N-Minus Resistance Control for 6 inch GaAs MESFET Manufacturing

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Abstract

The scale-up from 4-inch to 6-inch wafer size presents significant advantages to the GaAs IC manufacturer. This scale-up brings with it several challenges however including maintaining good process control and good process uniformity. As wafer size is increased, minimizing the variation in key parameters such as N-minus resistance becomes increasingly important since increased variation may result in increased yield loss. In this work variation of N-minus resistance associated with variations in the Ion Implant and Rapid Thermal Anneal (RTA) processes was investigated. Process monitors for these processes were used to detect changes in implant dose and activation temperature. The cause of any observed changes in the unit processes was investigated and action taken to restore affected process. It was determined that a significant fraction of the observed variation in N-minus resistance was caused by (previously undetected) changes in activation temperature. A process control scheme based on the RTA process monitor has enabled us to reduce the total variation of N-minus resistance by as much as 50%.

Introduction

Variation in N-minus resistance is thought to cause variation in device parameters such as Idss, gm, the intrinsic capacitances, and FET breakdown voltages. Variations in these device parameters may in turn lead to increased variations in circuit performance and consequent yield loss.

The objectives of this work were to identify the major sources of N-minus resistance variation and to a significantly reduce this variation.

Ion implantation and thermal activation processes are typically used to fabricate GaAs MESFET devices. These processes in large part determine the N-minus resistance value measured at the end of the process. Consequently, if the variation of these processes is reduced we would expect that the variation in N-minus resistance would be reduced.

We begin with an examination of N-minus resistance data to gain some understanding of the modes of variation that exists and to estimate the relative importance of these different components of variation. We then describe the fabrication of process monitor wafers and present process monitor data for the implant and the RTA processes collected over a period of several months. We discuss how the process monitors were used to detect changes in the unit processes and to determine specific causes of these changes. Finally, we present the N-minus resistance data to illustrate the significantly better control of N-minus resistance achieved.

Analysis of N-Minus Variation

The variation in N-minus resistance can be broken down into at least three components: site to site variation over a wafer, wafer-to-wafer variation and lot-to-lot variation. A variance components analysis was carried out on N-minus resistance data collected over a period of three months to determine the relative magnitudes of these components of variation. If the magnitudes of the individual components of variation are significantly different, it suggests certain causes of N-minus variation may be more important than others.

An example of the variance components analysis result is given in table 1.

TABLE 1
Analysis of Variance for N-minus resistance

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-------------------------------------------------------------------------------
Source                Sum of Squares    Df    Mean Square   Var. Comp.  Percent
-------------------------------------------------------------------------------
TOTAL (CORRECTED)          1.38898E7  10090
-------------------------------------------------------------------------------
Lot                        8.74311E6    17       514300.0      886.247    62.07
Wafer                      2.19133E6   124        17672.0      244.442    17.12
Site                       2.95533E6  9949        297.048      297.048    20.81
-------------------------------------------------------------------------------
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The relative magnitudes of the components of variation expressed as a percent are given in the last column of table 1. As indicated in this table, lot-to-lot variation (Lot) accounts for about 62 % of the total N-minus variation observed in these data. Wafer-to-wafer variation (Wafer) accounts for about 17 % of the total N-minus variation and site-to-site (Site) variation accounts for the remaining 21 % of the observed variation. We performed the same type of analysis on data from other implant and RTA process “families”. Lot-to-lot variation accounted for between 60% and 75% of the total N-minus variation in each case. Closer examination of the data sets suggested that the magnitudes of the components of variation should be interpreted as imprecise estimates only. With this caution in mind we conclude that lot-to lot variation is a significantly larger component of N-minus variation than wafer-to-wafer or site-to-site variation.

Development and Implementation of the Monitors for Implant and RTA Process

Measurements of electrical parameters such as N-minus resistance are typically made at several points in the wafer fabrication process. Our first measurement of sheet resistance is taken after the activation process to help ensure the integrity of the implant and activation processes. After this sheet resistance measurement the wafers undergo several levels of subsequent processing before fab processing is completed and the final N-minus measurement is performed. While many processes such as wet clean processes, plasma processes and photo processes can and do influence N-minus resistance, the sheet resistance measurement taken after activation is highly correlated with the N-minus resistance measurement taken at the end of the wafer fabrication process. This suggests that process monitors based on a sheet resistance measurement are suitable for monitoring the implant and activation processes. That is we would expect that a significant change in a process monitor measurement would also be reflected in a change in an N-minus resistance value. It also suggests that actions that reduce the variation in the output of the implant and RTA processes will result in a corresponding reduction in the variation of N-minus resistnace.

