# Electric Plasticity in Glass-Ceramic Thin Films

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## Introduction

Physical miniaturization is a limiting factor in future development of silicon-based semiconductor industry. For this reason, completely new approaches in computing architecture are necessary to overcome this issue. Two main solutions have gained attention in the last years: quantum computation [1] and brain-like computation [2]. The latter approach involves the use of electronic device with synapses-like behaviour in which the electric conduction between different elements of the neural network depends on past events occurred between them (Spike-Timing-Dependent-Plasticity)[3]. In this work, we propose a novel material, an oxide-in-oxide nanostructured glassceramic thin films, with potential application as artificial synapses.

## Material

The investigated material has been produced in form of thin films – 60nm thick – deposited on p-doped silicon wafer by radio frequency sputtering in standard conditions. The starting sputtering target is a glass with composition 7.5 $Li_2O$ – 2.5 $Na_2O$ – 20 $Ga_2O_3$ – 25 $SiO_2$ – 45 $GeO_2$ (%mol). In bulk form these glasses undergo thermally-assisted segregation of $Ga_2O_3$ nanoparticles (NPs) leading to the formation of nanostructured glassceramics [4]. By variance from bulk samples, in thin films sample nanostructuring occurs already in as-deposited samples, as demonstrated by AFM and SEM analysis, without the need of further thermal treatments. Finally, thin films were completed with top electrodes by gold evaporation.

## Experimental details

Measurements were carried out by means of an HP 4284A LCR-meter controlled by a custom LabView software. Impedance was measured by sending one or two square pulses with different length and delay (negative delays correspond to ”post synaptic” pulse sent before the ”pre-synaptic” which is always present, Fig. 1). Investigated quantities were the ratio of the measured resistance and capacity just before and just after the pulse(s). All the pulses had an amplitude of ± 5V and the oscillating probe signal was of 100 mV. Metal electrodes and silicon substrate were connected to “high” and “low” terminals of the instrument, respectively.

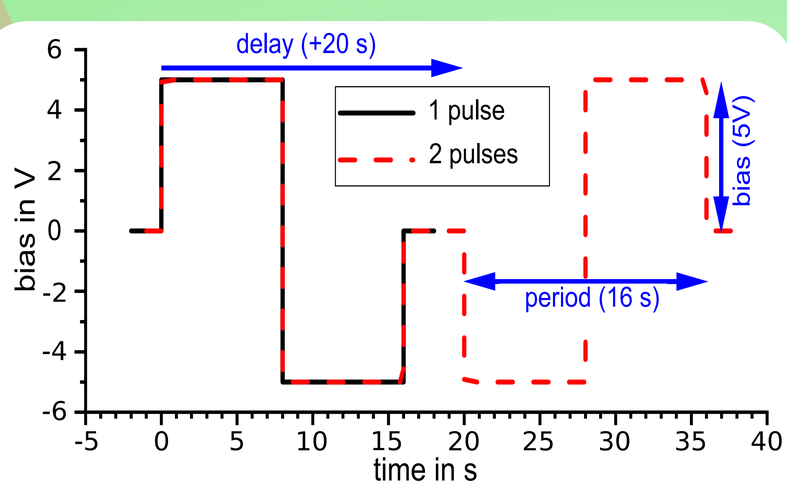



**Figure 1**: a schematic of our probe signal with an indication of the main parameters: pulse period, pulse intensity (bias) and delay between the two.

## Results

The most important result is the effective conditioning of the device induced by the pulses (Fig. 2). Actually we observe that only the last pulse effectively influences the response, differently from what has been observed in similar, but symmetric systems [3]. The response in the capacity (Fig. 2b) and the frequency-dependence of the response (Fig. 3) suggest that the observed effect is caused by charge trapping in the nanostructured material, likely in the NPs. To complete our analysis, we studied:

- **Timing between pulses**: pulses too shorts (< 1 second) do not influence the response at all (Fig. 4);
- **Decay time of the response**: we can safely store a bit of information as long as long as 1.15±12 seconds for positive pulses and 1.9±0.8 seconds for negative pulses seconds (Fig. 5);

