Control Chart developments for Gate Oxide thickness for an NMOS process

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Abstract:

A control chart system was developed to monitor the gate oxide thickness of an NMOS process. The control limits were XBB=149Å, RB=26Å, UCLXB= 164Å, LCLXB=134Å, UCLR=54Å and LCLR=0Å for the XB and Range charts. There were three violations due to exceeding s limits, indicating that while control limits were able to be determined, the process needs to be investigated for improvements. This report details the decisions and objectives of the SPC study, the procedure used to determine the control limits and recommendations.

Objective/Decisions relating to Control Charts:

The objective of this project is to learn control charts, and to determine if the process used to grow the gate oxide of an MOS transistor is in control. The oxide thickness will be used as the variable because it can be measured nondestructively with a nano-spec, and it affects the threshold voltage significantly[1]:

$$V_T = \varphi_{ms} - Tox((Q_D + Q_{SS})/\epsilon_{SiO2}) + 2\varphi_F$$

The subgroups will be five measurements taken according to standard operating procedure from each gate oxide run. One run will be considered a batch given that the data come from a single wafer process sing station. This should inquire that the sub group variability (five points from one wafer) is less than the wafer to wafer variability.

Procedure Used to Determine Control Limits:

The control limits for an XB, R chart were first estimated by taking the first 20 runs for the data (Figure 1). The Western Electric SPC rules[2] were then checked manually for violations.

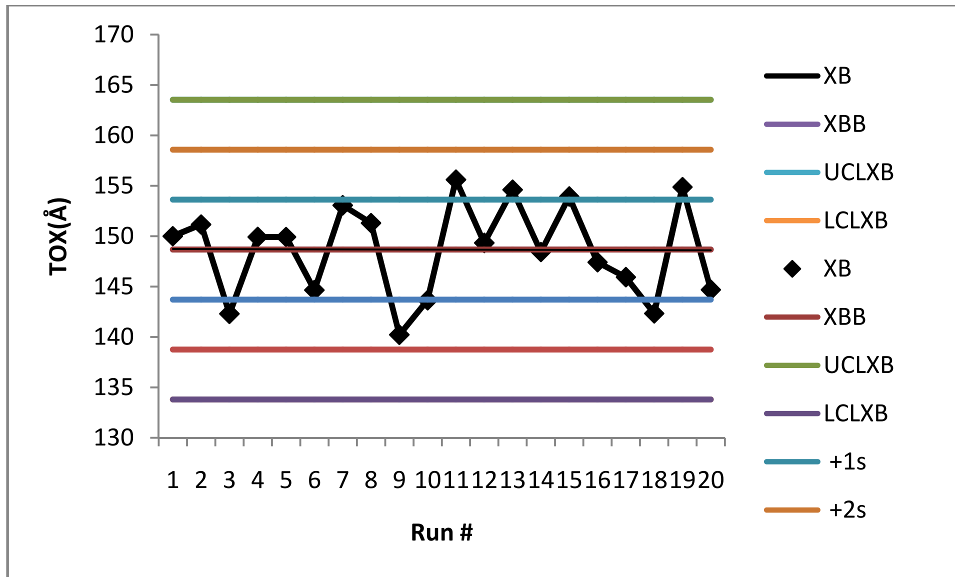

Figure 1: XB chart for the first 20 runs of data. XBB=149Å, RB=26Å, UCLXB= 164Å, LCLXB=134Å.

There is not one point beyond the 3σ control limit. 2 out of 3 consecutive points plot outside the 2σ control limit are not observed. 4 out of 5 consecutive points plotting outside the 1σ control limit are not observed. 9 consecutive points on the same side of the centerline were not observed. 6 consecutive points increasing or decreasing were not observed. 14 consecutive points oscillating up and down was not observed. 15 consecutive points inside the 1σ control limit were not observed. Given that no rules were violated for the XB chart, it is accepted pending review the RB chart.

The first twenty runs were used to create a RB chart (Figure 2). There were no observed violations of the data in the Range chart.

