Generation of Diode-Like Structures with Maxwellian Series Resistance in Electrically Stressed $HoTiO_x$ Thin Films

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Abstract

It is generally accepted that the dielectric breakdown (BD) of a thin oxide layer in a metal-insulator-metal structure is the consequence of a local accumulation of defects generated for example by the application of electrical stress. This accumulation of defects leads ultimately to the formation of a filamentary path spanning the oxide layer with a consequent leakage current increase. Depending on the magnitude of the localized current, the BD event is often referred to as a soft (SBD) or hard (HBD) breakdown. While the distinction between SBD and HBD does not follow strict criteria, SBD has been reported to be well-described by an exponential dependence with the applied bias whereas HBD has been mostly associated with ohmic-like behavior [1]. Interestingly, the formation of such current paths is closely related to the so-called resistive switching (RS) effect, which corresponds to the reversible formation and dissolution of filamentary conductive structures caused by the application of electrical stimulii. However, the nature of the electron transport along these filaments is still an opened question. It is worth mentioning that RS is the physical mechanism behind the operational principle of Resistive RAM devices, which are believed to revolutionize the memory market in a near future.

In this work, we have focused the attention on the post-BD current-voltage (*I*-*V*) characteristics of holmium titanium oxide ($HoTiO_x$)-based MIM capacitors [2]. The $HoTiO_x$ film was grown by ALD (18.7nm) on TiN layers deposited on p-type Si substrates. The structures were electrical stressed so as to generate post-BD currents of increasing magnitude and the resulting *I*-*V* curves were fitted (Fig. 1) using a diode-like transport model [1,3-6]:

$$I = I_0\left\{\exp\left[\alpha\left(|V| - IR\right)\right] - 1\right\} \quad (1)$$

where I_0>0 represents the diode saturation current, α>0 a constant, and $R \geq 0$ a series resistance. $|V|$ is the absolute value of V. The solution of Eq.(1) is given by:

$$I = \left(\alpha R\right)^{-1} W\left\{\alpha I_0 R \exp\left[\alpha\left(|V| + I_0 R\right)\right]\right\} - I_0 \quad (2)$$

where *W* is the Lambert function. Expression (2) can explain both the linear (HBD) and exponential (SBD) behavior (Fig.2): large currents are associated with small α values. The correlation among the model parameters was investigated and a strong correlation between *R* and I_0 was found. Assuming that I_0 is proportional to the area of the narrowest section of the filamentary path ($\sim r^2$), it is possible to demonstrate that *R* is consistent with a Maxwellian resistance ($R \sim 1/r$ with *r* the radius of the constriction) [7] (see Fig.3).

References

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Figures

Fig. 1 – Experimental (thick solid lines) and fitting (thin solid lines) results using the diode-like model for post-BD conduction in $HoTiO_x$.
Fig. 2 – I_0 vs α correlation for the diode-like model.
Fig. 3 – R vs $1/I_0^{-1/2}$ correlation for the diode-like model.

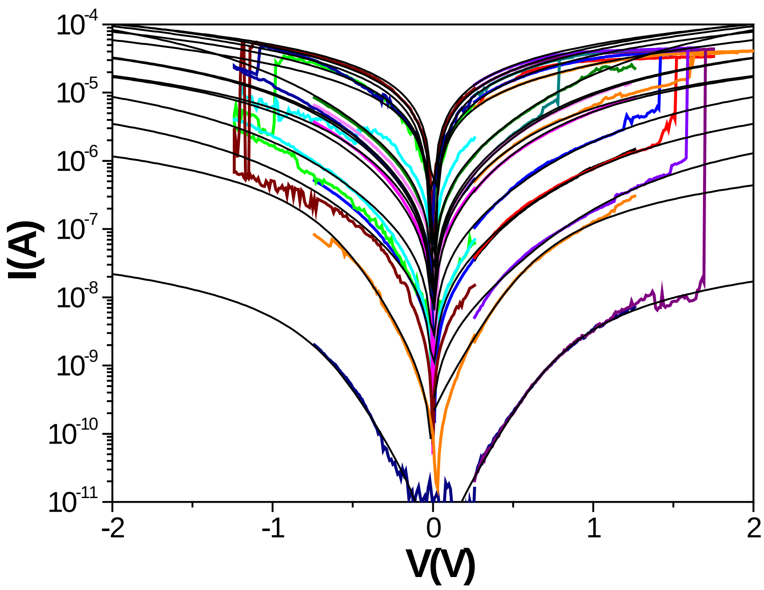

Figure 1

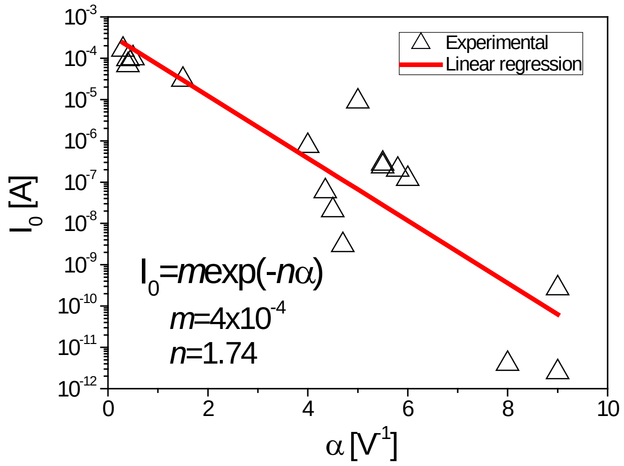

Figure 2

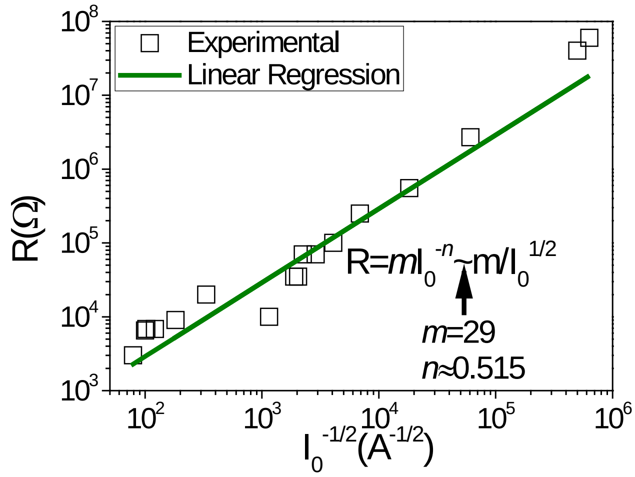

Figure 3