ALUMINUM CONTAMINATION REDUCTION IN 1980'S VINTAGE ION IMPLANTERS

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Abstract--- Ion implanters manufactured in the 1980's such as the Eaton NV10 series tools have been employed in an incredible number of semiconductor device manufacturing situations without regard for Aluminum contamination levels. For certain specific situations Aluminum contamination can not be allowed at the levels produced by these implanters as originally designed. Silicon coating methodologies were adapted from the more modern generations of high current ion implanters with only moderate success. Results from a more aggressive contamination control program targeting Aluminum contamination levels substantially lower than can be achieved simply by coating the process disk are presented. Factors limiting the effectiveness of partial solutions are discussed as are the degradation of performance with time. The results achievable by an aggressive solution targeted at the primary sources of Aluminum contamination other than the process disk are reported.

I. INTRODUCTION

Ion Implantation of dopants into silicon for the manufacture of semiconductor devices is a common and well characterized process. The nature of contamination by atoms other than the desired component of the implantation process is also reasonably well characterized. However there are application specific processes where control of contamination requires that additional measures be taken.

This particular study addresses aluminum contamination of an 80 KeV Arsenic implant into 5 inch <100> silicon. The target dose for the process is 5 E 15 ions/cm2 and initial study indicated aluminum levels that would be readily detectable and potentially damaging for some applications that employ these substrates. Therefore, methods to reduce the contamination level were explored and in the process an understanding developed of some of the mechanisms affecting this contamination.

II. EQUIPMENT AND METHODS

An Eaton NV10-80 implanter using a Bernas ion source and full ring clamped 4 inch wafer wheel was used for this test. The electron shower was an Eaton "type 2" unit and where a silicon-coated clamp is referenced it was one of the 13 clamping structures installed on the wheel. This silicon-coated clamp had been used for a shorter round of similar tests using Antimony.

The aluminum surfaces that conceivably could act as sources of the aluminum contamination found on the wafer were masked by metal a non-aluminum metallic foil to ensure that they would not contribute sputtered aluminum. In addition certain process variables were tested that might influence the rate of accumulation of the aluminum contamination.

There are typically 2 samples per test condition as the freshly masked clamp and the previously used silicon coated clamp each held a wafer during most tests. The preparations for testing and the specific conditions for the samples by slot number are in the descriptions and tables below.

- The process wheel with the silicon-coated clamp was installed on the tool and loaded with dummy wafers.

- The nominal process (5E15 Arsenic 75 ions/sq. cm., at 80 KeV and 8 mA) was performed on the wheel and dummy wafers three times for wheel conditioning.

- The dummy wafers were replaced with test wafers under one standard aluminum clamp (slot # 1) and the silicon-coated clamp (slot # 3) and the nominal process was performed to generate baseline data.

- The dummy wafers were removed and the masking foil applied to the wheel, the process chamber entrance and the freshly masked clamp.
- Testing proceeded as follows:

Silicon-coated Clamp sample	Fresh Mask Clamp sample	Energy (KeV)	Dose (ions/sq. cm.)	Ion Beam Current	Operational test condition
slot # 5	slot # 6	80	5 E 15	8	0
slot # 7	slot # 8	80	5 E 14	8	0
slot # 9	slot # 10	80	1.5 E 15	8	0
slot # 11	slot # 12	80	1.5 E 16	8	0

- The masking foil was removed from the process chamber entrance but left on the wheel and clamp and the testing continued.

Silicon-coated Clamp sample	Fresh Mask Clamp sample	Energy (KeV)	Dose (ions/sq. cm.)	Ion Beam Current	Operational test condition
slot # 13	slot # 14	80	5 E 15	8	1
slot # 15	slot # 16	80	5 E 15	8	0
slot # 17	n/a	65	5 E 15	8	0
slot # 18	n/a	50	5 E 15	8	0
slot # 19	slot # 20	80	5 E 15	1	0

A sample was also pulled from the same test wafer cassette and analyzed to assess the level of aluminum contamination from the material and analysis techniques (slot # 25).

