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Experimental Study of the Soft Breakdown I-V Characteristics in Ultrathin SiO_2 Layers

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In this work the soft breakdown failure mode in ultrathin (<5nm) SiO_2 layers is examined. Current-voltage measurements were performed on samples with different gate areas, oxide thicknesses, substrate types and illumination levels. The observed astounding matching between some of these characteristics lead us to propose that the current flow in this regime is controlled by the lateral dimensions of the soft breakdown spot as it occurs in a point contact configuration.

1.Introduction

The application of a high-field stress to a gate oxide thinner than 5 nm in a MOS structure can originate the appearing of a failure conduction mode known as soft breakdown (SBD). The leakage current in this regime exceeds by several orders of magnitude the direct tunnel component in a fresh sample but is well below the catastrophic breakdown (BD) current level. Several conduction models have been proposed mainly based on tunneling [1,2] and hopping [3] mechanisms and therefore addressing the conduction problem only to the oxide layer. Nevertheless, a systematic experimental approach reveals essential features of the I-V characteristics that can not be consistently explained by the existing models. Our results indicate that the effect of the atomic-scale dimensions of the SBD conduction channels must not be overlooked if a modelization of this regime is intended. Moreover, we suggest that the SBD spot shows effects similar to that in a Sharvin-type point contact [4].

2.Experimental results and discussion

The devices are conventional polysilicon-gate MOS capacitors with gate oxide thickness ranging from 3 to 4.3 nm, area of 10^{-5} cm^2 fabricated on P and N type (100) Si substrates. Negative and positive voltages were applied for the P and N samples respectively. Fig. 1 shows the typical evolution of the gate voltage under the application of a constant current stress. The appearing of sucessive SBD spots is detected by the small voltage drops (events) and finally, the BD regime is identified in the last part of the trace. The associated I-V characteristics to each regime are shown in Fig. 2. SILC (Stress Induced Leakage Current) mode can not be seen in Fig. 1 since at this current level the Fowler-Nordheim mechanism dominates. In this way, under constant voltage or current stress, a family of SBD I-V characteristics is obtained for the whole set of capacitors and in order to put in evidence the common features, we proceeded to select those exhibiting the better matching.

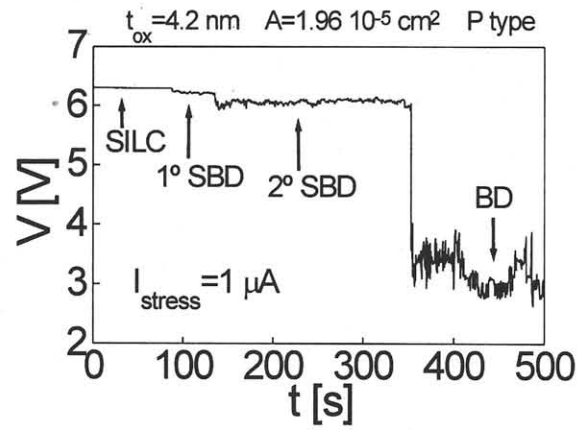

Fig. 1- Temporal evolution of the gate voltage under a constant current stressing.

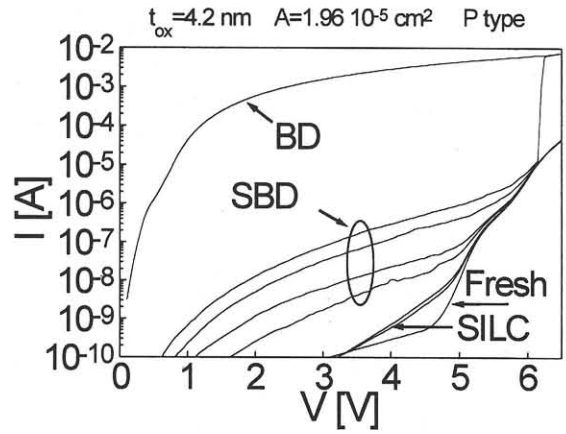

Fig. 2- Typical stages observed in the I-V characteristic of a sample as the degradation proceeds.

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Fig. 3 shows the fresh and SBD I-V characteristics measured after the detection of the first two events. It is clearly seen that SBD does not depend on the gate area neither on the oxide thickness. The first point indicates that we are dealing with a local area phenomenon while the second seems to rule out, due to the exponential dependence of tunneling on the oxide thickness, an explanation based on simple trapezoidal-triangular potential barriers [1,2]. Fig. 4 illustrates the dependence of the fresh and SBD I-V characteristics on the injecting electrode. In the case of P type substrate the injection is performed from the polysilicon gate and for the N type from the Si substrate. Again, the curves corresponding to the first and second events perfectly match, denoting that the shape of the SBD I-V does not depend on the particular characteristics of the injecting interface.

