Design of Experiments Using TMA WorkBench

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Abstract - **TMA WorkBench software is used to interface with Suprem4 process simulator and Medici electrical test software in order to set up, run and analyze Design of Experiments for process simulation. A method for simulation tuning was found, and an example experiment was run and analyzed. Comparison to a fabricated experiment was planned in order to provide feedback for simulation tuning and to verify a simulated approach to process experimenting. Least squares analysis was used to find response function coefficients, as well as to plot factor-response contour maps.**

I. INTRODUCTION

Process simulators are very effective tools for gaining process knowledge while minimizing time and resources. However, simulated results are of limited use unless the simulation has been tuned to a base process. This requirement of feedback is an important part of accurate simulated experiments.

Suprem4 is commonly used for process simulation and Medici is used for device electrical performance simulation. These two programs can provide accurate two-dimensional models of real devices. However, they are not properly equipped for running multi-level experiments. This can be done, but it is very cumbersome, since multiple input decks must be individually run for each split. Once the process simulation is complete, Medici must then be run for each of these splits. In addition, to do any complex statistical analysis additional software is also necessary. This makes an experiment time consuming and awkward to manage.

The TMA WorkBench software is a very useful for preparing, running and analyzing experiments. This software seamlessly interfaces with Suprem4 and Medici input decks in order to manage all of the process splits. In addition, WorkBench contains statistical analysis tools needed to make sense of experimental data (see Figure 1). This software has not yet been used at RIT. Therefore, this project is to qualify this program for general use by RIT classes, and to verify simulated results against an actual fabricated experiment.

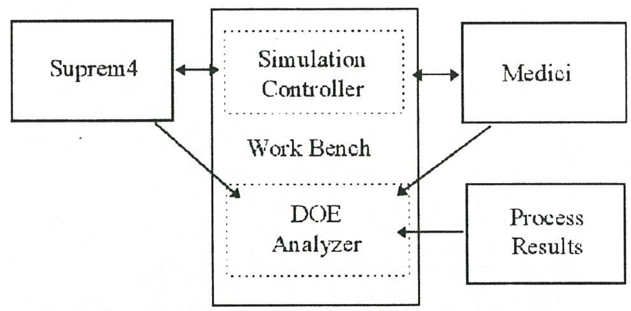

Figure 1: WorkBench simulation management

Results from a simulated experiment are of little use unless they will correlate well with an actual experiment. Thus, a method of feedback is required in order to tune a simulation to process specifications.

An example experiment was then chosen to be used with this software. The experimental structure was chosen for its process simplicity. This device is a N+ doped region in P type wafers, with aluminum contacts on both ends. It can be tested as a resistor between the contacts, in order to get values of sheet resistance. Or, it can be tested with the through the junction, in order to get diode parameters such as V_{BD}, I_O and n.

This experiment could then be run in both simulation and actual fabrication. This would be done in order to properly tune the simulation and to verify final experimental results.

II. THEORY

A method for running and comparing the two simultaneous experiments was developed. First, the process center point (or, base process) was simulated. An identical process was then fabricated and tested. The resulting feedback knowledge from the fabricated device was used to tune the simulated base structure. After

tuning, if these two approaches yield similar results, then results from a full experiment should also correlate.

Once tuning is complete, the full experiment is both simulated and fabricated. Analysis of the two experiments should produce similar results. If this is so, then the validity of a simulation approach using this software should be confirmed (see Figure 2). Otherwise, other tuning methods should be explored, and simulation results should be held suspect.

