Efficient 2D approximation for Layout-dependent Relaxation of Etch Stop Liner Stress due to Contact Holes

Rainer Liebmann, Muhammad Nawaz, Karl Heinz Bach
TCAD Simulation, Infineon Technologies AG,
D-81726 Munich, Germany
E-mail : rainer.liebmann@infineon.com

***Abstract* – Stress engineering to enhance device performane has become widespread. One way is to apply an etch stop liner with intrinsic stress, which causes stress and thus changed mobility in the channel of the device. Etching contact holes reduces this stress. Investigating the dependence of the channel stress on the position of the contact holes is a genuine 3D problem. Here we describe a method to determine the width-averaged channel stress by a much more efficient 2D simulation.**

Keywords: liner stress; layout dependence; contact holes

I. INTRODUCTION

Many publications on stress engineering deal with its layout dependencies, but to our knowledge only one [1] mentions the effect of contact holes etched through a stressed etch stop liner (ESL). We present here the first systematic study on the dependence of channel stress on the position of contact holes (CAs). Verified by 3D process simulation for different geometries we show how the width-averaged stress in the channel can be obtained by 2D simulation. This method can be integrated easily in the productive TCAD device simulation flow, with the piezo-resistance coefficients used to determine the change in mobility.

II. 3D STRESS SIMULATION

As an example of the 3D case Fig.1 shows a device with contact holes etched through the stressed ESL down to bulk silicon, generated with TAURUS process [2]. In both length and width direction reflecting boundaries are assumed, so we discuss here only periodic structures characterized by a gate pitch and a CA pitch.

Fig.2 shows the (quite small) variation of the stress Sxx long a cutline 5nm below the Si surface in the width (here z) direction at the channel center, which is cosine-shaped for not too large CA pitch. The same is true for the other stress components. Compared to the value without holes Sxx is reduced most at the z values of the CA centers, and the least in the middle between them, as expected.

In this range of CA pitches the width-averaged mean stresses are $\langle S_{ii} \rangle = (S_{ii}\text{-min} + S_{ii}\text{-max})/2$. As long as the variation of stresses along width is not too large, for predicting device performance only these mean values are needed.

III. 2D STRESS APPROXIMATION

The basic idea to determine these mean stresses by 2D simulation [3] is illustrated in Fig.3. Instead of etching circular holes vertically into the ESL, holes are etched horizontally into the liner at the same distance from the gate. Their shape is obtained by simple conformal compression of the original horizontal shape of the hole into a vertical shape <u>preserving the volume cut out from the liner</u>. In the special case of circular holes with radius r this leads to elliptical holes with horizontal semiaxis a = r and vertical semiaxis b with

$$b \,/\, \text{ESL-thickness} = r \,/\, \text{CA-pitch} .$$

The idea is that if the same volume is cut from the liner at the same distance from the gate, the averaged stress components should be very similar. This is verified by comparing results from this 2D approximation with full 3D simulation in the next section.

IV. COMPARISON 3D VS. 2D APPROXIMATION

Fig. 4 shows the 3D results for the width-averaged mean longitudinal stress <Sxx> at the channel center 5nm below the Si surface for gate pitches of 0.26, 0.72, and 1.26 µm.

Points belonging to the same gate pitch are connected by lines. For each gate pitch there are three curves corres-ponding to CA pitch values of 140, 190, and 240 nm marked a, b, and c. The dots on the left side mark the stress values for the gate pitches without CAs. For the two larger gate pitches <Sxx> first decreases with decreasing distance gate-CA, but then increases again. Altogether Fig. 4 shows the <Sxx> reduction to depend strongly on the three layout parameters considered, which has to be taken into account in liner stress engineering.

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The same combination of layout parameters was used to calculate <Sxx> with the 2D approximation. As the results look quite similar, for better comparison in Fig.5 the ratios of the 2D to 3D results are plotted. The deviations are in the range of $(5 \pm 5)\%$. This holds even for the smallest distance gate-CA, where the vertical part of the liner is partially etched in 3D, which was taken into account by modifying the part of the transformed etched shape below the vertical part of the liner. Simple rescaling by 5% reduces the deviations to < 5%, and in addition they are quite smooth.

