MEASUREMENT AND MODELING OF A NEW WIDTH DEPENDENCE OF NMOSFET DEGRADATION

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Abstract — NMOS transistors with widths between 1.2μm and 10μm and length of 0.8μm have been stressed for up to 5000 hours. Investigating the threshold voltage shift a new width dependence of degradation has been measured, analysed and modeled by a simple theory. Because of the increasing degradation of NMOSFETs with decreasing width this effect will be more and more important for small-channel LOCOS transistors.

I. INTRODUCTION

One of the most conspicuous parameters regarding the degradation of MOSFETs is the threshold voltage shift. Many papers discussed the degradation of MOSFETs by describing the threshold voltage shift [1] [2] [3]. These investigations show that there are two causes for threshold voltage shift. The generation of interface states as well as the occupation of oxide states cause a change of charges in and at the gate oxide leading to a threshold voltage shift. Both of these degradation mechanisms are caused by hot carriers. Thus the influence of these effects on the degradation of MOSFETs depends on the hot carrier distribution and thus on the electrical field.

Scaling the devices down to submicrons requires a decrease of the voltages in order to limit the degradation of MOSFETs and other hot carrier effects. Up to now the voltage and length dependence of MOSFET degradation has been analysed. However, the width dependence of MOSFET degradation has never been analysed so far.

In this letter the measured width dependence of the threshold voltage shift is represented and described by a simple theory.

II. MOSFET FABRICATION AND TECHNOLOGY

Figure 1 shows a LOCOS (local oxidation of silicon)-MOSFET. Its cross-section (A-B) is displayed in figure 2. The LOCOS nitride serves as an oxidation mask. The LOCOS poly is used to reduce shearing forces [4]. Pay attention to the wedge-shaped runner of the field oxide under the nitride, the so called bird's beak.

After the LOCOS oxidation of the field oxide LOCOS nitride, LOCOS poly and thin oxide are etched away (dashed line in figure 2). However, a rest of the bird's beak stays

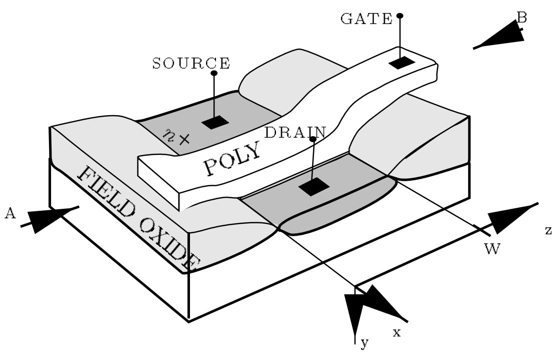

Figure 1: Typical structure of a MOSFET device.

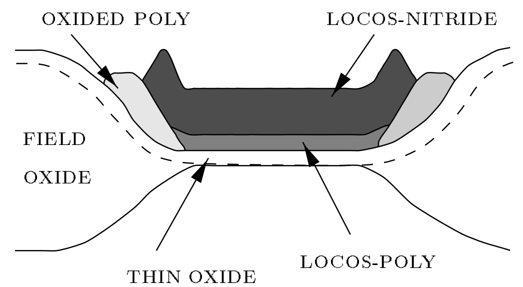

Figure 2: Cross-section from A to B (fig. 1) after the LOCOS Oxidation.

behind. Thus the channel of the MOSFET is covered by two types of oxides: the high-quality gate oxide and the low-quality field oxide (figure 3).

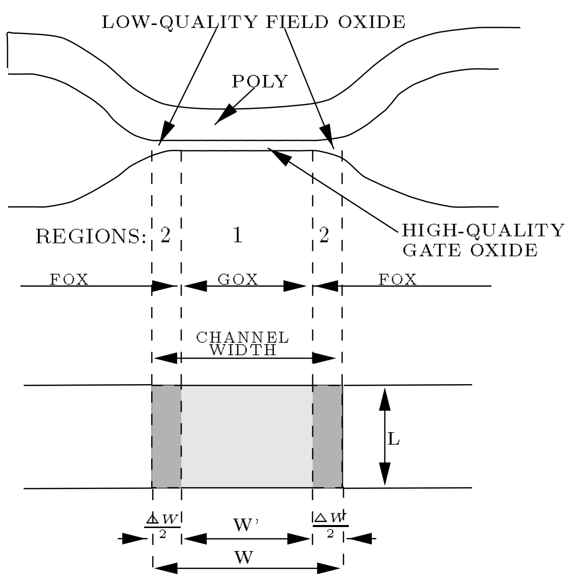

Figure 3: Cross-section from A to B (fig. 1) through the final transistor and top view illustrating the edge regions (regions 2) and the central region (region1).

III. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 4 shows the stress time dependence of the threshold voltage shift. The n-channel MOSFETs have been stressed by a drain voltage $V_{DS} = 7V$ and a gate voltage $V_{GS} = 3V$ for up to 5000 hours (nearly 7 months). The threshold voltages have been determined in the linear region ($V_{DS} = 0.1V$). Figure 3 shows the threshold voltage shift of transistors differing just by different widths.

Contrary to any expectations one can observe a strong width dependence of the degradation. In the following paragraph the reason of this width dependence will be explained.

