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Optimization of a Recessed LOCOS using a tuned 2-D process simulator

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Abstract

The application of the conventional LOCOS technique (LOCal Oxidation of Silicon) to grow oxide structures for IC device isolation is no longer effective below 0.5 μm. In order to support the optimization of an alternative isolation technique, adequate simulations tools are required. In this work we describe an accurate tuning of 2-D simulation program, which uses a viscoelastic model for the oxidation of silicon, and its application to the optimization Recessed LOCOS isolation.

1. Introduction

LOCOS is the most common and simple isolation technology which has been used successfully over the last 20 years. There are several reasons for this success: the reduced number of materials involved and the use of simple and well controlled process steps (oxide growth, nitride deposition and nitride etch) are the most important ones ensuring a high manufacturability. Below the 0.5 μm limit, the lack of planarity, the lateral encroachment and the field oxide thinning prevent the use of this isolation scheme and force to the development of other structures. Due to the manufacturing process complexity and costs, simulation tools have become more and more necessary to save time and money. The aim of this work has been the calibration of a 2-D process simulation tool (*ATHENA*) [1] through the fitting of LOCOS profiles, and the application of the tuned program to the geometrical characterization and optimization of a different isolation scheme, a Recessed LOCOS structure.

2. Tuning of coefficients

Several LOCOS isolation samples have been processed by growing a 150 Å padoxide followed by a nitride layer deposition of various thicknesses (from 900 Å to 2000 Å). After etching, a wet field oxidation has been performed at different temperatures (from 920°C to 1100°C). All samples have been submitted to SEM and TEM analysis. Oxidation was simulated using the stress-dependent oxidation parameters extracted from [2]. The accurate fitting work which has been developed to produce this set is in a good agreement with previous fitting works [3], [4]. Those parameters are the activation volumes of the stress-dependent diffusivity of the oxidant in the silicon dioxide (V_d), the stress-dependent reaction rate (V_k) and the stress dependent oxide viscosity (V_c) (see table 1). Furthermore, other two important parameters are the nitride and the oxide viscosities. Their proper values have been extracted through a careful fitting of the experimental profiles (see as two examples fig. 4, 5). The fitted values are reported in table 1. As a result, the dependence of the oxide viscosity stress-independent factor shows an exponential behaviour with an activation energy of 2.3 eV. This value might be correlated with the binding energy of adjacent oxide layers. At high temperature (1000°C, 1100°C) a good agreement between the experimental photos and the simulated profiles has been achieved, while at low temperature (920°C) the result is only partially satisfactory. For this process condition the viscous equation implemented in the simulation program reaches its limit and a non-linear viscoelastic description of the nitride behaviour, similar to the oxide, is required [2].

3. Recessed LOCOS optimization

The set of coefficients defined with the previous fitting allows us to elaborate a Design Of Experiment (DOE) on the Recessed LOCOS. An Empirical Model Building program, *ULYSSES* [5], has been used to perform the design varying five process factors (temperature, nitride and padoxide thicknesses, etch depth and etch angle): the extracted responses (fig. 1) allow a complete morphological characterization of the isolation profile. A quadratic design has been chosen and the interpolating polynomial of the responses presents satisfactory correlation coefficients. By means of contour and pareto plots of the responses a clear understanding of the most important process factors effect has been obtained. Field oxide temperature, nitride thickness and etch depth are the most relevant ones (fig. 2). The Recessed LOCOS optimized condition has been achieved by minimizing the bird's beak under the nitride mask (*l*), the height of the bird's beak head (*h1*) and the difference between the bird's beak head and the field oxide surface (*diff*) (see fig. 1). The results obtained show an unexpected independence of the etch angle in the silicon on the responses (fig. 3). Besides, the optimization algorithm suggested a high oxidation temperature, two different conditions for the ratio of the nitride and padoxide thicknesses in the range $[\frac{7}{1} \div \frac{9}{1}]$, and an etch depth in the silicon substrate. One of the particular morphological conditions proposed has been processed and a satisfactory agreement with the simulation has been obtained (see fig. 6).

