AC and DC characterization of γ-Ga_2O_3 containing glass-ceramic thin films

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INTRODUCTION

Oxide materials are used in many applications as semiconductors. Usually they need some special deposition technique to be effective. With this work we want to show the possibility to have nanostructured semiconductor-based device in which the semiconductor is an amorphous oxide easily (and cheaply) sputtered on a substrate.

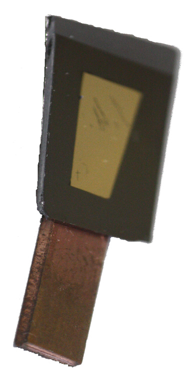

figure 1: one of our sample.

MATERIAL/SAMPLE PREPARATION

Our device was build on a p-doped Si wafer. Via Radio Frequency Sputtering we deposited a layer about 60-80 nm thick from a glass target with composition $7.5Li_2O - 2.5Na_2O - 20Ga_2O_3 - 25GeO_2 - 45SiO_2$. On top of it we deposited a metal electrode (Al, Cr, Au or Au +Cr). From previous studies on bulk samples[1] we know that, in these glasses, gallium oxide can undergo to phase segregation if thermally treated at about 700°C leading to a nanostructured glassceramic. In this view half of the samples were treated (TT), while the others were used as-deposited (AD). By variance with bulk samples, AFM analysis show that some particles are already present in the AD samples and that the thermal treatment partially lead to their coalesence into bigger particles. An example of our device can be found in fig. 1.

