Oxidation Kinetics of Nitrogen Implanted Silicon

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Abstract- Incorporation of nitrogen into the silicon lattice has been shown to severely retard the oxidation rate. The objective of this experiment was to determine a) whether it was a damage related issue and b) the kinetics. Equal doses of silicon were implanted along with the diatomic nitrogen (AMU ~ 28) to determine whether it was a damage related issue. The added silicon did not hinder or benefit oxide growth. From this experiment, the oxidation rate of nitrogen implanted silicon can be best fit by the use of a linear model. Surface charge analysis indicated that flatband charge, interface trap density, and lifetime increased after nitrogen implant.

1. INTRODUCTION

The use of nitrogen in oxidation is becoming more and more necessary as the gate oxide reaches sub 50 Angstroms. Boron doped poly gates allow boron to punch through the thin oxide layer and cause unwanted device failures. Hot carriers pose a similar threat at said thicknesses. Nitrided oxides can be an effective barrier to impurity diffusion.

Another benefit to nitrogen assisted oxidation is the control of oxide growth. Since nitrogen severely reduces the oxidation rate, it is much easier to grow controlled thin oxides.

2. EXPERIMENTAL RESULTS

Diatomic nitrogen (AMU ~28) was implanted into half a (100) p-type wafer at 70KeV through a 950 Angstrom screen oxide. The other half of the wafer was then implanted with equal doses of silicon (AMU~28) at the same energy. The doses were 0, 2e13, 1.1e14, 4e14, 9e14 cm^{-2}. Figure 1 shows the predicted range and straggle of the nitrogen implants.

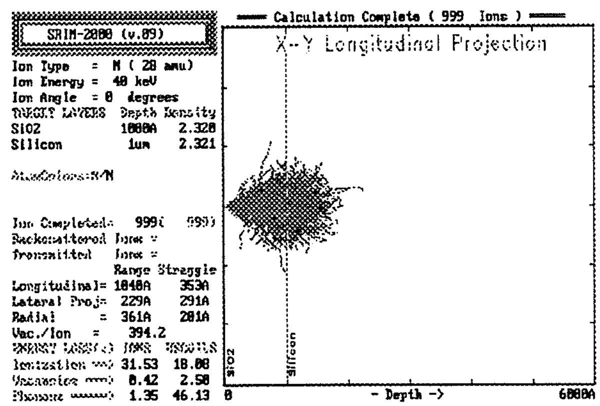

Figure 1: TRIM Simulation of N_2 implant.

Fifteen wafers were used which allowed for five doses, three temperatures, and four times.

Once implanted, the oxide was stripped using a buffered oxide etch for 45 seconds. An RCA clean was then done in order to remove any other possible contaminants.

Oxidation was performed on every dose at 850°C, 900°C, and 950°C for times of 5,10, 15, and 20 minutes in dry O_2. Due to constraints, only one group (consisting of every dose) of wafers could be tested for each temperature. Therefore, in order to obtain thicknessess for the multiple times, the wafers were soaked for 5 minutes, unloaded, measured, and soaked again for another 5 minutes (up to 20 minutes). To decrease the amount of unwanted oxide growth caused by moisture, the wafers were loaded and unloaded at 700°C in N_2.

After each oxide growth, the wafers were measured along 15 sites using ellipsometry. Tables 1 and 2 describe the average values for each wafer on both the silicon implanted side and the nitrogen implanted side.

850C	0	2.00E+13	1.10E+14	4.00E+14	9.00E+14
5 min	10.9	11.5	10.9	12.5	13.0
10 min	21.2	22.8	23.0	24.0	24.8
15 min	30.4	32.8	33.2	34.1	34.1
20 min	38.8	42.4	42.6	42.9	42.8

Table 1: Oxide Thickness for various Si implants

850C	0	2E+13	1.1E+14	4E+14	9E+14
5 min	10.9	10.3	4.7	1.8	1
10 min	21.2	20.5	12.5	4.4	2.6
15 min	30.4	30.7	20.6	7.9	3.5
20 min	38.8	39.1	29.2	10.2	4.3

900C	0	2E+13	1.1E+14	4E+14	9E+14
5 min	24.5	23.2	14.2	3.9	1.5
10 min	45.3	44.7	32	8.2	3.5
15 min	67.5	67.6	55.4	17.5	5.7
20 min	82.9	83.3	71	24.1	7.5

950C	0	2E+13	1.1E+14	4E+14	9E+14
5 min	44.9	43.9	32.1	7.3	2.7
10 min	84.3	85.6	73.2	23.9	6.2
15 min	117.9	120.0	110.1	53.7	9.4
20 min	148.6	152.3	142.1	85.3	12.7

Table 2: Oxide Thickness

As shown in table 1, the oxide thickness from the silicon implant was about the same as the thickness for the non-implanted wafer for all doses. Minor variation was simply due to wafer placement and furnace error. It can be seen that the silicon implant neither benefited or hindered the oxidation rate. From this, it can be deduced that implant damage and silicon implant prior to oxidation do not effect oxidation.

