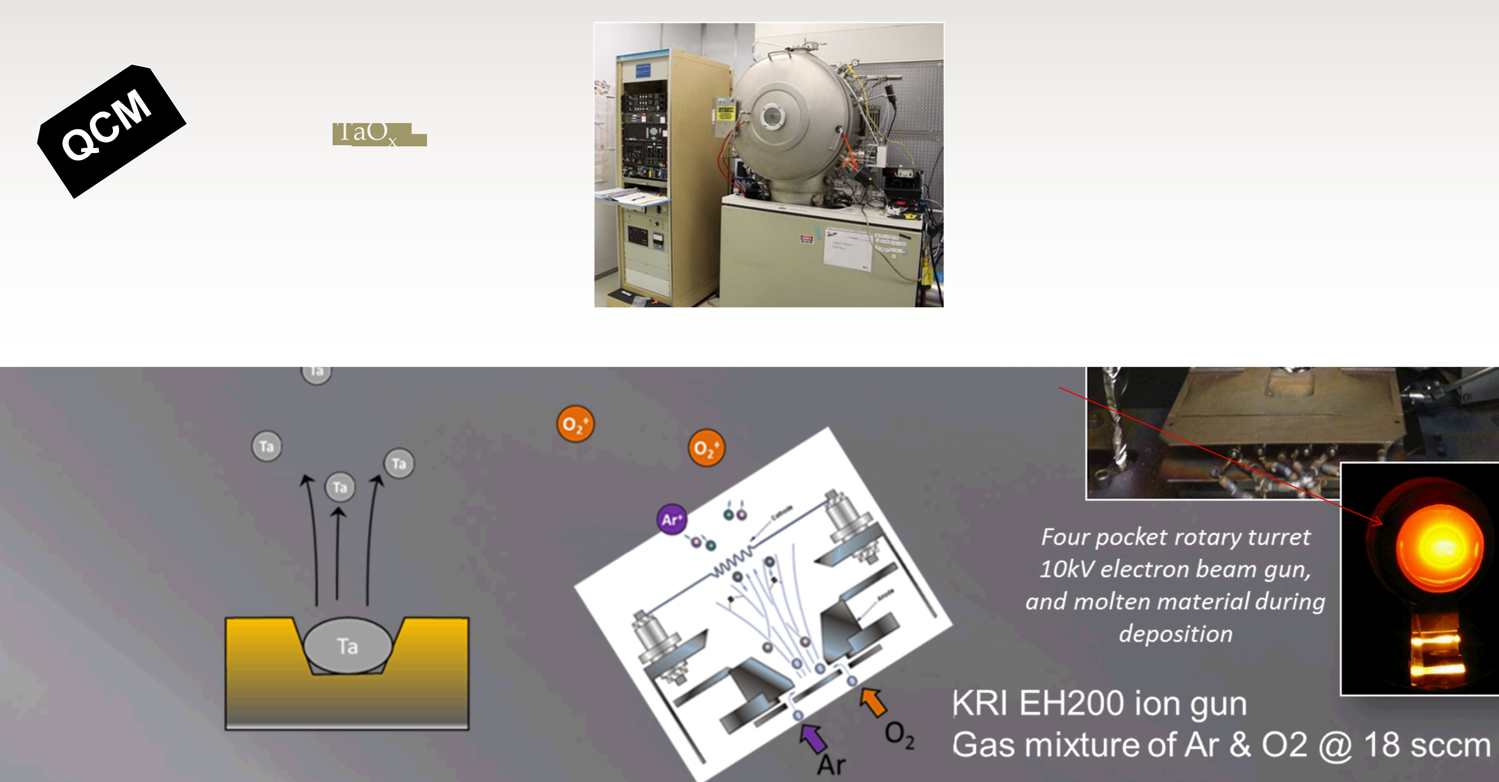
With current advances a full sized power plant will soon be needed to power one super computer.

Panasonic recently released the first commercially available memristor device. According to Panasonic this Resistive RAM (ReRam) is 5-10 times faster than traditional RAM and uses half the power.