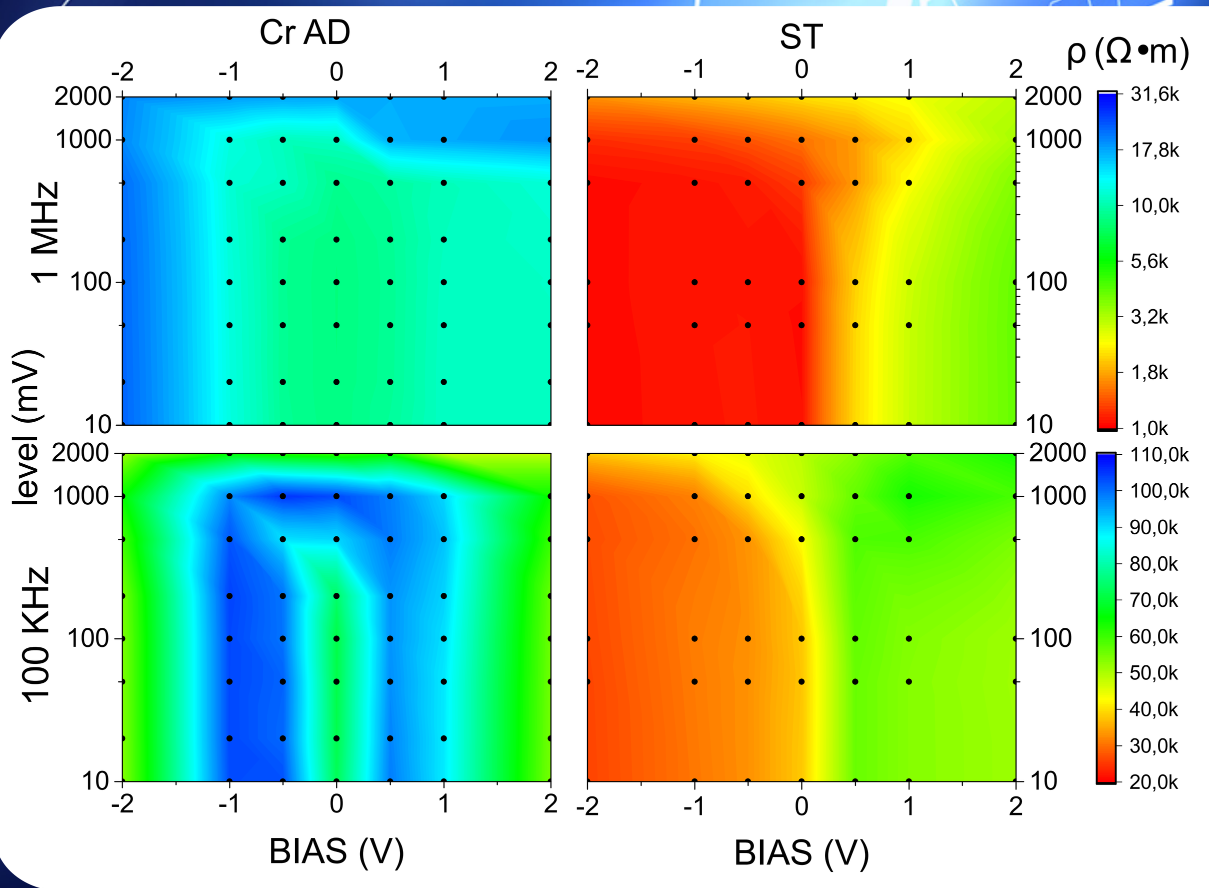

figure 2: map of resistivities measured at different frequencies (Y axis) and levels (X axis) for the Cr AD sample (left) and for the ST MOS (right) for reference. This second device show always a lower resistivity than the Cr one .

RESULTS AND DISCUSSION

Comparison between the data collected at 1MHz (fig. 2 top) from the experimental device (left) and a standard p-MOS (right)[4] show that our device, despite we used a p substrate, acts more similarly to a n-based MOS, but maps obtained at lower frequencies show some completely different behaviour (fig. 2 bottom), strongly dependant on BIAS.

Impedance spectra were represented as Bode plots (fig. 3a).

Pseudo DC resistances were evalueted from such plots considering the R values when X=0 at low frequency (right side). Plotting such data in a R-V (fig. 3b) or I-V (fig. 3c) graph show a trend typical of assimetric devices, such as schottky diodes. Despite the resistance without BIAS in our AD device and in the standard is similar, with stronger DC electrical field (both way) our sample show a greater conducibility.

In Bode plots we can usually find 2 different semi-circles, and that translate to an EC behaviour with no less than 2 couples of parallel resistance and capacitance. Different design were tested, but the best results were obtained with the 2 couples in series (as show in the insect of fig. 3a) where the standard capacitors were substituted with some Constant Phase Elements (CPE, $Z_{CPE} = \frac{1}{Q_0\omega^n} e^{-i\frac{\pi}{2}n}$). In fig. 4d-f only the resistance values are shown.

Finally we investigate the behaviour of our samples at different temperatures: the pseudo-DC resistance decreases linearly with the temperature (figure 4a). We also performed some fits on the same data sets according to frequency power laws to obtain some information regarding the conduction mechanism (hopping/tunnelling/...) from the exponent trend. Results show opposite trends between AD and TT samples (fig. 4b) and the interpretation will require to consider also other parameters (including an optional BIAS).

These materials could be uses as UV-C solar blind detectors, in-depth investigation on this aspect are still in progress to statistically validate such data.

CHARACTERIZATION METHOD

The focus of this work is the electrical characterization of Metal – Oxide – Semiconductor (MOS) structure described. The data collection were performed using an HP 4284A LCRmeter in the region between 100 Hz and 1 MHz. These data were analysed using some equivalent circuit (EC) models[2], fitted to Jonsher "Universal law"[3] and compared to a standard[4]. The responsivity of our devices were tested under different AC levels (10mV~2V), DC bias (0~±5V) and at different temperatures (77-350K). Thickness was measured with a profilometer.