Fig.6 shows the ratio of the averaged vertical stresses <Syy> analogous to Fig.5. Here the error of the 2D approximation is even smaller, less than 1% for gate-CA distances ≥ 100 nm.

V. 2D RESULTS FOR POLY PITCH VARIATION

After this validation of the 2D approximation we investigated the combined effect of contact hole etching and removal of the nitride spacer on the reduction of the stress at the channel center as a function of the poly pitch. Contact hole position was in the middle between neighboring polys, contrary to the case discussed before. The contact hole pitch along the poly was 190 nm, corresponding to similar values for hole diameter and hole distance. For large poly pitch the contact holes are also far from the poly, and have little effect on the channel stress. With decreasing poly pitch the contact holes get closer, and therefore reduce stress more.

For the horizontal stress Sxx this can be seen in Fig.7. This is true for both presence or absence of a nitride spacer. Removal of that spacer brings the stressed liner closer to the channel, and therefore, increases stress under otherwise identical conditions. Independent of details Fig.7 shows that the reduction of stress from isolated to nested structures is quite large (known before), and that contact holes produce a significant further reduction when the contact hole pitch is small.

The analogous plot for the vertical stress <Syy> in Fig.8 shows a weaker dependence on poly pitch and contact hole etching (note the shifted Syy scale). This can be understood, as the vertical stress in the channel of short devices is caused mainly by the vertical parts of the stressed liner on the sides of the poly gate; and this part is quite independent of the poly pitch as long as vertical liners from neighboring devices don't touch. Also contact holes have only a small influence, as long as they don't cut into the vertical liner parts.

With our 2D approximation it is also straightforeward to vary the contact hole pitch. The change of stress <Sxx> with contact hole pitch turns out to be almost linear in contact hole density, which means that stress changes from different holes can be superimposed with reasonable accuracy.

VI. CONCLUSION

Our 2D approximation for the strong layout-dependent stress reduction by contact holes reproduces the full 3D results very closely. Considering the uncertainties in the piezoresistance coefficients for inversion layers, its accuracy is fully sufficient for predicting layout dependencies. The main advantages of our 2D method are (1) it can be integrated into the standard 2D TCAD process/device simulation flow, and (2) it enables using much larger simulation regions. Thus, long-range stress effects such as that from nonuniform dummy poly lines will be investigated.

REFERENCES

[1] S.M.Cea et al., IEDM Tech.Dig. pp.963-966, Dec. 2004
[2] tool from Synopsys
[3] TSuprem4, also from Synopsys

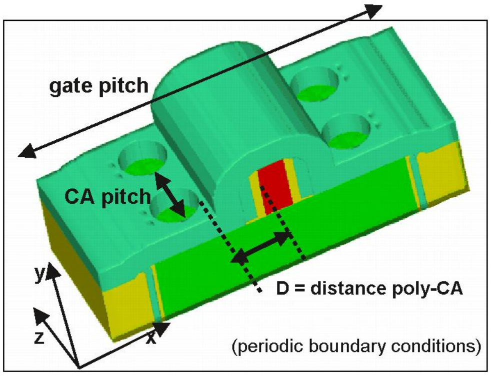

Fig.1: An example 3D structure of a device with contact holes etched through an etch stop liner

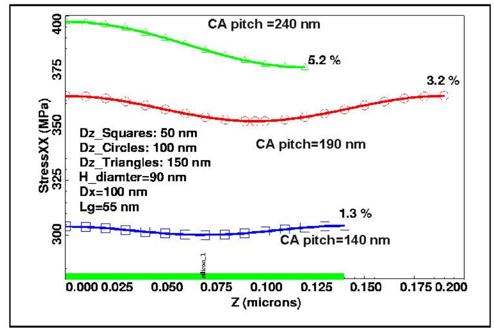

Fig.2: Longitudinal stress Sxx at the channel center (x=0) in width (=z) direction for CA pitches of 140, 190, and 240 nm and CA diameter of 90nm.