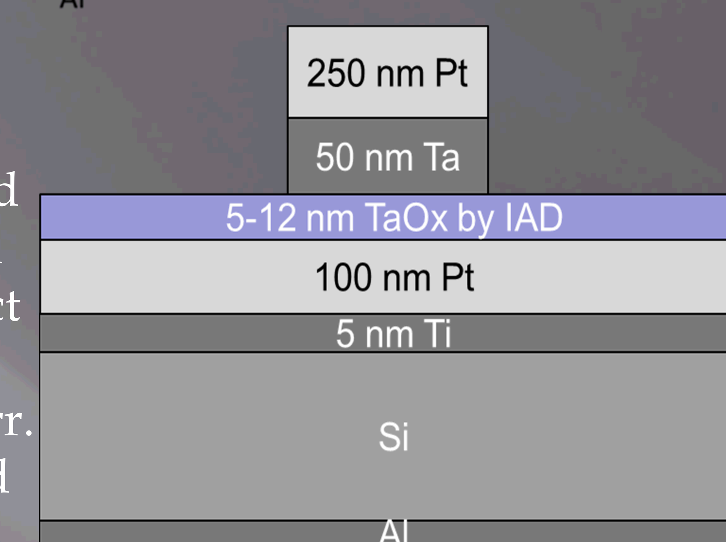


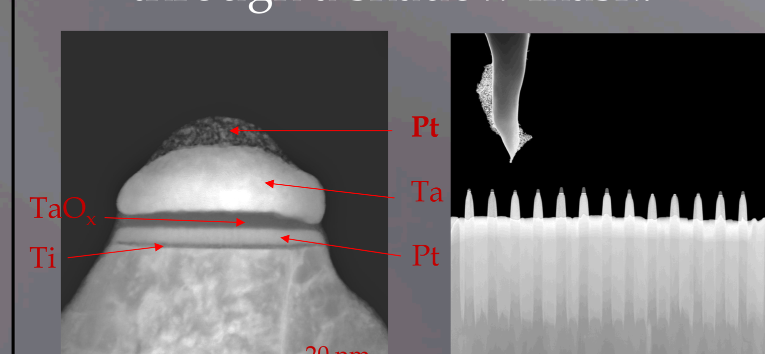
ReRAM Mounted Low Power Consumption Microcomputer, MN101LR Series

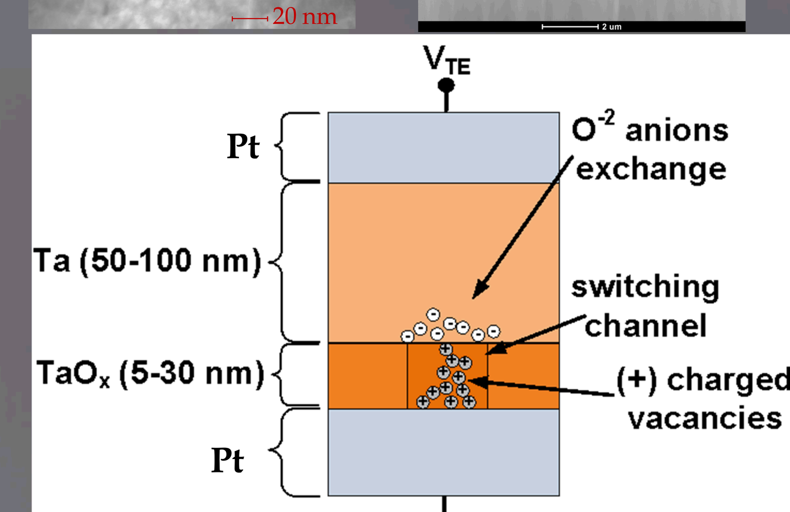
Experiment Setup



- The film is grown at 0.5 Å/s.
- The TaO_x film is blanket coated on the wafer. Ions plus partial pressure from the ion gun react with the Ta source.
- Deposition pressure $1x10^{-4}$ Torr.
- The Ta/Pt dot cap is deposited through a shadow mask.



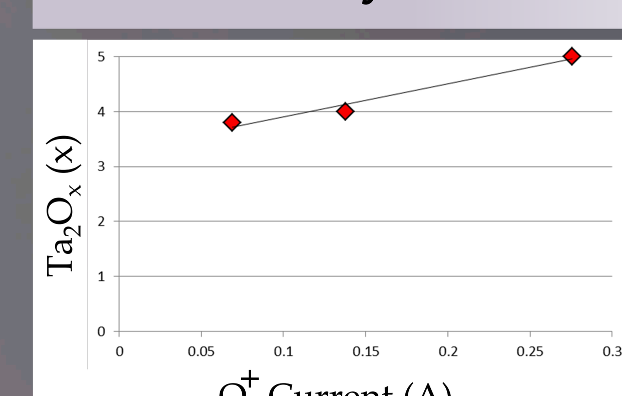




- In this experiment TaO_x was deposited on micro-needles fabricated by focused ion beam (FIB)
- From the transmission electron microscopy (TEM) image we see surface roughness is very minimal throughout the film stack.

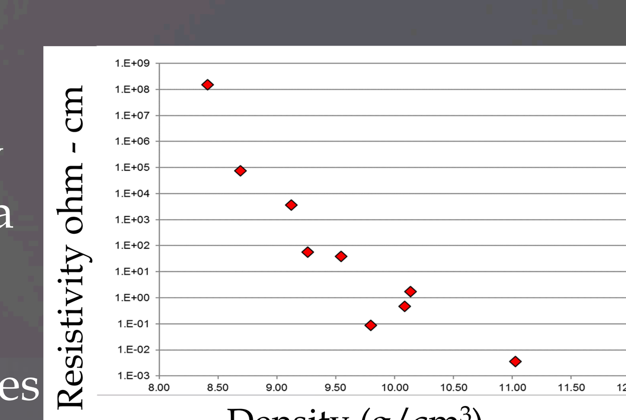
- Voltage and current are applied to the top of the electrode to change the resistance.