In order to detect the changes in implant and activation processes that result in increased variation in N-minus resistance, it was essential to develop the process monitors which are sensitive to the small changes in implant dose and RTA temperature.

Implantation Monitor

To maximize the sensitivity of a process monitor to changes in a single process, the effect of all other processes used to fabricate the monitor must be minimized. An implant monitor therefore must be designed such that the variability of the activation process is minimized. The approach outlined below was suggested by M. R. Wilson, et al.[1] several years ago.

Implant monitors are fabricated by: (i) depositing silicon nitride over the whole wafer, (ii) covering the right half of the wafer with photo resist and implanting the left half with a standard implant, (iii) stripping the photo resist off of the right half wafer and depositing photo resist on the left half of the wafer.

The result is a wafer that has been implanted on the left half but has received no implant on the right half of the wafer. When it is desired to check for a change in implant dose – perhaps after a maintenance event -- the second (un-implanted) the right half of the monitor is implanted using the same standard implant schedule as was used to implant the left half of the wafer. After this second implant the entire wafer is activated and the sheet resistance of each half is measured. The difference between the average sheet resistance measured on left half of the wafer and average sheet resistance measured on the right half of the wafer is a measure of the change in implant dose.

Figure 1 is a plot of the left-to-right side change in sheet resistance observed on a series of implant monitors. The data was collected over a six week period and captures many of the maintenance events typical of this implanter. The average decrease in monitor sheet resistance is about 1.7 ohms per square.

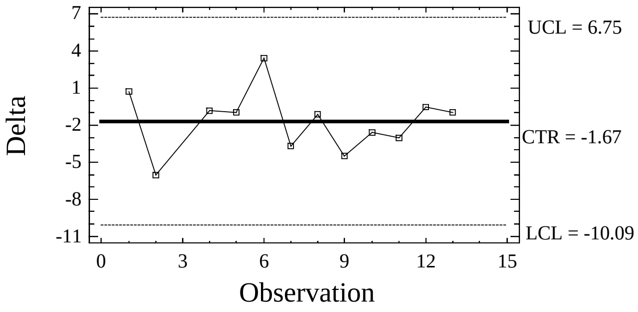

Fig. 1 Implant dose monitor data.

Assuming the variation in sheet resistance shown in figure 1 is typical of that caused by the variation in implant dose, we estimate that variations in implant dose can account for no more than 20% of the total observed variation in N-minus resistance.

RTA Monitor

The activation efficiency of Si-implanted GaAs depends on several factors including the stoichiometry of raw material, implantation-induced surface damage, and the details of the activation process[2,3]. Over the range of implant doses and activation temperatures typically used in GaAs MESFET processing our experience suggests that N-minus sheet resistance becomes more sensitive to changes in RTA processes at higher implant doses and lower implant energies. Accordingly a high dose / low energy implant schedule was used to fabricate the RTA monitor.

This RTA monitor wafer was used to verify the RTA system periodically through the run cycle of the tool (that is between scheduled maintenance events), immediately before and after each scheduled and unscheduled maintenance event, and any time the tool required verification.

The major components of the RTA system under study include two optical pyrometers to control temperature, a quartz chamber and a graphite susceptor. One pyrometer probes the quartz chamber while the other pyrometer probes the both the susceptor and the quartz chamber. The difference in two pyrometer signals is interpreted by the RTA electronics as a measure of wafer temperature. The susceptor is made of a silicon carbide coated graphite and it is comprised of upper and lower shells. The wafer to be processed is sandwiched between the shells.

Figure 2 is a plot of the RTA monitor sheet resistance measurements taken over a three month period. As illustrated in the figure several anomalous spikes occurred in this time period.