III. RESULTS AND DISCUSSION

There are phenomena present that make the sequence of testing a significant (though not overwhelming) influence on the data collected. The slot number attached to each data label reflects the order of the testing. The profiles of aluminum concentration as a function of depth by SIMS are collected below:

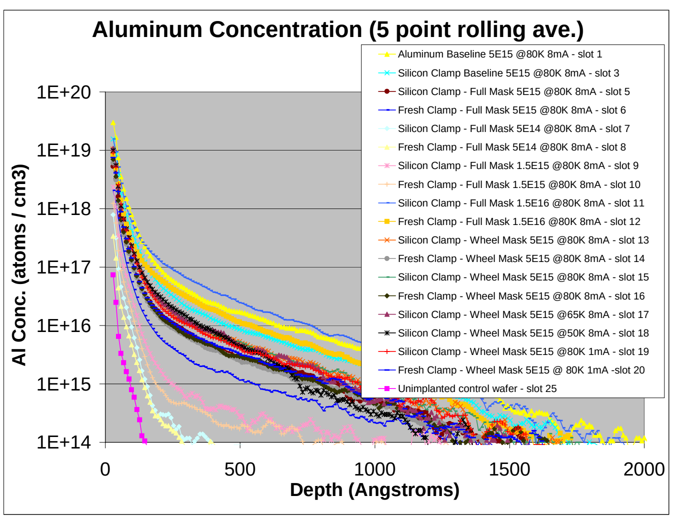

Figure 1. Aluminum Concentration by SIMS for all test conditions

Figure 1 illustrates the wide variation in aluminum contamination levels observed in this study. Considering only the tests with the required process dose still leaves more than an order of magnitude change in concentration of aluminum at the depths of interest.

To couple the data analysis to the expected process it will be useful at times to examine the aluminum concentration at a depth roughly equivalent to an expected screen oxide thickness. For this particular implant condition a screen oxide thickness of about 300 angstroms would place about 2/3 of the implanted arsenic dose into the silicon. It would also trap a substantial portion of the aluminum contamination and allow it to be eliminated during wafer cleaning.

Figure 2 illustrates the cascading character of the sputter and "knock-down" contamination mechanism. The aluminum baseline curve and the unimplanted control wafer are shown only for reference. Examining the four different dose levels processed with the freshly masked clamp and full masking of the sources of aluminum contamination one sees much more change in concentration than change in dose. Until a sufficient aluminum concentration has been accumulated at depth such as 500 angstroms it is essentially unavailable to be "knocked down" or cascaded to 600 angstroms. This points out a "brute force" method that could be employed to achieve complete control of the aluminum contamination . If a screen oxide were grown and the implant stopped just before the aluminum contamination penetrated to the silicon the oxide could be stripped and this process iterated until the accumulation of the required dose. This is not a practical solution but it illustrates how the contamination mechanism and screen oxide choices interact.

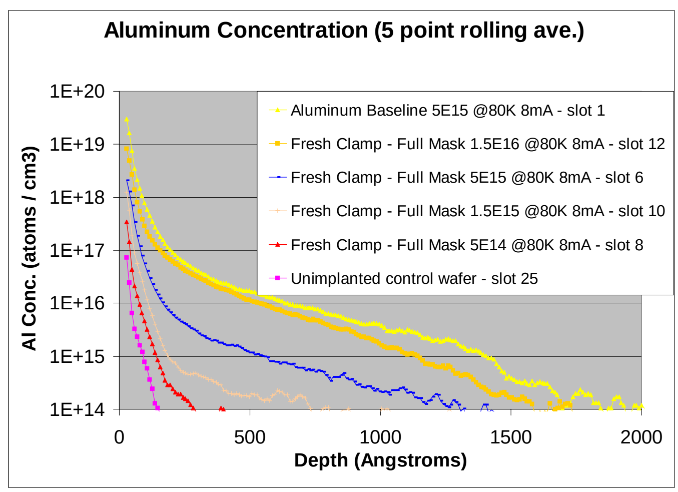

Figure 2. Dose effect on Aluminum Conc. by SIMS

Examining the concentration at a 300A depth in the silicon we see there is an order of magnitude change in the aluminum concentration each time the dose is changed by a factor of 3.