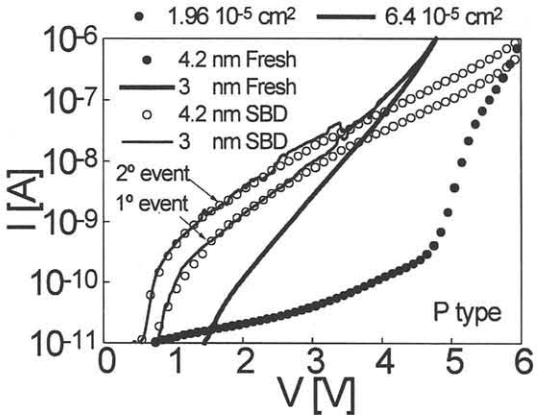

Fig. 3- Area and thickness dependence of the fresh and SBD I-V characteristics.

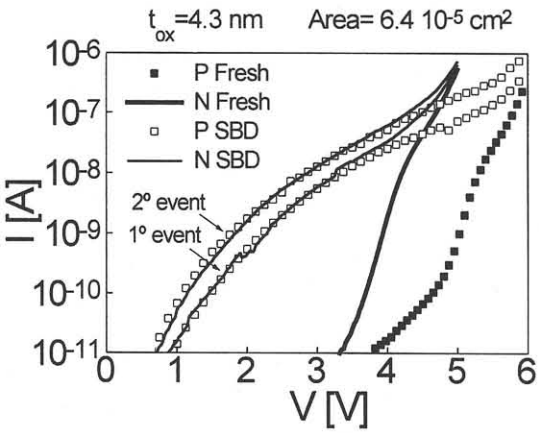

Fig. 4- Substrate and polarity dependence of the fresh and SBD I-V characteristics.

It is worth noticing that the voltage shift existing between the fresh characteristics, due mainly to the potential drop at the P type substrate, is not present in the corresponding SBD curves. This possibly means that, in all the cases, the applied voltage is largely supported by the SBD conduction path. Moreover, since the SBD current is voltage instead of field dependent, the voltage drops could be localized at the two ends of the constriction, as frequently considered in a point contact configuration [5].

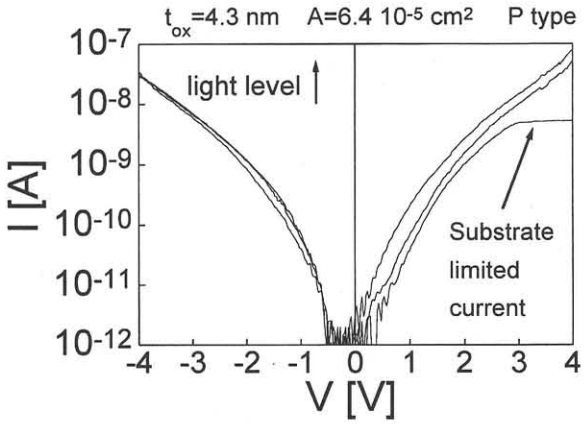

Fig. 5- SBD I-V characteristic under different illumination levels. The lower curve corresponds to a dark measurement.

Fig. 5 shows that the current level through one SBD spot depends on the disposable charge at the injecting contact. The I-V characteristic is totally symmetric with the polarity at dark and is dependent on the illumination level only when the sample is in inversion. In this regard, we believe that an "energy funneling effect" is taking place in some sense analogous to the well-known spreading resistance effect but in energy [6]. Besides, this striking symmetry makes the models based on unilateral oxide damaging or thinning [1,2] very questionable. Finally, variable range hopping has been also proposed as the conduction mechanism [3]. Although it can not be ruled out, it is difficult to think that at this thickness level (3 nm in Fig. 3) a description based on activation energies and tunneling distances turn out to be so insensitive to the oxide inner conditions.

3. Conclusion

Although many questions concerning SBD conduction remain unsolved, we have shown experimental results compatible with the behavior expected for a point contact configuration and that can not be satisfactorily explained by the existing models.

References

1. S. Lee, B.Cho, J. Kim and S. Choi, IEDM 1994, p. 605.
2. T. Yoshida, S. Miyazaki and M. Hirose, SSDM 1996, p.539.
3. K. Okada and K. Taniguchi, Applied Physic Letters **70**, 351 (1997).
4. Y. Sharvin, Sov. Phys. JETP **21**, 655 (1965).
5. J. Pascual, J. Torres and J. Sáenz, Phys. Review B **55**, 16029 (1997).
6. R. Landauer, Phys. B -Condensed Matter **68**, 217 (1987).