Low Energy Ion Implant Capabilities at RIT

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Abstract-- With the ever-decreasing size of device geometries today, all aspects of processing must allow for proper scaling of device parameters including junction depths. Currently in industry this challenge is met with ultra-low-energy ion implants combined with rapid thermal annealing to create the necessary profiles. It is also important to have good uniformity and throughput in order for the process to be acceptable in a manufacturing environment. Since the installation of RIT's Varian 350D last year, there have been no implants performed at less than 30KeV. In order to develop future processes for the student-run factory and open research possibilities, ion implants of Arsenic, Phosphorus, and BF_2 were performed at 10, 15, and 20KeV in drift mode into 6" wafers covered with a thin screen oxide. Implant simulations and sheet resistance uniformity along with other information were examined to investigate the 350D's capabilities.

1. INTRODUCTION

Low energy ion implantation is a necessity in industry today to create the shallow junctions needed by state of the art devices. Most challenging is the p+/n source/drain junction, whose depth is generally required to be 1/5 to 1/6 of the gate length in a MOS transistor.

Creating junctions within the first few hundred angstroms of the wafer surface is a challenge that is met today by a combination of ultra-low-energy ion implant and limited thermal processing enabled by rapid thermal anneal (RTA). Also, pre-amorphization of the wafer surface by the use of inert implants is done to minimize channeling effects.

Transient enhanced diffusion (TED) is a condition where excess interstitials, which are caused by implant damage, increase the diffusion rate of dopant ions. The defects present at the end of implant range are mostly responsible for this effect. This is most common in boron implants, due to the high diffusivity characteristics of boron ions. Commonly this is minimized through the use of BF_2 implants. The BF_2 ions are larger and heavier than B11 ions, effectively decreasing the implant range into the substrate. Previous cited work [4,5] has also shown a chemical based slowing of TED effects by fluorine on boron.

Currently no ion implants below 30KeV are performed on RIT's Varian 350D. While this tool does not have the capabilities of specially designed ultra-low-energy ion implanters, it does have the theoretical lower limit of 5KeV. Two distinctly different modes of operation are available on the Varian 350D to allow low energy operation. These are drift mode, and deceleration mode.

In deceleration mode, the ions are extracted from the source at a fixed potential such as 30KeV. The acceleration column is then used in reverse to retard the ions, resulting in the desired low energy implant. Advantages of this mode are increased beam current and uniformity. Disadvantages are a required physical reconfiguration of the tool each time deceleration mode is needed, resulting in tool downtime, and energy contamination. Energy contamination occurs when neutrals are formed in the beam line due to collisions with residual gases. Since these particles do not have a net charge, they are not subjected to the deceleration, and are implanted at a higher energy.

Drift mode is where the extraction voltage is simply reduced to the desired implant energy. The advantages of this mode are no energy contamination and, in the case of our particular implanter, no physical re-configuration. The disadvantages are lower beam current and decreased uniformity across the wafer.

2. EXPERIMENTAL DESIGN

Ion implants were performed on a Varian 350D in drift mode for phosphorus, arsenic, and BF_2. The implants were performed at Agere Systems to meet project deadlines due to unforeseen tool issues. Activation of the implants was performed on an MPT RTP600s tabletop annealer also at Agere Systems, which is similar to RIT's AG Associates RTP610 that was unavailable during the time of this investigation.

An L9 fractional factorial design was chosen to investigate the input factors of implant energy, anneal time, and anneal temperature. This resulted in 9 treatment combinations, and was repeated for each dopant. Responses were sheet resistance and within-wafer uniformity. The treatment combinations are listed below in Table 1.

T.C	Implant Energy (KeV)	Anneal Time (s)	Anneal Temp. (C)
---	10	45	950
-0+	10	60	1050
-+0	10	75	1000
0-+	15	45	1050
000	15	60	1000
0+-	15	75	950
+-0	20	45	1000
+0-	20	60	950
+++	20	75	1050

Table 1 – Experimental Design

A 6" p-type wafer was used for each treatment combination. The dose was 5E14/cm^2 for each treatment. At the time of this investigation, n-type wafers were unavailable so an n-well was created using the standard RIT Advanced CMOS n-well process. This is a phosphorus implant with a dose of 9.5E12/cm^2 at 150KeV, followed by a thermal diffusion. The resulting oxide was stripped and a thermal oxide of 150 angstroms was grown on all wafers for use as a screen oxide during implant, since an inert implant was not available to pre-amorphize the wafer surface.

The wafers were then sent to Agere Systems for ion implant and RTA as per the DOE outlined above. The wafers were then returned to RIT for removal of the screen oxide. Sheet resistance measurements were performed on a Tencor Omnimap RS75 sheet resistance mapping system at Veeco/CVC. 46 points were measured on each wafer to determine mean sheet resistance and within wafer standard deviation.

Ion Implant simulations using the SRIM 2000 software package were performed for the implants to determine implant range and damage created by the implant.

3. RESULTS

A. *Simulation*

Simulations using the SRIM 2000 program were performed to explore the range of the implants in this investigation. Shown in Figure 1 is the ion range for a phosphorus implant into a silicon substrate covered with 150 angstroms of screen oxide. The simulated values from SRIM underestimate the ion range since the program does not take into account factors such as channeling due to the structure of silicon.