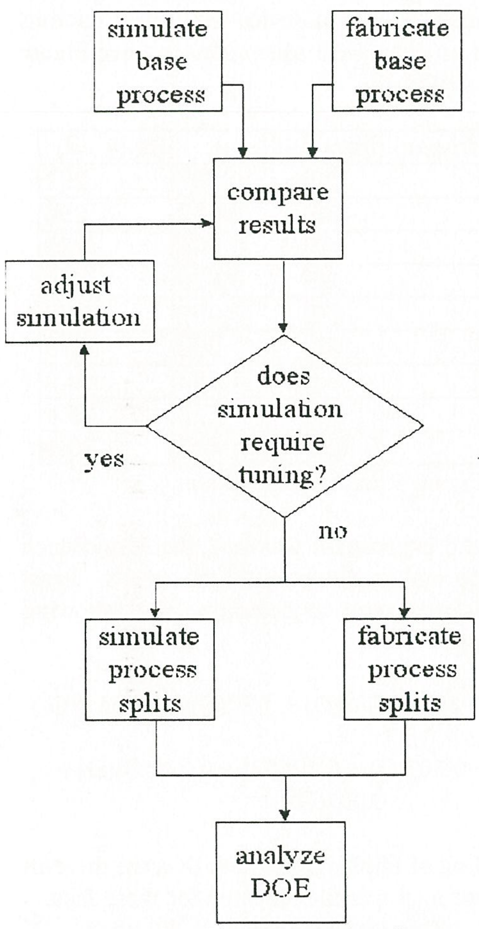

Figure 2: project flow

III. EXPERIMENT

An example test structure was developed for the project (see Figure 3). This structure was chosen for its processing simplicity and ability to yield responses, and not for any practical application. It is a P+ region doped into an N substrate, with two aluminum contacts for testing. In addition, it has a heavily N-doped back surface so that the backside can be used as an additional contact.

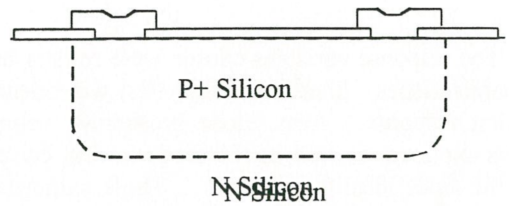

Figure 3: test device

1. grow protective oxide - 1100° C, 30min, H20
2. coat resist
3. etch backside oxide in BHF - 5min
4. spin dopant onto backside
5. diffuse in dopant - 1000 ° C, 30min, N2
6. etch in BHF to strip all oxide - 5min
7. RCA clean
8. grow screen oxide - 1000 ° C, 30min, O2

* 9. pattern window for implant
\# 10. perform implant - B11, 1E14, 60KeV
\# 11. drive in implant - 1100° C, 30min, N2
* 12. pattern contact cuts
13. etch in BHF to open contact cuts - 2min
14. deposit aluminum
* 15. pattern aluminum
16. etch aluminum - form contacts

* indicates photolithography step
\# indicates process split

Figure 4: test device process

Initially, the device was planned to be an N-region doped into a P-wafer. However, previous experiments have shown that charges in the insulating oxide are frequently sufficient to invert the field regions, which would cause all devices to be shorted together.

By electrically testing between the two contacts, resistor characteristics can be found. Or, by shorting these contacts together, and using the backside as another contact, the device can be tested through the junction as a diode.

An experiment was set up with three 3-level factors and four responses. This results in nine combinations. Two center points were added so that a measure of variance could be determined. Therefore, a total of 11 runs was decided upon.

Implant dose was chosen as the first factor. Settings were varied from 1E13 to 1E15 ions/cm^2 of boron. Implant drive-in time was selected as the second factor. It was varied from 20 to 40 minutes. The third factor is device size, which ranges from 200 to 400 microns.

The response variables chosen were resistor and diode characteristics. Sheet resistance (Rs) was selected as the first response. Also, diode breakdown voltage (V_{BD}) was explored, as well as the diode reverse current (I_o) and the diode ideality factor (n). These parameters can be simulated using Medici, and can be extracted from actual devices using the HP4145 test equipment.

Due to time constraints and software unavailability, an abbreviated experiment was run instead. This experiment explored only the implant and drive-in factor, and used a device size held constant at 6 microns. Response variables of only junction depth (Xj) and sheet resistance were instead explored.

IV. PROCESS

The base structure (or, the experiment center point) was first simulated in order to focus in on a reasonable device. This including ensuring that the resist could block the implant in field areas, and targeting the junction depth at roughly one micron in the active area.

The base structure was then fabricated in the RIT fab, followed by electrical testing. Tuning can be done by adjusting simulation deck specifics such as the minority carrier lifetime and the simulation cross section grid density.