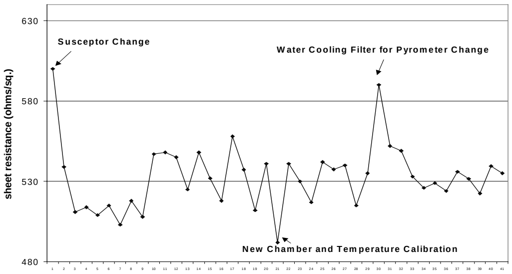

Fig. 2 The sheet resistance of the RTA monitor

The first point in the graph of figure 2 is a high sheet resistance point that was observed immediately after a susceptor change. We hypothesize that the characteristics of the newly installed susceptor were sufficiently different from the characteristics of the old susceptor so as to cause a decrease in activation temperature. To confirm that the actual activation temperature had changed with the change of susceptor we measured the actual substrate temperature with a series of thermocouples installed on a test wafer. We found that switching susceptors could result in a temperature difference of as much as 30 degrees Celsius.

To determine if regular maintenance items such as instrument calibrations could compensate for the change in susceptor, we performed the recommended equipment calibrations. These procedures were not able to compensate completely for the effect of the changed susceptor however. To compensate for the changed susceptor we adjusted the emissivity constant in the instrument setup. Changing the emissivity constant causes the differential pyrometer to “see” a different intensity that is interpreted as a different temperature. After several additional monitor runs the emissivity constant was again changed slightly to center the sheet resistance of the monitor at 530 ohms per square.

At the point labelled, “New Chamber and Temperature Calibration”, the quartz chamber of this RTA system was changed out and a routine calibration procedure performed. As indicated in the figure these procedures resulted in an apparent shift in the RTA temperature. In response to this anomalously low point the maintenance procedures were updated.

At the point labelled, “Water Cooling Filter for Pyrometer Change”, the filter for the pyrometer water cooling was changed as part of a regular preventative maintenance program. This caused a change in pyrometer temperature that in turn caused the pyrometer to interpret the substrate temperature differently. To compensate for the changed substrate temperature the emissivity constant of the tool was adjusted.

Discussion and Conclusions

As illustrated in the examples presented in the previous section, the RTA monitor was found to be extremely useful in detecting unanticipated changes to the activation temperature. We have incorporated both the implant monitor and the RTA monitor into our process control procedures for these operations and we consider these monitors to be key elements of these process control plans.

The improvement in N-minus resistance control that has been obtained using these monitors is illustrated in Figure 3 where we have plotted the Lot Average N-minus resistance for a series of lots. A comparison of the lot-to-lot variation in N-minus resistance before the project was started to the lot-to-lot variation in N-minus resistance achieved after the monitors were introduced into the process control plans indicates a significant improvement in N-minus control has been achieved. We estimate the total variation in N-minus resistance has been reduced by about 50%.

If we repeat the variance components analysis using N-minus data taken after the monitors were incorporated into the control plans for these processes we find the total variation was decreased and relative magnitudes of site-to-site, wafer-to-wafer and lot-to-lot are approximately equal.

Since the relative magnitudes of the components of N-minus variation have changed, the approach to achieving further reductions in N-minus variation may change. Examination of current N-minus data suggests that within the data there are patterns of non-random variation. Follow-on work may therefore include investigating the origins of this non-random behavior.

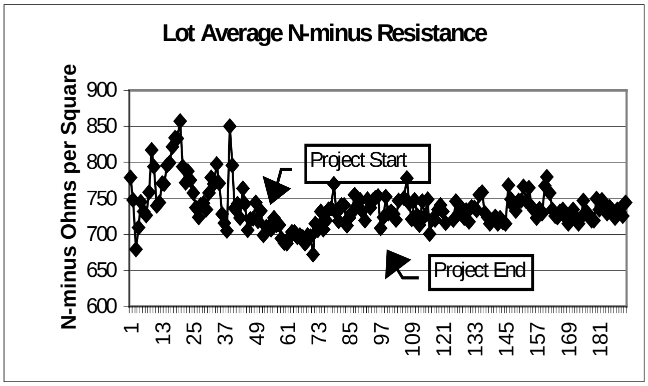

Fig. 3 Lot average N-minus Resistance

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