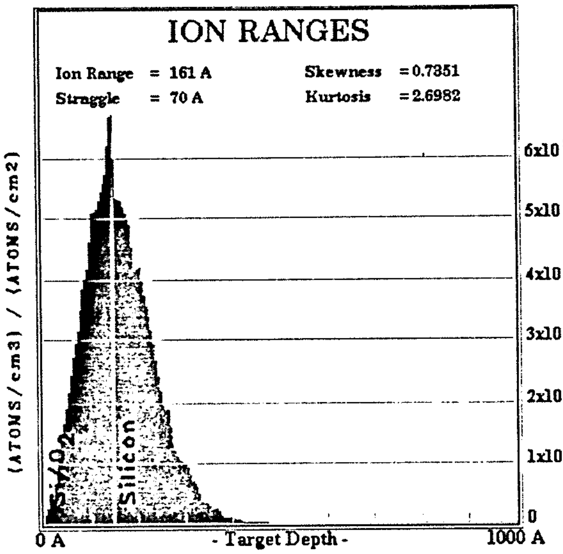

Figure 1 – 10KeV P11 implant

B. *Sheet Resistance*

Listed in Table 2 are the sheet resistance and within wafer uniformity values obtained from this experiment.

Wafer #	T.C.	Mean Rs (Ω/sq.)	Std. Dev. (%)
		BF$_2$	
C1	---	914.0	5.34
C2	-0+	1448	15.2
C3	-+0	1289	8.44
C4	0-+	850.1	11.3
C5	000	883.3	10.3
C6	0+-	869.1	5.1
C7	+-0	634.2	5.84
C8	+0-	689.3	5.67
C9	+++	577.3	4.61
		Phosphorus	
C11	---	1252	17.1
C12	-0+	517.2	12.6
C13	-+0	679.5	18.5
C14	0-+	299.9	9.28
C15	000	350.8	7.76
C16	0+-	448.8	8.7
C17	+-0	270.8	5.41
C18	+0-	320	4.88
C19	+++	212.4	4.12

		Arsenic	
C21	---	10440	37.6
C22	-0+	3300	23.6
C23	-+0	4847	17.4
C24	0-+	1306	18.6
C25	000	987.7	9.81
C26	0+-	2894	40.4
C27	+-0	799.9	13.5
C28	+0-	880.7	18.7
C29	+++	593	10.8

Table 2 – Sheet Resistance and Uniformity Data.

4. DISCUSSION

As previously mentioned, sheet resistance and within-wafer standard deviation were measured on a Tencor Omnimap RS75, which provides automated sheet resistance mapping of the entire wafer.

The sheet resistance values are a function of both junction depth and amount of electrically active dopant that is in the sample. Naturally, the deeper the junction depth, the less sheet resistance is due to a larger conducting path. This is seen in the data by a decrease in sheet resistance with an increase in implant energy. If SIMS data were available, theoretical sheet resistance could be calculated to determine how well the RTA activated the dopant. Equation 1 would be used to determine theoretical sheet resistance. The value yielded by Equation 1 assumes all dopant ions detected by SIMS analysis are electrically active which inherently gives a lower sheet resistance than actual measurements.

$$Rs = \frac{1}{q\int_0^{x_j} C_b(x)\mu_p(x)dx} \qquad (1)$$

The values for x_j and C_b are obtained from SIMS analysis, while μ_p is dopant mobility.

For all three dopants, analysis of the data in JMP shows that implant energy had the largest correlation to sheet resistance data. Anneal time and temperature used are dependent upon desired sheet resistance and junction depth for a particular device. Longer anneal times and higher anneal temperatures will result in deeper junction depths. The data suggests that acceptable levels of dopant activation were attained at 1050°C for at least 60 seconds for both arsenic and phosphorus. BF_2 was sufficiently activated at 950°C for times greater than 45 seconds.

The within-wafer standard deviation is quite high for all samples, especially the arsenic implants. There are several possible factors contributing to this, which would need to be investigated before low energy implants would be feasible in drift mode on the 350D. First source of possible variation is the screen oxide. Changes in oxide thickness across the surface of the wafer will result in variations of the amount of dopant the wafer is actually subjected to. After simulating a change of 30 angstroms in the screen oxide, it was apparent while this will contribute somewhat to the standard deviation, this would be a minimal effect. Another source of variation is during rapid thermal anneal. The RTA system used consists of many high intensity lamps to heat the front and back of the wafer. However, heating non-uniformities occur due to the size of the lamps compared to the wafer. Generally, the outer parts of the wafer are not heated as high as the center of the wafer, resulting in higher sheet resistance at the outside of the wafer due to less electrically active dopant. However, in the case of this experiment, the wafers actually had higher sheet resistance at the outside of the wafer, indicating that heating uniformity was not an issue.

This leaves the source of the majority of variation as the implanter itself. There are a few different situations that would cause serious variations such as the ones observed here. First, no flood gun was used during these experimental implants. The flood gun is used during an implant to neutralize charge build-up on the surface of the wafer. If this build up of charge is not remedied, the dopant ions will repel each other and migrate towards the edge of the wafer. Another possible option is known as beam blow-up. This occurs when the shape of the ion beam is out of control and presents a less than ideal beam to the wafer surface. This can result in dosing inaccuracies and uniformity degradation. It is quite possible that a combination of both of these was occurring during this investigation.

5. CONCLUSIONS

The feasibility of low energy ion implants on RIT's Varian 350D to create shallow junctions was investigated using a similar tool at an off site location. The implant/RTA resulted in poor within wafer uniformities, most likely due to implant problems. Further work would be needed to refine the process in order to provide acceptable uniformity in drift mode. Possible alternatives include the investigation of deceleration mode for low energy implants at RIT.

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