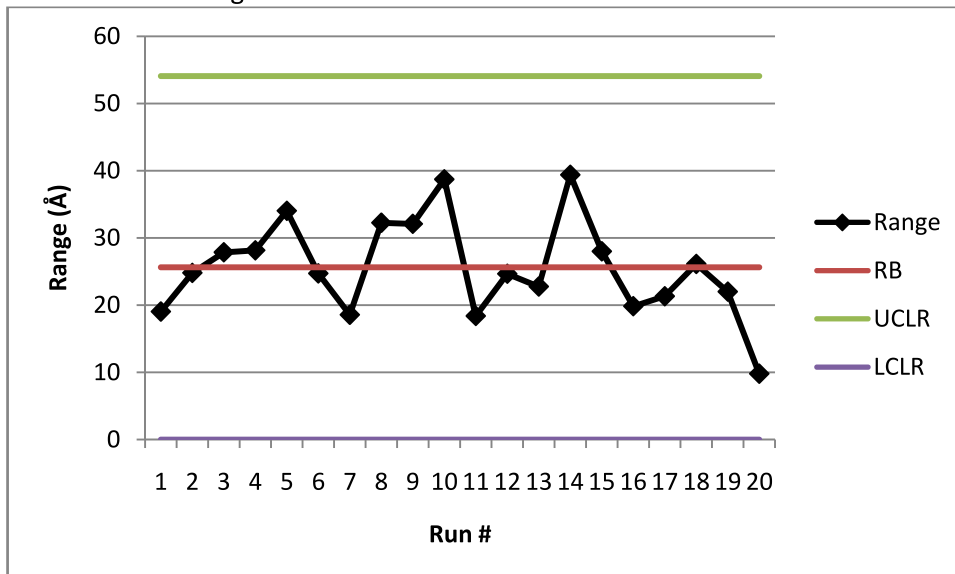

Figure 2: Range chart, RB= 26Å, UCLR=54Å LCLR=0Å.

Given there were no violations in the XB, and Range chart the rest of the data was plotted using the control limits shown in Figure 1and Figure 2. Runs 1 through59 can be seen in Figure 3.

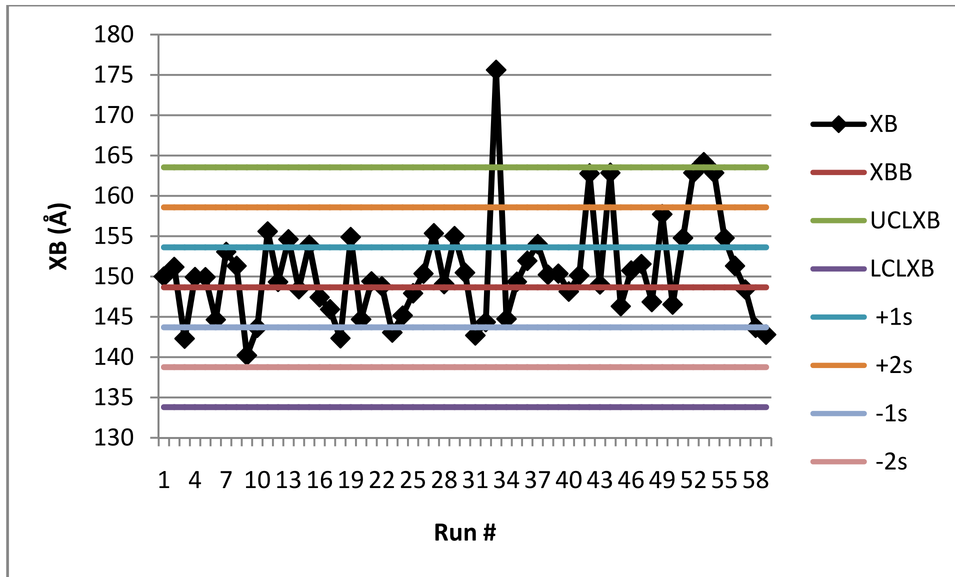

Figure 3: XB chart for complete data set. XBB=149Å, RB=26Å, UCLXB= 164Å, LCLXB=134Å.

Looking at Figure 3 it is observed that there are two data points outside the 3s limits (runs 32, and 55). There are also two set of data where two out of three points lay outside the 2s limits (runs 41-43, and runs 52-55). In addition, the last six runs have data the successively decreases. The data that violates the 3s and 2s rules might be explained by the original 20 data points not being sufficient to characterize the process, and by recalculating the control limits based on the whole data set might shift the limits such that the violations disappear. Regardless of recalculating the control limits, the trend for the last six runs is clearly decreasing and it indicating the process is very likely out of control and that resources should be dedicated to fixing the problem.

To test whether the control limits should be recalculated, an XB chart was created with the entire data set (Figure 4). It can be seen that there are still three outside a control limit type error and one trend error, even with the adjusted control limits.

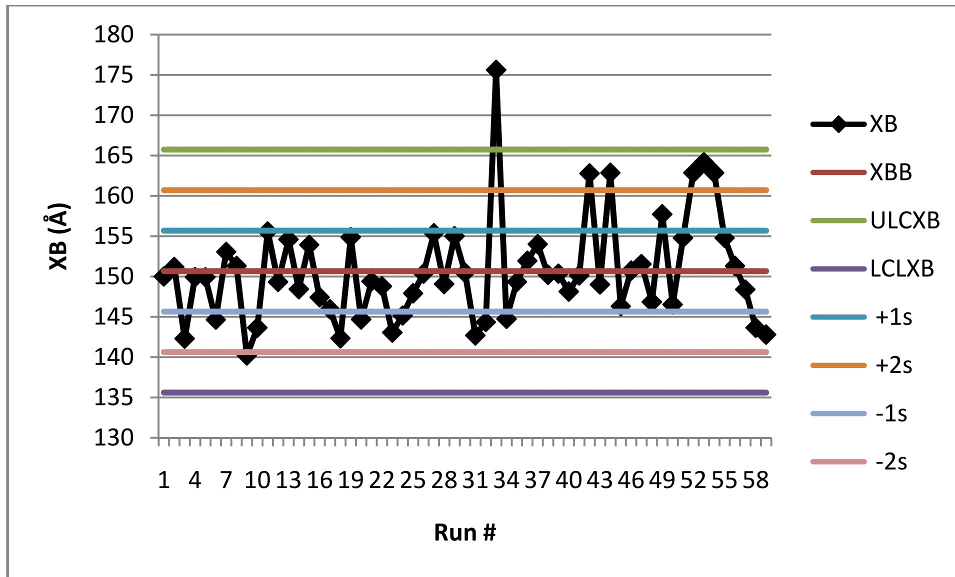

Figure 4: XB chart for whole data set. XBB=151Å, RB=26Å, UCLXB= 166Å, LCLXB=136Å.

