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Thermally induced effects on the injection and retention of electrical charges in SiO₂ layers containing silver nanoparticles

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Introduction

Under electrical stress, dielectric materials can accumulate electrical charges. This may even lead to a breakdown, *i.e.* to a system failure^[1,2]. To prevent the harmful consequences of this phenomenon, charge trapping by metallic, silver nanoparticles (AgNPs) has been considered^[3]. Even though the space charge build-up mitigation was demonstrated, the underlying mechanisms remain poorly described. To identify the AgNPs influence, their response needs to be probed at relevant scale, *i.e.* at the nanoscale. Thus, our overall objective is to determine the impact of AgNPs on the charge injection and retention in thin dielectric layers.

The considered structures consist of nanostructured thin SiO₂ layers; a bare SiO₂ layer and two SiO₂ layers containing a 2D-plan of AgNPs of 20 nm of size, located at 7 nm and 21 nm from the free surface. The structuration of the dielectric layers is achieved in a hybrid plasma process^[4].

A Bruker multimode 8 apparatus, equipped with a controlled environment cell, is used to probe the surface potential in Amplitude Modulation Kelvin Probe Force Microscopy (AM-KPFM) with 50 nm lift. Charge injection and surface potential measurements are performed using a PtIr-coated Si AFM tip. The injection and KPFM measurement are done at temperatures varying from 20°C to 140°C with a step of 30°C.

Results and Discussion

First of all, one can notice that both carriers, electrons and holes, present the same behavior for charge distribution (lateral spreading and increase of the amount of injected charge with the applied bias) and decay dynamics. As far as the injection is concerned, the AgNPs close to the free surface (*i.e.* at 7 nm), induce an increase of the amount of injected charge mainly due to enhanced lateral spreading compared to the bare SiO₂ or to the layer with AgNPs embedded far from the surface (*i.e.* at 20 nm). The temperature increase influences in different ways the charging process. Indeed, for the bare SiO₂ or for the SiO₂ layer with AgNPs far from the surface, the lateral spreading and the amount of injected charge increase in the temperature range from 20°C to 80°C and then decrease for higher temperatures. When the AgNPs are embedded close to the free surface, the lateral

spreading and the amount of charges increase slowly with the temperature in the whole range.

For each temperature the bare SiO₂ layer presents good charge retention with a constant lateral spreading and a slow release of the charge with time. For the nanostructured layers the charge decay presents different behavior. The lateral charge spreading is increased while the amount of charge is decreased with time. The evolution is faster when the AgNPs are situated close to surface. It means that the charge decay follows a volume-type mechanism for the bare SiO₂ and a coupled lateral and volume-type mechanism in presence of AgNPs.

Conclusions

It is found in this work that during charge injection at low temperature, the AgNPs located close to the surface act as charge traps. For temperatures higher than 80°C, the amount of injected charge is higher for the bare SiO₂ or for the SiO₂ layer with AgNPs situated far from the surface. The temperature increase induces more important charge decay when the AgNPs are embedded close to surface.

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