Conversely, the rate of oxidation was severely impaired by the nitrogen implant when compared to the non-implanted wafer (table 2). When plotted versus time, it can be seen that the oxidation follows a linear trend (Figures 2-4). The model can be best fit by the standard linear equation:

$$X_{ox} = C_1 t + C_2$$

Where C_1 and C_2 are constant growth rate and initial oxide thickness and t is time in minutes.

These plots also emphasize the importance of dose. They clearly show a significant reduction in growth rate for doses greater than 1.10e14 cm^{-2}. This is largely in part of nitrogen's inherent properties, which are still

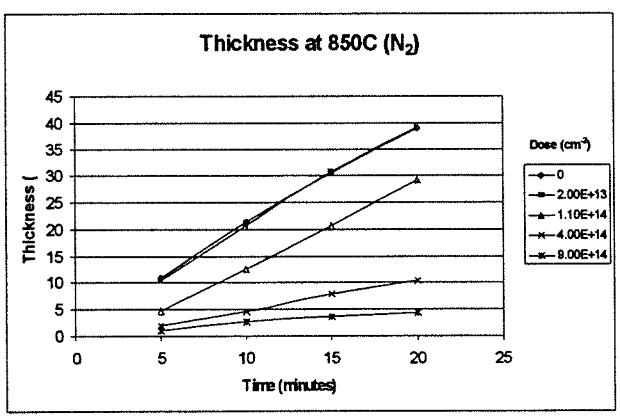

Figure 2: Oxide Thickness versus time for different N_2 implant doses at 850°C

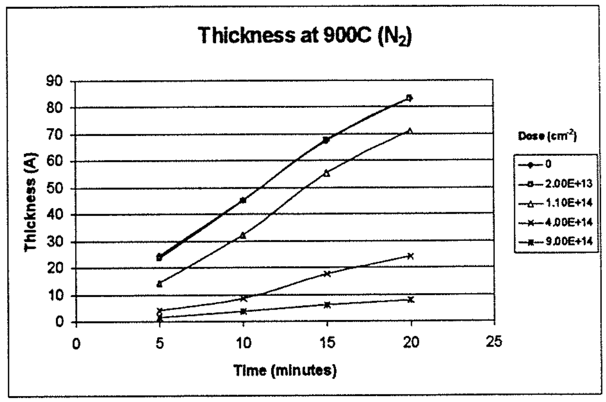

Figure 3: Oxide Thickness versus time for different N_2 implant doses at 900°C

under investigation. It should also be noted that the best fitting lines occurred at the 9e14cm^{-2} dose. And further more, the slope (oxidation rate) doubled after each temperature increase.

The statistical program RS/1 was used to derive a model equation for C_1 and C_2 from the gathered data. It determined that constant C_1 was dependent on dose, temperature, dose*temperature, and temperature^2. The r^2 value was calculated to be 0.99. The C_2 value was found to be dependent upon dose^2. However, it was a very poor fit, having a r^2 of 0.44. Table 3 shows the corresponding values for C_1 and C_2.

Table 3: C_1 and C_2 for N_2^+ Oxidation

	850		900		950	
Dose	C1	C2	C1	C2	C1	C2
0	1.858	2.1	3.948	5.7	6.886	12.745
2.00E+13	1.932	1	4.064	3.9	7.191	10.557
1.10E+14	1.632	-3.65	3.876	-5.3	7.344	-2.417
4.00E+14	0.574	-1.1	1.388	-4.05	5.275	-23.413
9.00E+14	0.216	0.15	0.404	-0.5	0.666	-0.563

