

# INVESTIGATION OF LOCOS PROCESS USING NITROGEN IMPLANTATION

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## ABSTRACT

A localized oxidation of silicon (LOCOS) process was investigated using nitrogen ion implantation. The doses of  $2 \times 10^{12}$ ,  $2 \times 10^{13}$ ,  $2 \times 10^{14}$ , and  $1 \times 10^{15}$  atoms/cm<sup>2</sup> were implanted through a photoresist mask using the Varian/Extrion 40-100 ion implanter. The results show the initial formation of a LOCOS oxidation. The localized image faded on extended oxidation which indicates the implanted region did not adequately inhibit the diffusion of oxygen.

## INTRODUCTION

Localized Oxidation of Silicon (LOCOS) processes are used throughout the VLSI industry [1]. This process involves exposing silicon and silicon nitride to an oxidizing environment. As shown in Figure 1 this process produces silicon dioxide regions on the wafer through localized oxidation.

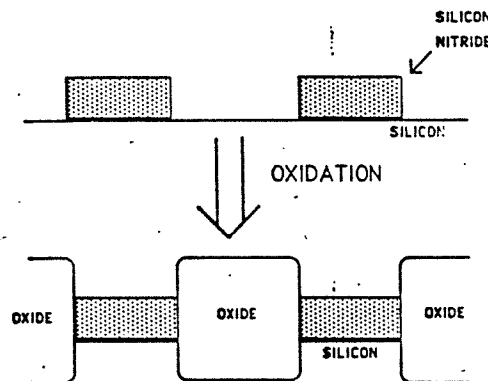


FIGURE 1: The LOCOS Process

Typical LOCOS processes in industry utilize a silicon nitride film that has been generated through low pressure chemical vapor deposition (LPCVD). The film is deposited uniformly on a wafer and then patterned through typical lithographic techniques. In conjunction with this nitride, the process requires a thin silicon dioxide film to underlie the LPCVD nitride. This pad oxide acts as an etch stop during the silicon nitride patterning process. A large etch selectivity is required between the silicon nitride and silicon dioxide films so the appropriate silicon nitride regions are totally consumed before the pad oxide is broken through. This ensures that the silicon wafer underlying the pad oxide is not damaged by the nitride etch.

The major disadvantage to this type of LOCOS process is the formation of the bird's beak feature[1]. This feature, shown in Figure 2, results from the accelerated oxidation around the pad oxide residing under the patterned nitride[2]. The increased oxidation in these regions is caused by a greater diffusivity of oxygen in the silicon dioxide film. The lateral growth can be minimized in this process by choosing the correct thicknesses for the silicon nitride and silicon dioxide films. The minimum growth obtained, however, can still represent a significant distance that the oxide extends under the silicon nitride region. The extension of the localized oxidation into these areas reduces the ultimate resolution of the process.

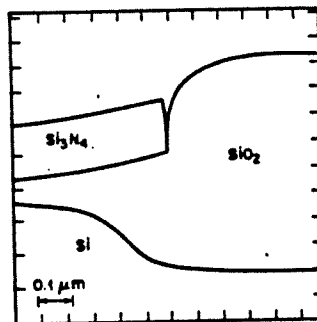


FIGURE 2: Bird's Beak

A different type of LOCOS process has been developed which reduces the bird's beak by four fold [1]. This process uses nitrogen implantation to create the silicon nitride regions in the wafer. As shown in Figure 3, the nitrogen is selectively placed in a wafer using a photoresist mask and implantation. Depending on the implant energy and the implant current the nitrogen is transformed into a silicon nitride material either immediately upon implant or during a post implant anneal step. Experiments have shown that low energy, high current implantation create the nitride layer in situ. The high energy, low current implantation require an anneal step to generate the nitride.