Stoichiometry Control



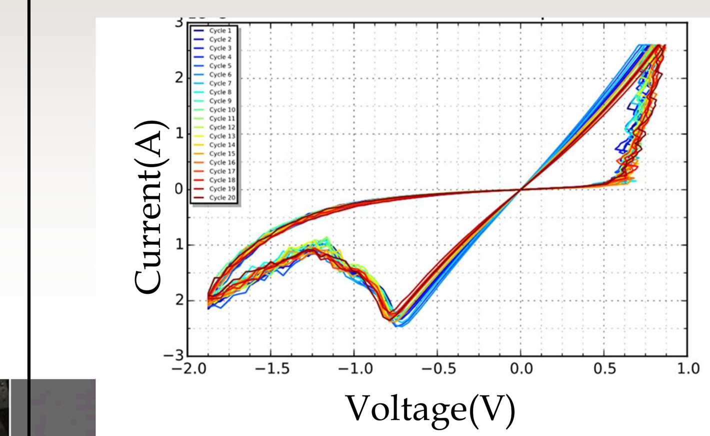
We have shown the current O_2^+ ion current affects the stoichiometry of the film. The lower the current the fewer oxygen atoms in the film.

- Density, Resistivity & Stoichiometry are all correlated. As shown above, a slight current change in the ion gun can make a change that allows multiple film sub-stoichiometry states to be studied very easily.

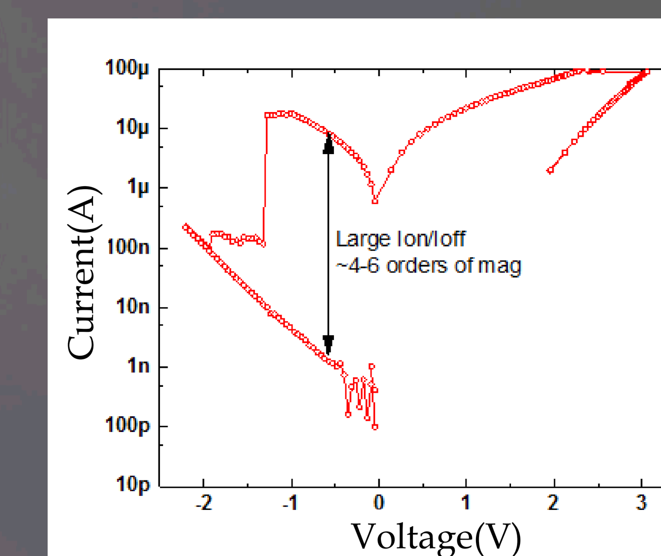


Ta_2O_5 = 8.37 g/cm³ Ta = 16.69 g/cm³

Results



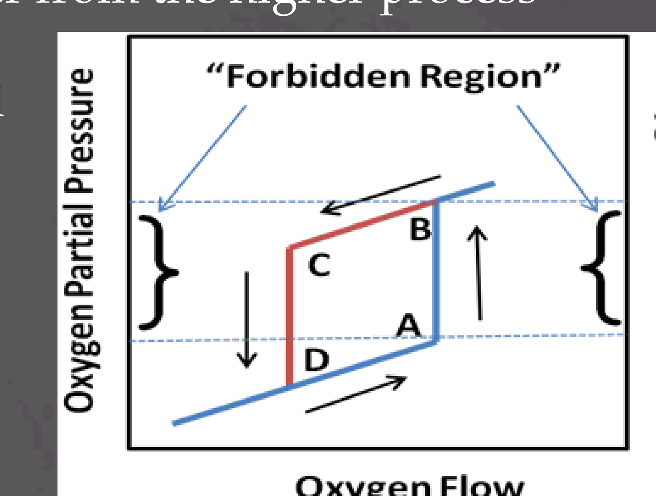
- Film was shown to have very high switching capabilities.
- Cycle to cycle reliability has been shown to be very high.



- Very high resistance on-off switching.
- Some films were six orders of magnitude.
- Some batches had 100% yield. Much less waste.

IAD Advantages

- Ion assisted deposition (IAD) has been used by the optics industry extensively. The films are hard, dense and have fewer pinholes from traditional evaporation. Using a known technique has been a time and money saver in film process development.
- Having an independently controlled ion source, and quartz crystal monitor (QCM) gives us excellent stoichiometry control.
- An independent QCM gives us a more accurate film thickness compared to time/power used in reactive sputtering.
- Process adjustments are easier from the higher process repeatability.
- Using evaporation you avoid target spoiling as you get in reactively sputtered films. There is no "forbidden region."



A.J. Lohn et al APL 103, 063502 (2013)

Conclusions

IAD evaporation appears to be a viable method in creating memristors. With an independent ion source, rate, and thickness control, the sub-stoichiometric TaO_x films are switching with a very high success rate. Film properties are repeatable allowing for easier process changes and more effective research and development. Since IAD evaporation is widely used in industry, it is a well understood process making R&D and process development cheaper. As data growth continues to increase exponentially, memristors appear to be the solution to the growing energy needs of tomorrows supercomputers and data centers. IAD evaporation may expedite memristors to the commercial market.

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