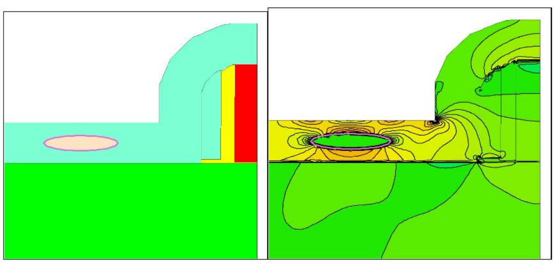

Fig.3: A properly scaled elliptical hole is etched horizontally into the ESL liner. Left: structure, right: contours of constant average stress <Sxx>

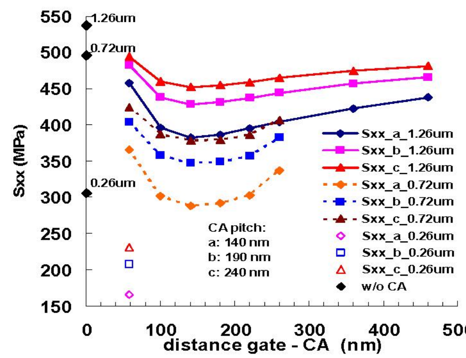

Fig.4: Average stress <Sxx> at the channel center 5nm below the Si surface as a function of distance gate-CA. Parameters are gate pitch and CA pitch.

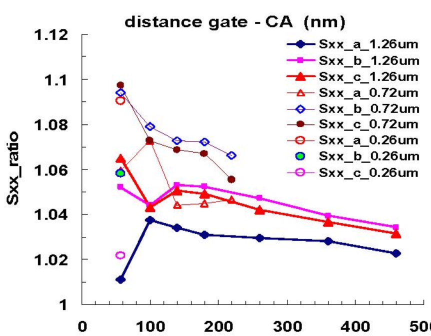

Fig.5: ratio of <Sxx> determined by 2D respective 3D stress simulation for the parameters of Fig.4

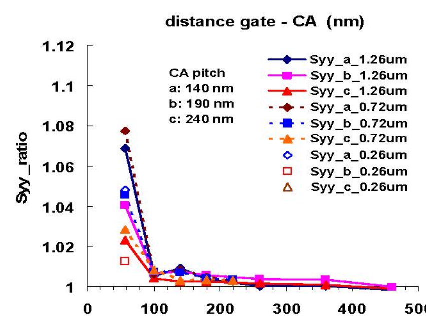

Fig.6: ratio of <Syy> determined by 2D respective 3D stress simulation for the parameters of Fig.4

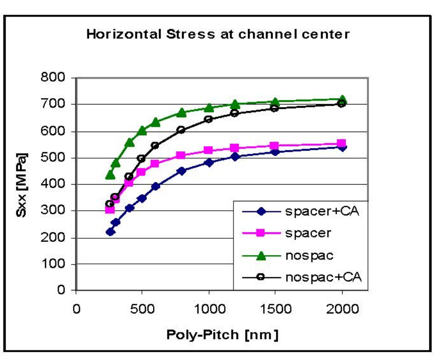

Fig.7: <Sxx> variation with Poly pitch without / with contact holes in middle between gates for presence or absence of nitride spacer

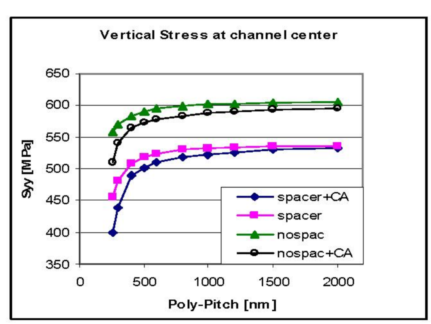

Fig.8: <Syy> variation with Poly pitch for same cases as in Fig.7