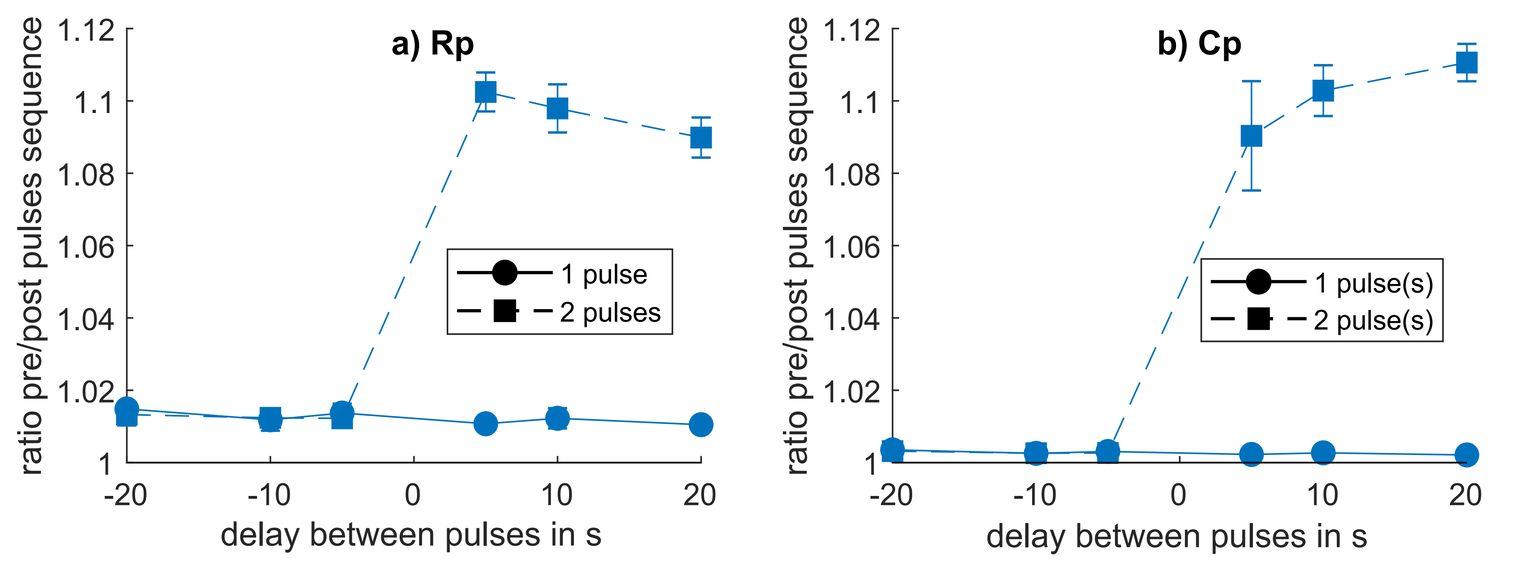
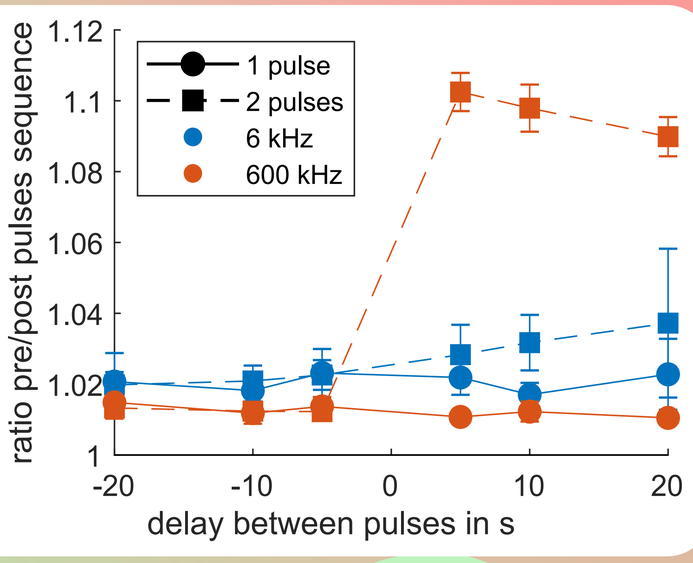



**Figure 2**: ratio of real (a) and imaginary (b) part of impedance before and after the pulse train made of just one (squares/dashed line) or 2 pulses (circles/solid line) for different delays between them. When the delay is positive, the ratio change notably, as a result of memory effects.