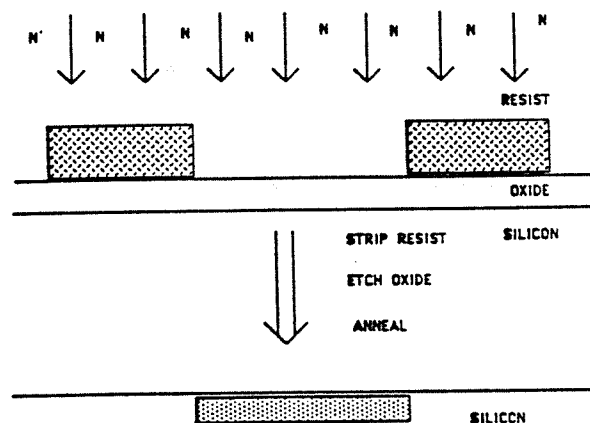


FIGURE 3: LOCOS THROUGH IMPLANTATION

Once the silicon nitride is formed the process behaves like the other LOCOS process. Exposing an implanted wafer to an oxidizing environment generates silicon dioxide in localized areas. The bird's beak is diminished because there is no pad oxide to act as a conduit for oxygen diffusion.

The emphasis of this study was to determine if a LOCOS process could be developed at RIT using its Varian 400-10 ion implanter. To develop the process the following parameters had to be determined: peak dose required to form silicon nitride, implant dose which provided the peak dose, projected range of the ions given specific implant energies, and the oxide thickness required to bring out the LOCOS effect.

The literature points out that a peak concentration of approximately  $5E21$  atoms/cm<sup>3</sup> is required to form a silicon nitride compound [1]. This number is slightly less than concentration required for stoichiometrically correct Si<sub>3</sub>N<sub>4</sub> as shown by the following derivation. This equation provides the concentration of Si<sub>3</sub>N<sub>4</sub> molecules:

$$[ \text{Si}_3\text{N}_4 ] = ( D * NA ) / \text{M.W.}$$

In this equation D is the density of silicon nitride (2.8 g/cm<sup>3</sup>), NA is Avogadro's number, and M.W. is the gram molecular weight of silicon nitride (140 g/mole). The concentration resulting from this calculation is  $1.2E22$  molecules/cm<sup>3</sup>. Remembering that there are four nitrogen atoms per molecule of Si<sub>3</sub>N<sub>4</sub> results in a nitrogen concentration of  $4.8E22$  atoms/cm<sup>3</sup>.

The nitrogen concentration of  $4.8E22$  atoms/cm<sup>3</sup> represents the peak concentration of the implanted profile. The implant dose required to obtain this concentration is obtained from the formula for peak concentration [3]

$$[ N ] = ( 0.4 * D_i ) / St$$

In this equation N is the peak nitrogen concentration, D<sub>i</sub> is the implant dose, and St is the straggle associated with the implant profile. The formula was rearranged to solve for the required implant dose (D<sub>i</sub>). The value for straggle used here, 0.1 microns, accounted for the implant energies used in this experiment. This number was obtained from Reference 1. The required implant dose for stoichiometrically correct Si<sub>3</sub>N<sub>4</sub> came out to  $1.2E18$  atoms/cm<sup>2</sup>.

The last process parameter concerning nitrogen implantation is the time required for the implantation. The implant time required to obtain the proper dose is given by the following formula:

$$t = ( D_i * A * q ) / I$$

In this equation t is time, D<sub>i</sub> is the implant dose, A is the implant area, q is  $1.6E19$  Coulombs, and I is the implant current.

## **EXPERIMENT**

The substrates used were <100> p-type silicon wafers. The ion implanter used was a Varian/Extrion 400-10. In the first experiment the wafers were prepared for implantation through the following process. They initially received an RCA clean followed by a dry oxidation (1100 C for 11.0 minutes) which grew a surface oxide 450 Angstrom thick. The wafers were then coated with KTI-820 positive resist and prebaked resulting in a film thickness of 1.2 um. The photoresist mask was generated by subsequent exposure via the ETM mask at 58 mJ/cm<sup>2</sup> using the Kasper Contact Aligner. The ETM mask contains several resolution charts and line space pairs. After exposure the RIT standard development process was performed. This process incorporated KTI-934 developer and a 140 C post bake.

At this point the wafers were ready for implantation. Two wafers were implanted with 2E12 atoms/cm<sup>2</sup> and 2E13 atoms/cm<sup>2</sup> using an implant energy of 30 KeV. The other two wafers were implanted with 2E14 atoms/cm<sup>2</sup> and 1E15 atoms/cm<sup>2</sup> using an implant energy of 60 KeV. After implantation the resist was stripped using an oxygen plasma asher. The wafers were then annealed in a nitrogen ambient at 1000 C for 30 minutes. After annealing the samples were oxidized at 1000 C for 1.0 hours in steam ambient. A post oxidation inspection was performed by both eye and optical microscope to determine if a localized oxidation was present. After inspection the wafers were submitted for a second oxidation using the same conditions but increasing the time to 2.0 hours. A second inspection was then performed.