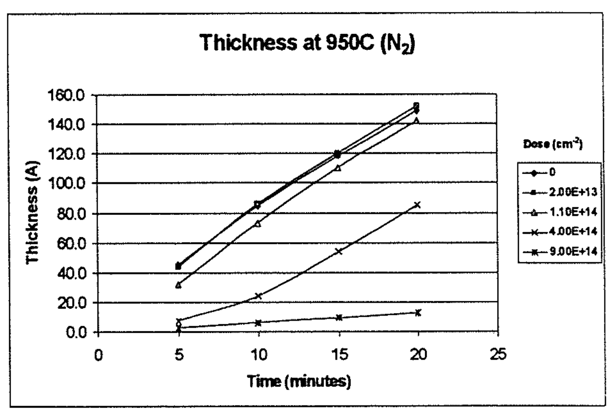

Figure 4: Oxide Thickness versus time for different N_2 implant doses at 950°C

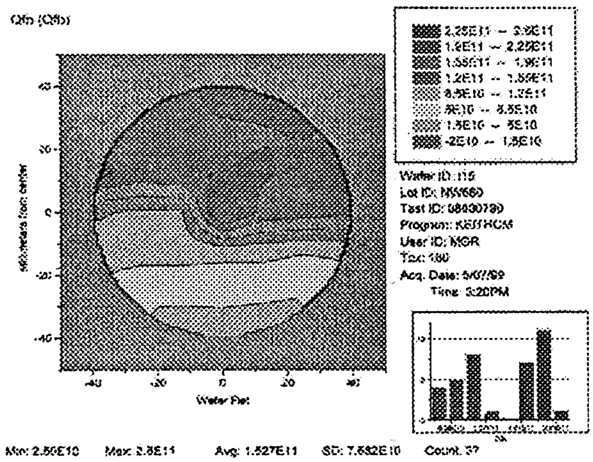

Figure 5: Flatband Charge

Surface charge analysis was performed upon a 4e14 cm^{-2} doped wafer. It concluded that there was a rise in flatband charge, density of interface traps, and carrier lifetime on the nitrogen implanted side (Figures 5-7).

3. SUMMARY

The effect of silicon implant prior to oxidation was negligible, as was the effect of implant damage. The effect of the nitrogen was profound. It relied heavily upon dose and temperature to a certain extent. A medium dose of 9e14 cm^{-2} of nitrogen grew 4.3 Angstroms after 20 minutes at 850°C compared to 38.8 Angstroms from the undoped sample. The model was best fit by a simple linear relationship. There is some discrepancy in the C_2 value. Surface charge analysis revealed that implanting with nitrogen increases flatband charge, density of interface traps and lifetime.

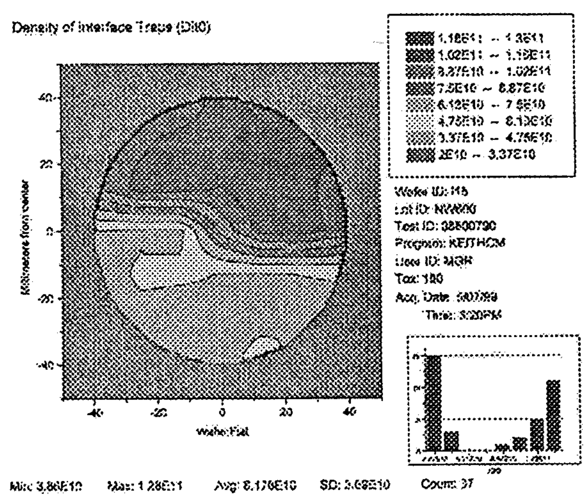

Figure 6: Density of Interface Traps

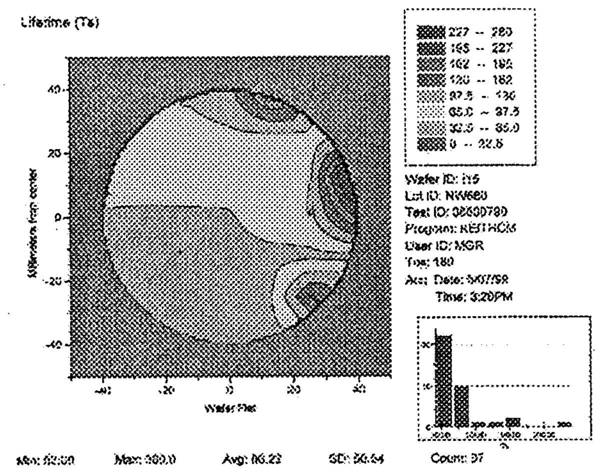

Figure 7: Lifetime

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