4. Conclusion

The physical parameters of the oxidation with a nitride mask have been successfully fitted; the tuned process simulator has been used with a DOE program which has allowed to optimize a Recessed LOCOS isolation technology, with a strong reduction of development time and costs. Ultra large scale integration requires new isolation schemes which introduce a greater complexity of development and manufacturing. Therefore, simulation tools such as EMB, RSM, DOE [5] and calibrated process simulators becomes more and more useful in development activities.

5. Acknowledgments

We are grateful for the SEM pictures of the LOCOS structures provided by *LETI* laboratory in Grenoble and for TEM analysis provided by *IMETEM* in Catania.

References

[1] Silvaco International *"ATHENA 2D Process Simulation Framework User's Guide"* Santa Clara, California, mar 1994

[2] V. Senez, D. Collard, P. Ferreira, B. Baccus *"Simulation of advanced field isolation using calibrated viscoelastic stress analysis"* IEDM, pp. 881-884, 1994

[3] C.S. Rafferty *"Stress effects in silicon oxidation: simulation and experiments"* Ph. D. Thesis, pp. 184-186, Stanford University, dec 1989

[4] P. Sutardja, W.G. Oldham IEEE Trans. Electron Devices, vol. ED-36, pp. 2415-2421, nov 1989

[5] *"ULYSSES User's Guide"* IMEC - SGS-Thomson, jun 1993

equation	parameter	range
$D_{diff}(T,P) = D^0_{diff} e^{-\frac{E_d}{kT}} e^{-\frac{PV_d}{kT}}$	V_d	75
$k_s(T,\sigma_{nn}) = k_s^0 e^{-\frac{E_k}{kT}} e^{\frac{\sigma_{nn}V_k}{kT}}$	V_k	15
$\mu_{ox}(T,\sigma_{ox}) = \mu^0_{ox} e^{\frac{E^{\mu}_{ox}}{kT}} \frac{\frac{\sigma_{ox}V_c^{ox}}{2kT}}{\sinh\left(\frac{\sigma_{ox}V_c^{ox}}{2kT}\right)}$	V_c^{ox} $\mu_{ox}(T,\sigma_{ox})$	[300-1000] $[4.0 - 72]\cdot 10^{13}$
$\mu_{ni}(T) = \mu^0_{ni} e^{\frac{E^{\mu}_{ni}}{kT}}$	$\mu_{ni}(T)$	$[1.2 - 2200]\cdot 10^{12}$

D_{diff}	diffusivity coefficient ($\mu m/min^2$)	μ	viscosity (poises)
P	hydrostatic pressure ($dyne/cm^2$)	E	activation energy (eV)
σ_{nn}	normal stress ($dyne/cm^2$)	V	activation volume ($\AA^3$)
k_s	reaction rate ($\mu m/min$)		

Table 1: The equation and the parameters of the oxidation model

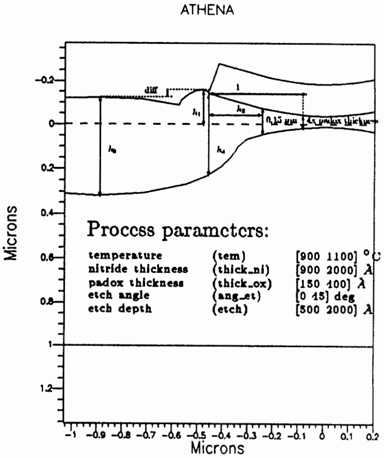

Fig. 1: Geometrical parameters of a Recessed LOCOS

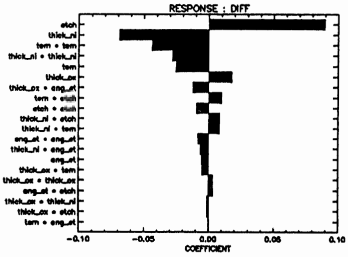

Fig. 2: Pareto plot of 'diff' response (difference between the head and the field oxide)