A constant grid density was selected, and a grid factor was used to adjust accuracy. This grid factor, which is a whole number larger than 1, is used to multiply the number of grid points used during simulation. Grid points are the device "resolution" used by Suprem4 and Medici. A higher density will yield more accuracy, but will take longer to run. Thus, a balance had to be reached. A grid factor of 4 was selected as being sufficiently accurate without leading to long run times.

Once tuning of the base process was complete, the entire experiment was run.

V. RESULTS AND ANALYSIS

Since Suprem4 and Medici model only two dimensional devices, resulting current values were extracted as Amps/micron, where a value of current can be estimated be multiplying by a device width value. Thus, extracted values of resistance were in the form of ohm-microns. However, values of sheet resistance were desired, which comes in the form of ohms/square, or equivalently the resistance of a square device of any size. Since this device is 6 microns long, values of ohm-microns were multiplied by a device width of 6 microns in order to find an equivalent square device. See Figure 5 for a table of results.

dose	drive-in (min)	Xj (um)	Rs (e /□)
1.00E+13	20	0.597	261
	30	0.662	256
	40	0.724	255
1.00E+14	20	0.855	80.3
	30	0.956	80.3
	40	1.069	75.8
1.00E+15	20	1.133	10.9
	30	1.272	10.4
	40	1.417	10.1

Figure 5: experiment results

Once the experiment was run, the WorkBench analysis software was used to analyze the results. Least squares analysis was used to determine the following response functions:

$$Rs = 78.8 - 123.4(Q) - 1.88(D) + 1.30(Q)(D) + 55.1(Q^2)$$

$$Xj = 0.958 + 0.307(Q) + 0.104(D) + 0.039(Q)(D) + 0.007(Q^2)$$

where Q is the Log of implant dose, and D is the drive-in time. A response map was then created for these factors and responses. This can be seen in Figure 6. X represents the junction depth (Xj) and R is the sheet resistance (Rs). R-square values, a measure of model fit, came out to be 0.999 for both responses. This was expected, as a software approach naturally has very little variability relative to an actual fabricated experiment.

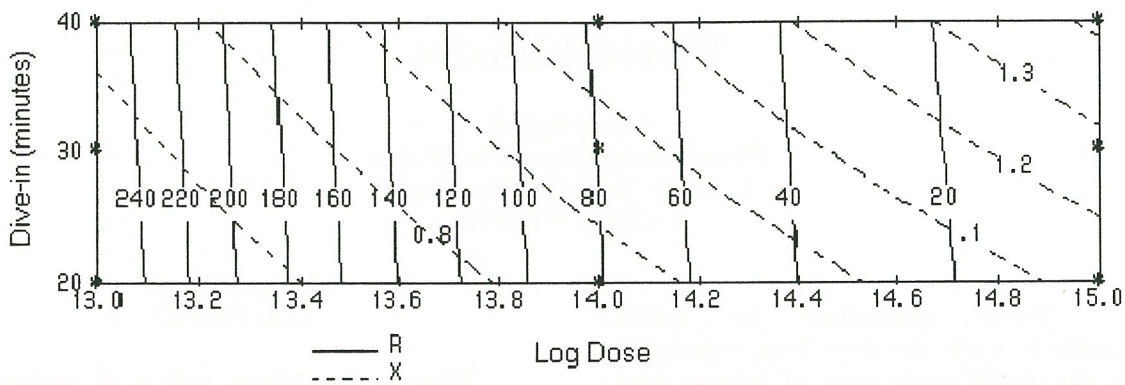

Figure 6: response contour map

VI. CONCLUSION

Use of TMA WorkBench for the design, management and analysis of an experiment was explored. A method of incorporating feedback for the tuning of the simulated device was developed, as well as a framework for comparing final experimental results between simulated and fabricated devices. A complete test device was designed from the ground up, including detailed process steps. This device was then used for an example experiment in order to demonstrate the power of this software.

Due to time constraints, an abbreviated experiment was simulated. Results from this experiment were analyzed by the WorkBench analysis software, yielding response functions and contour maps.

References:

[1] Bipolar Junction Transistor Optimization in TMA WorkBench, TMA Times, Spring 1997.