**Figure 3**: high (red line) and low (blue line) frequency response of data shown in Fig. 1.



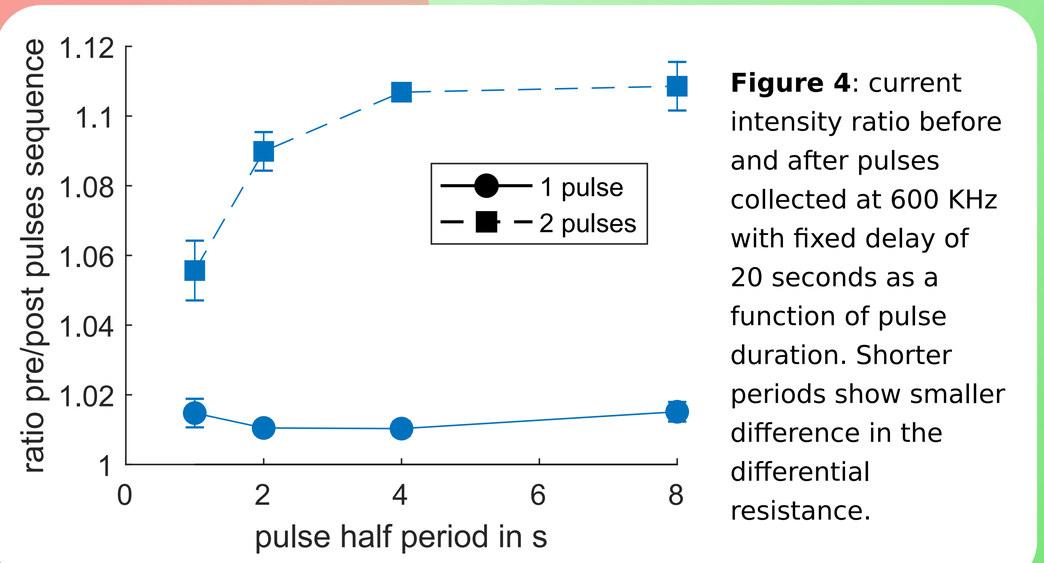




**Figure 4**: current intensity ratio before and after pulses collected at 600 KHz with fixed delay of 20 seconds as a function of pulse duration. Shorter periods show smaller difference in the differential resistance.

## Conclusions

This preliminary work demonstrates the occurance of an electrical plasticity can exist in nanostructured oxide materials. The response is transient and does not last indefinitely. The response is a boolean value and its state can be controlled by the presence of a “writing” pulse.

## References

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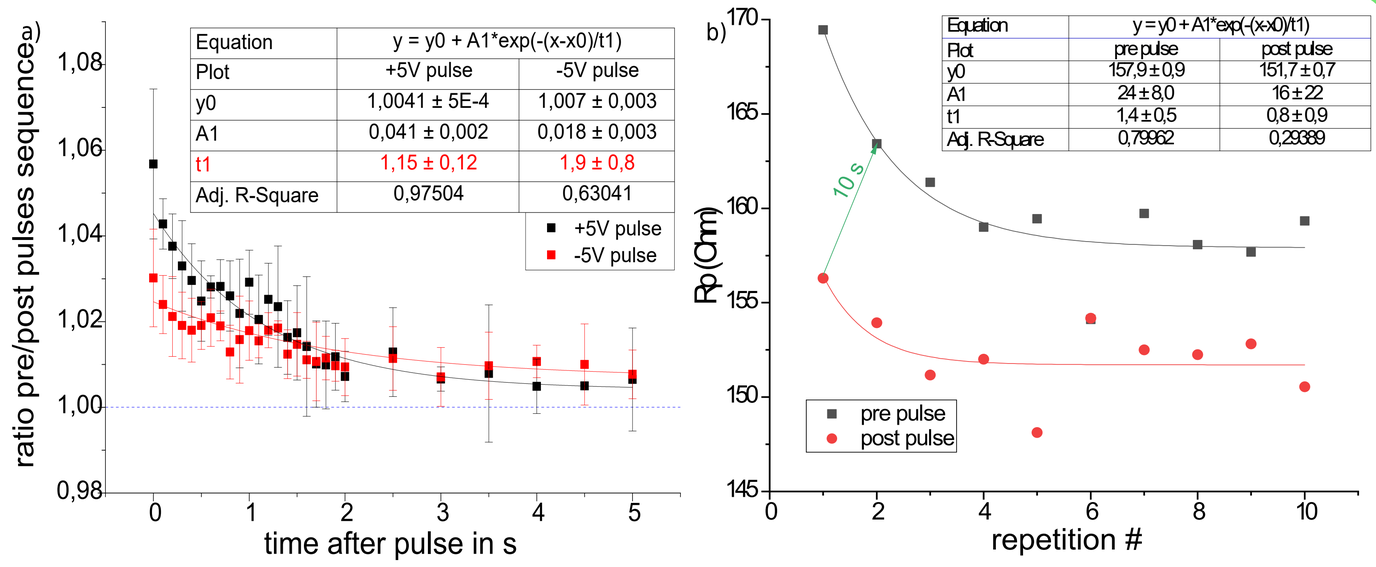


**Figure 5**: a) Analysis of the time-to-live value for the device after a positive (black) or negative (red) half pulse with duration of 5 s and relative exponential decay fits; each point is the average of 10 subsequent measurements. b) Raw resistance data used to evaluate the first black point in (a) at 20 msec as a function of scan repetition number.