The second experiment processed the wafers differently in order to bring the surface of the wafer closer to the implanted region. In this experiment the surface oxide was grown through wet oxidation at 1000 C for 12 minutes to provide a thickness of approximately 1500 Angstrom. The photoresist mask was patterned in the same manner. The implant dose for the wafers was boosted to 2E15 atoms/cm<sup>2</sup>. The post implant process also varied slightly from the first experiment. After the resist was stripped, the surface oxide was etched back using buffered HF to expose the silicon surface. The wafers then went through an RCA clean. The anneal step followed at 1000 C for 60 minutes in nitrogen ambient. The wafers were inspected visually and then oxidized at 1000 C for 15 minutes through wet oxidation. The samples were inspected again and then oxidized for a second time. The second oxidation was 5.0 minutes in duration. A third inspection was performed and then a third oxidation. This last oxidation time lasted 3.0 minutes. The wafers were then inspected a final time.

## **RESULTS**

Localized oxidation was observed on the wafers that received implantation doses of 1E15 and 2E15 atoms/cm<sup>2</sup>. The LOCOS effect, however, was weak. When the two samples mentioned above were further oxidized the localized image faded. Equipment limitations prevented implantation of higher doses.

In the first experiment the sample that received an implant dose of  $1E15$  atoms/cm<sup>2</sup> was the only wafer to show localized oxidation. The oxide pattern mimicked the pattern of the resist mask. The oxide grown on all wafers after the anneal was 0.33 microns thick. This thickness was of sufficient depth to detect the presence of the nitride material. The projected range for nitrogen at 30 and 60 KeV implant energies was 0.06 microns and 0.1 microns, respectively. This wafer was oxidized a second time to bring the total oxide thickness to .66 microns. At this point the localized image was nearly faded. An etch back using buffered HF was attempted to bring the image back. This step had limited success. It was observed that after a time all materials on the wafer were removed exposing the bare silicon. This indicated that the material formed through implantation is not a pure silicon nitride since HF does not etch silicon nitride readily..

The second experiment attempted to more clearly differentiate the LOCOS effect by bringing the surface of the wafer closer to the implanted region. This entailed growing an initial oxide which was almost the depth of the implanted nitrogen. The initial oxide grown was .15 microns. After implantation this oxide was etched back exposing the silicon surface. This resulted in bringing the silicon surface nearer to the implanted region.

Subsequent oxidations provided the same results as the previous experiment, however. The first oxidation provided the strongest image. Further oxidations washed the image away. This indicated that the implanted material allowed oxygen to diffuse through it given enough time.

Higher implant doses were not obtainable using the Varian/Extrion 400-10 implanter due to time constraints. Initially the maximum implant current was found to be 4 microamperes. Using the implant time formula stated in the introduction yields an implant time of 2 hours for an dose of  $2E15$  atoms/cm<sup>2</sup>. To obtain the doses stated in the literature ( $5E16$  atoms/cm<sup>2</sup>) an implant time of 51 hours would be required using our implanter. The implant current limited the dose that could be implanted.

It was observed that the implant current slowly rose to higher currents during long implant times. For the dose of  $2E15$  atoms/cm<sup>2</sup> the initial current was 4 microamperes. As the implant proceeded the current had increased to 6 microamperes after the first hour and up to 10 microamperes by the end of the implant. This resulted in an implant time of only 1.25 hours for that dose. This current creep could indicate that the machine is not as limited as previously thought.

## **CONCLUSIONS**

The LOCOS process using nitrogen implantation was not developed at RIT. The present implant current limitation of the Varian 400-10 restricted the implant dose by requiring implant times which were unobtainable in practice. The current creep observed during long implant times indicates that the machine may not be as limited as previously thought.

Although the LOCOS process was not developed it was observed that a silicon nitride like material starts to form at doses of  $1E15$  atoms/cm<sup>2</sup>.

## **ACKNOWLEDGEMENTS**

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