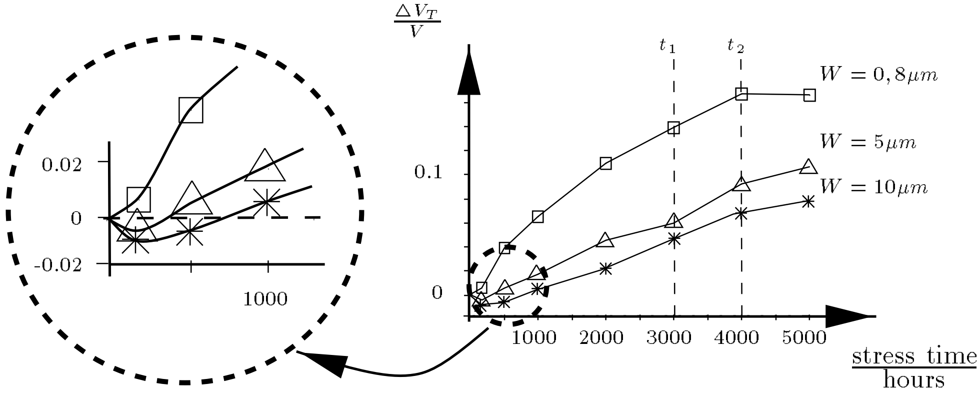

Figure 4: Stress time dependence of threshold voltage shift.

A negative threshold voltage shift is caused by additional positive charges in or at the gate oxide whereas a positive threshold voltage shift is caused by additional negative charges. More detailed investigations result in an initial negative threshold voltage shift which turns into a positive shift after some hundred hours (figure 4). Obviously the two mechanisms of changing the oxide charge lead to threshold voltage shifts with different signs. The interface states of a turned-on NMOS transistor are always negative or neutral. So the measured positive threshold voltage shift must be caused by generation of interface states and the initial negative threshold voltage shift by occupation of oxide traps by hot holes. According to [5] both mechanisms can be modeled by exponential functions very well.

As seen in figure 4 the main width dependence is observed in connection with positive threshold voltage shifts. Thus the width dependence seems to be caused by different oxide types leading to different generation rates of interface states.

IV. THEORY

According to section II two oxide types with different qualities cover the channel. Because of the different oxide qualities in the edge regions (region 2) a stronger degradation by broken Si-O-bonds and generated interface states than in the central region (region 1) can be observed.

$\triangle N_{it}^{FOx}$ describes the average change of interface states per unit area in the edge regions. $\triangle N_{it}^{GOx}$ stands for the average change of interface states per unit area in the central region. Thus the total average change of interface states per unit area is:

$$\triangle V_T \propto \triangle N_{it} = \frac{\triangle W}{W} \triangle N_{it}^{FOx} + \frac{W'}{W} \triangle N_{it}^{GOx} \quad (1)$$

$$= \frac{\triangle W}{W} \triangle N_{it}^{FOx} + \frac{W - \triangle W}{W} \triangle N_{it}^{GOx} \quad (2)$$

$$= \triangle N_{it}^{GOx} + \frac{\triangle W}{W} \left(\triangle N_{it}^{FOx} - \triangle N_{it}^{GOx} \right) \quad (3)$$

Considering fixed stress times t_1 and t_2 for example (figure 4) $\triangle N_{it}^{FOx}$ and $\triangle N_{it}^{GOx}$ are constant. Assuming the length of the bird's beak remains constant for the same technology $\triangle W$ also remains constant and does not change with changing W. In this case (1) and

(3) provide a 1/W-dependence. The plot of the threshold voltage shift against the width for several stress times shows a excellent agreement with the 1/W-dependence (figure 5).

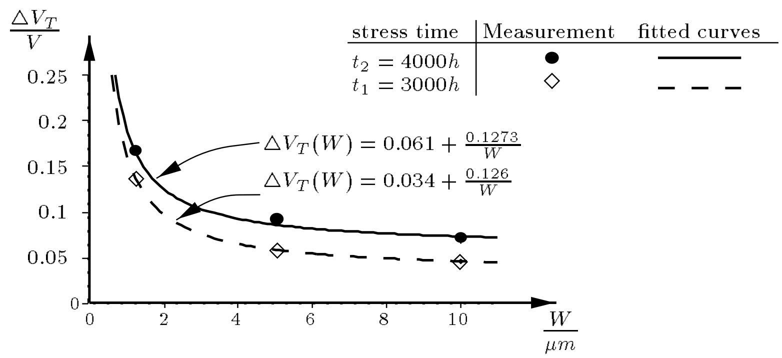

Figure 5: 1/W-dependence of voltage shifts for fixed stress times t_1 and t_2 (see figure 4)

V. CONCLUSION

NMOS transistors with widths between 1.2 μm and 10 μm have been stressed and their threshold voltage shifts have been measured and analysed. A width dependent threshold voltage shift of up to 180 mV has been observed for this measured CMOS technology. Scaling down the transistor width from 10μm to 1.2μm the degradation increases by a factor of three. An extrapolation to widths of less than 1 μm shows, that it is important to reduce the bird's beak and to improve the quality of the field oxide.

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