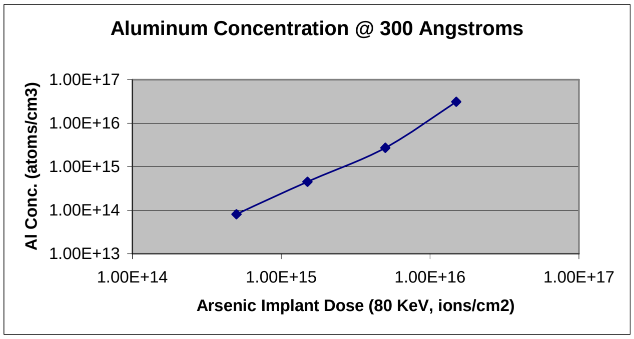

Figure 3. Aluminum Conc. at 300 Angstroms

This is clearly the result of the cascading character in the contamination mechanism - any contaminant that was a constituent of the ion beam (for example aliased or other energetic contaminants) would change proportionally with dose. Looking then at the impact of differing masking strategies we can pull a series of plots that are all at the nominal implant condition but with differing mask strategies. The freshly masked clamp combined with the full masking strategy yields a full order of magnitude improvement over the baseline process. The other approaches and data points yield intermediate results. The significance of the prior use of the silicon-coated clamp is that any testing without a complete masking strategy would impart sputtered aluminum to the surface of the silicon coated clamp. We can see this effect in a number of ways not the least of which is the increase contamination level as a percentage of dose as testing proceeded. There are other factors that have a similar effect such as the continued heating of the source objects increasing their sputter yield. Comparing the rate of increase in the contamination as a percentage of dose for the fresh clamp vs. the silicon coated clamp allows us to identify two separate phenomena. The silicon-coated clamp should be much closer to its equilibrium aluminum contamination level than the freshly masked clamp. The rate of increase this clamp is significantly lower than for the freshly masked clamp.

The above discussion highlights two issues to be addressed in future work. The testing of these types of effects would be best approached with an implanter that is in steady state process mode for some time prior to testing to achieve equilibrium conditions (esp. temperature) in the tool. The second issue is to insure and test for 100% efficiency of the masking of the aluminum sources in the tool. There will inevitably be some accumulation of aluminum on the silicon coated liners intended to suppress aluminum contamination. Naturally this will result in increasing levels of aluminum reaching the wafers. The unanswered question is how long the coatings will last if this process continues and rises above tolerable levels or whether instead this effect will equilibrate at levels that are acceptable in the process.

Process variables tested had little or no effect on the rate of Aluminum contamination. This is perhaps best illustrated by a factor of 8 reduction in the beam current showing a small decrease in Aluminum contamination level for the silicon coated clamp and small increase in contamination level for the freshly masked clamp. The proposed explanation is that the continued increase in aluminum level on the fresh surfaces and the increase in their temperature as testing proceeded results out weighed the effect of reducing the current. For the silicon-coated clamp the effects were reduced because its initial contamination level was so much higher at the beginning of the test. Other process variables tested were of much less significance though some have proprietary interest. For that reason while the variable will be obscured by a code the following plot shows the lack of impact

The aluminum concentration profiles show monotonically decreasing concentration with increasing depth. While this clearly indicates the sputter and “knock-down” mechanism it is particularly interesting to examine the problem by looking at the concentration at a proposed screen oxide thickness (we’ll use 300 angstroms) as a function of dose. At the 300 angstrom depth the cascading character of “knock-down” results in a full order of magnitude change in concentration for each 3X change in dose. There is a corresponding but even greater change in the integrated dose that would be found in the silicon if a 300 angstrom screen oxide were employed. In short the multipliers be come quite favorable.

At the depth of 300 Angstroms we found a greater than 4X reduction in contamination from masking the process wheel.

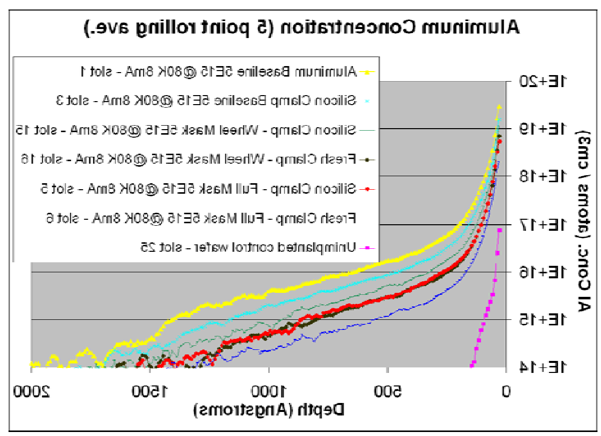

Figure 4. Effect of resputtered contamination

Masking the process chamber entrance resulted in between a 2.5X and 3X reduction in contamination level under the tested conditions.

IV. Conclusions

The method of using a metallic foil to substitute another element for the normal aluminum surface allowed the sputtering contribution of components to be subtracted out individually. A properly configured set of silicon coated shielding would be expected to result in reductions of aluminum contamination by an order of magnitude. This requires shielding of both the process chamber entrance and the surfaces of the wheels that are struck by the beam.