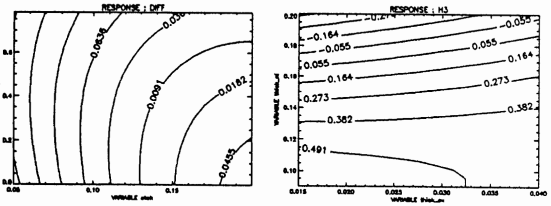

Fig. 3: Contour plot of some of the most relevant factors (ang_et: etch angle in silicon substrate, etch: depth etch, thick_ni: nitride thickness, thick_ox: padoxide thickness)

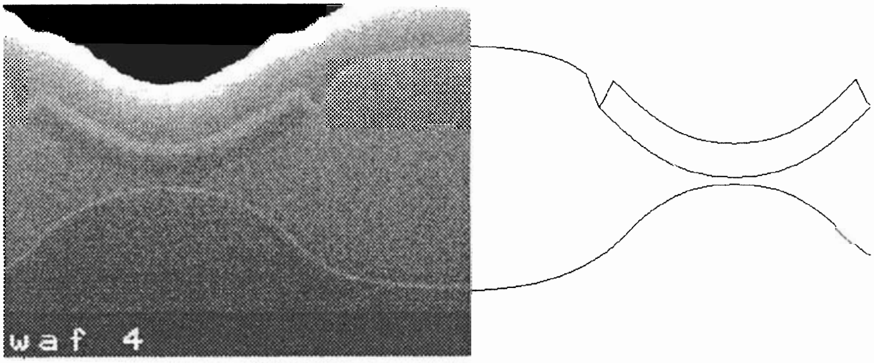

Fig. 4: SEM photo vs simulated profile (temperature 1100 °C, nitride thickness 900 Å)

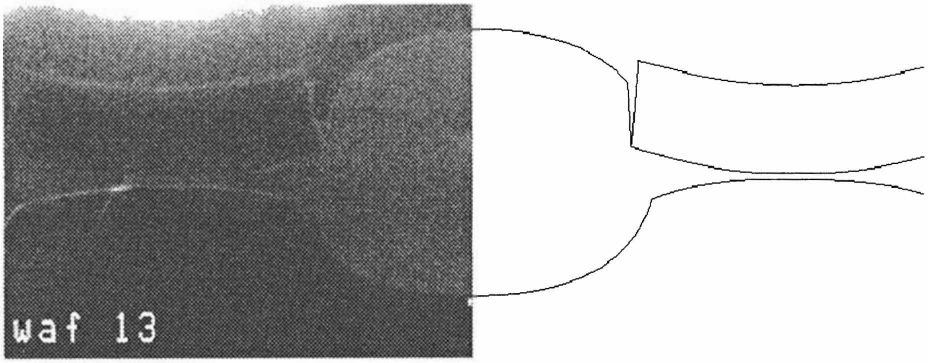

Fig. 5: SEM photo vs simulated profile (temperature 920 °C, nitride thickness 2000 Å)

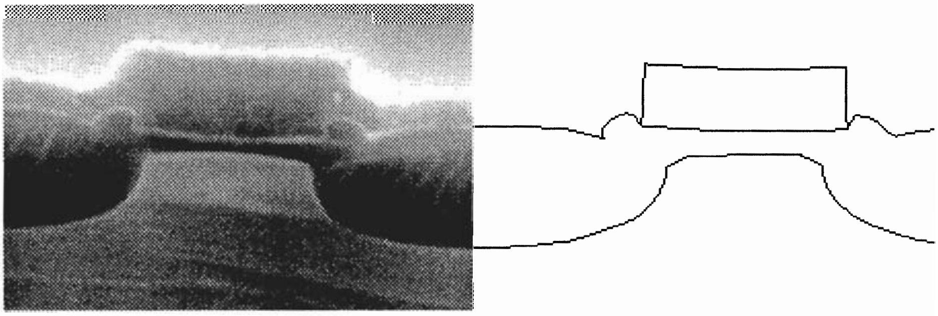

Fig. 6: Recessed SEM photo vs simulated profile