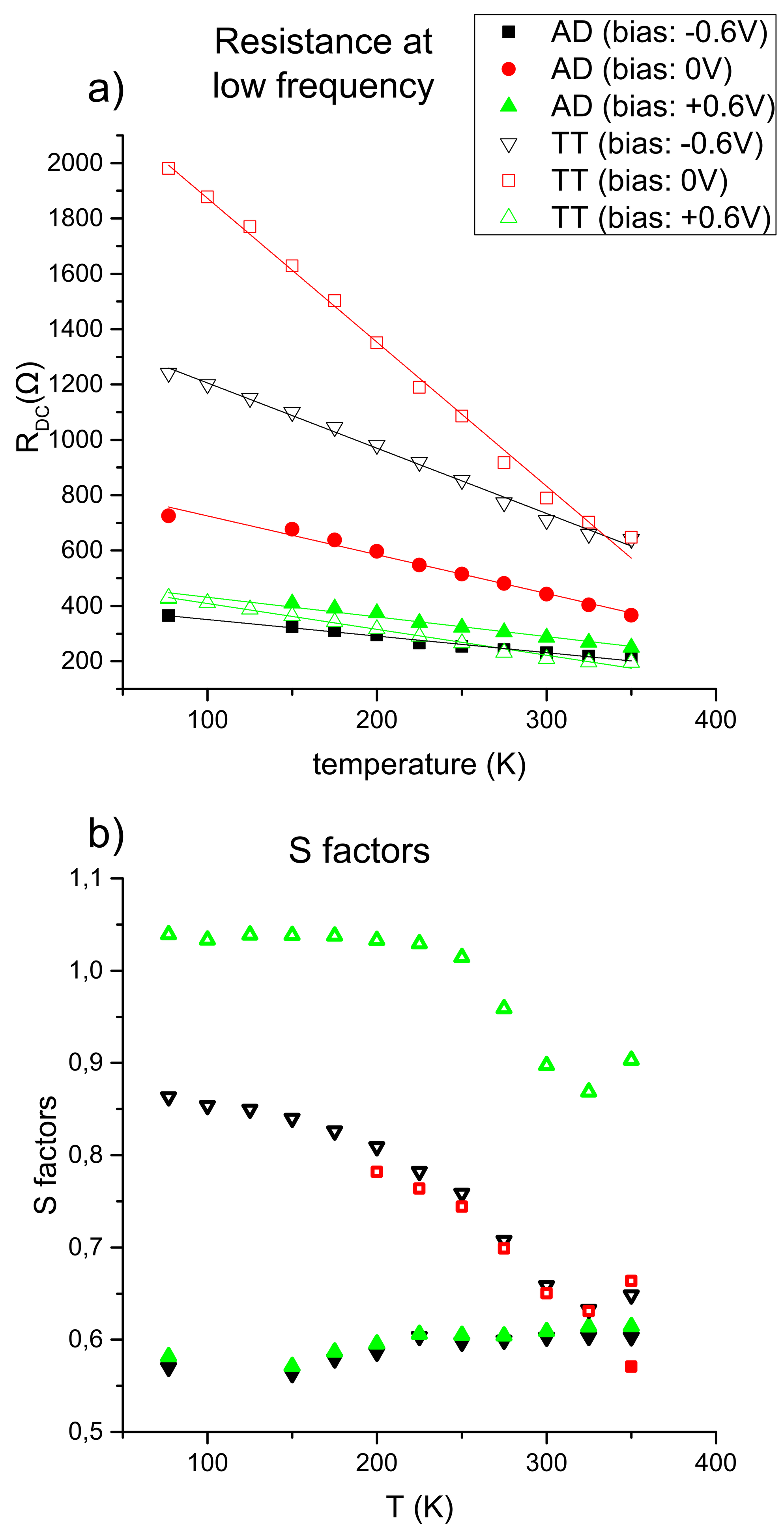

figure 4: data acquired at different temperatures (LN2 to 350°C). a) values of pseudo RDC are almost perfectly linear with temperature (R decrease with augmenting T). We fit the same raw data using a Jonsher model (formula: $\tilde{G} = G_0 + G_1 \cdot \omega^s$) and we plot the plot the exponential factor s in b), finding a completly different behaviour. Moreover, this behaviour depend o the thrmal history of the sample. the applied bias and also the frequency range we use for the fit.

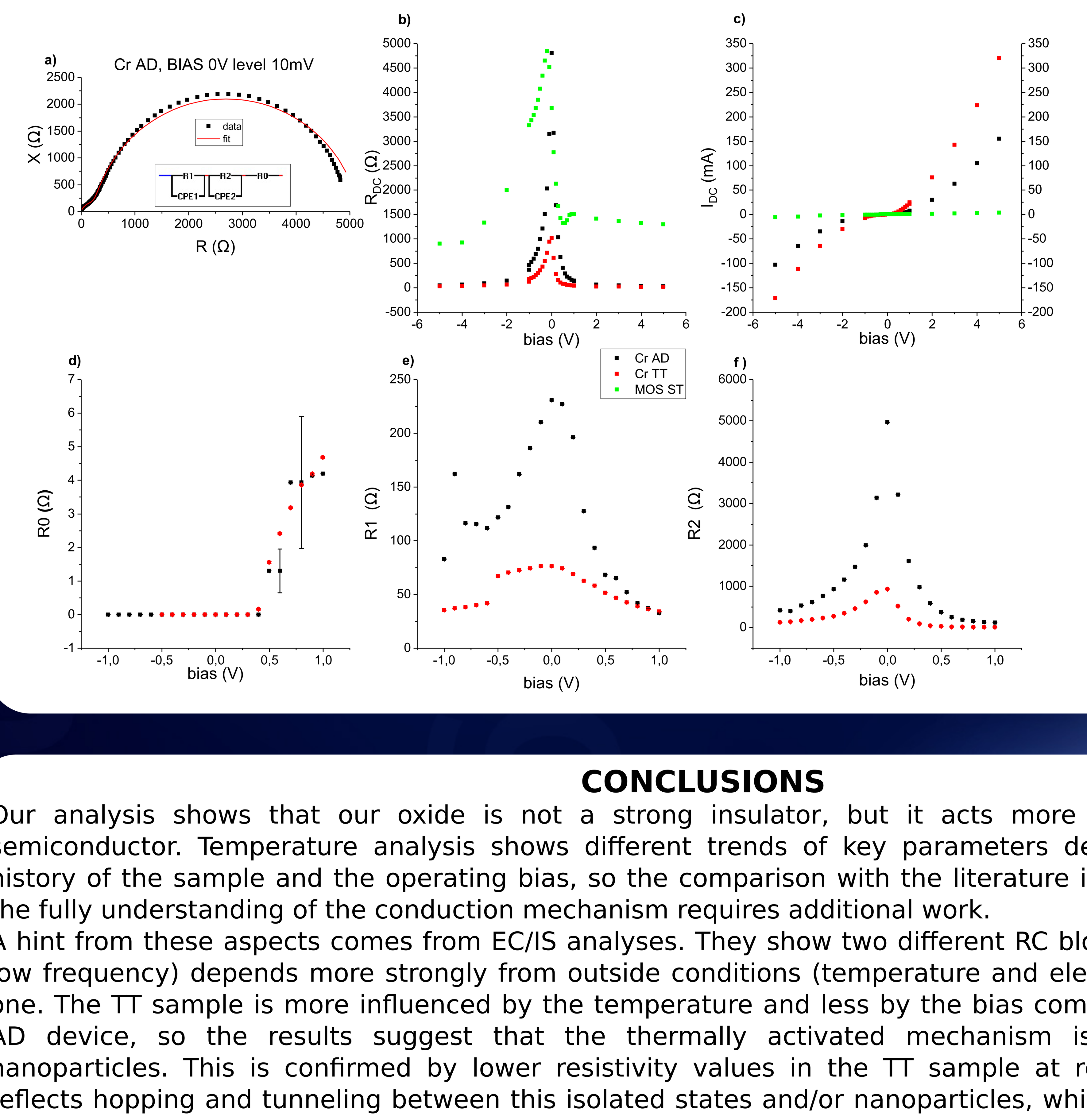

figure 3: a) an example of the collected spectra (dots) with its fit (red line) using the EC reported in the insect. "Closing" the semi-circle at low frequency (right end) we can define some pseudo-DC resistances; in b) we report such data from different spectra collected at different BIAS on the Cr AD, Cr TT and ST-MOS, easily translated in the I-V curve in c). If we instead use the EC fits, we will obtain one (or more) graph for each element in the EC. In d)-f) are reported the ones for the 3 resistances: R0, R1 and R2.

CONCLUSIONS

Our analysis shows that our oxide is not a strong insulator, but it acts more likely as an intrinsic n-semiconductor. Temperature analysis shows different trends of key parameters depending on the thermal history of the sample and the operating bias, so the comparison with the literature is not straightforward and the fully understanding of the conduction mechanism requires additional work.

A hint from these aspects comes from EC/IS analyses. They show two different RC blocks, and one of them (at low frequency) depends more strongly from outside conditions (temperature and electric field) than the other one. The TT sample is more influenced by the temperature and less by the bias compared with respect to the AD device, so the results suggest that the thermally activated mechanism is probably mediated by nanoparticles. This is confirmed by lower resistivity values in the TT sample at room temperatures which reflects hopping and tunneling between this isolated states and/or nanoparticles, which, in turn, are registered by AFM analyses.

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[4] MOS from STMicroelectronics: p-silicon substrate with 100nm of undoped silica glass (PECVD) and a dye area of $7.87mm^2$.