Figure 5 shows how the control limits change when the 3s violation is removed. The other violations remain however.

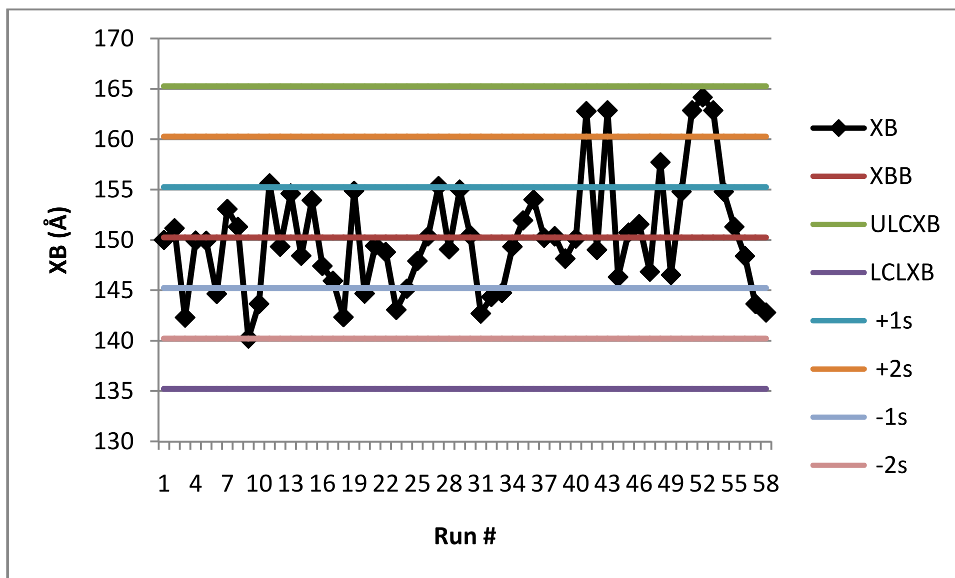

Figure 5: XB chart with 3s violation removed. XBB=150Å, RB=26Å, UCLXB= 165Å, LCLXB=135Å.

Figure 6 and Figure 7 show how the control limits change after removing the 2s violations. Interestingly enough, after these violations are removed the trend violation disappears. Figure 7 seems to represent a good estimate of the control chart parameters required to monitor the oxide thickness. Figure 8 is a Range chart based on the clean data and shows no violations.

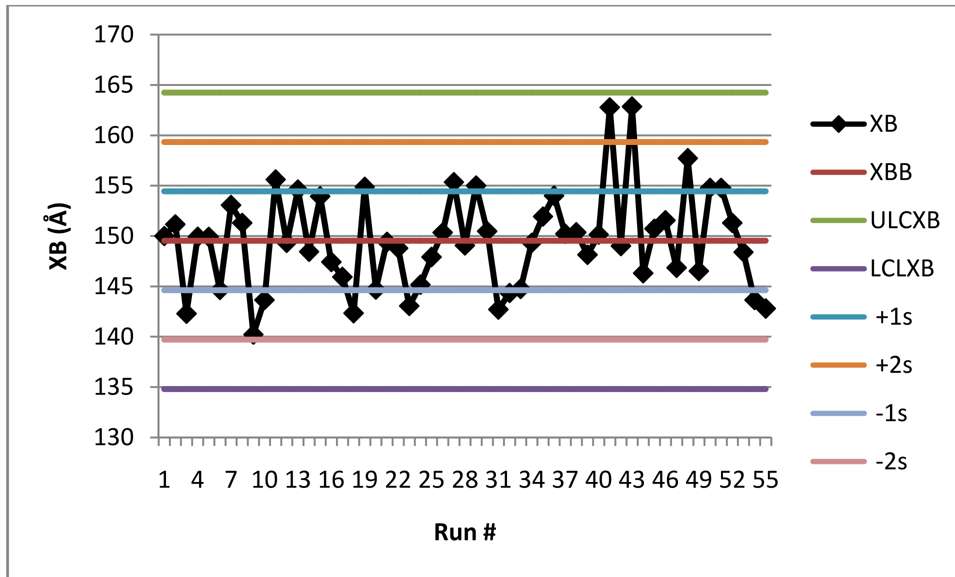

Figure 6: XB chart with three 2s violation removed. XBB=150Å, RB=25Å, UCLXB= 164Å, LCLXB=135Å.

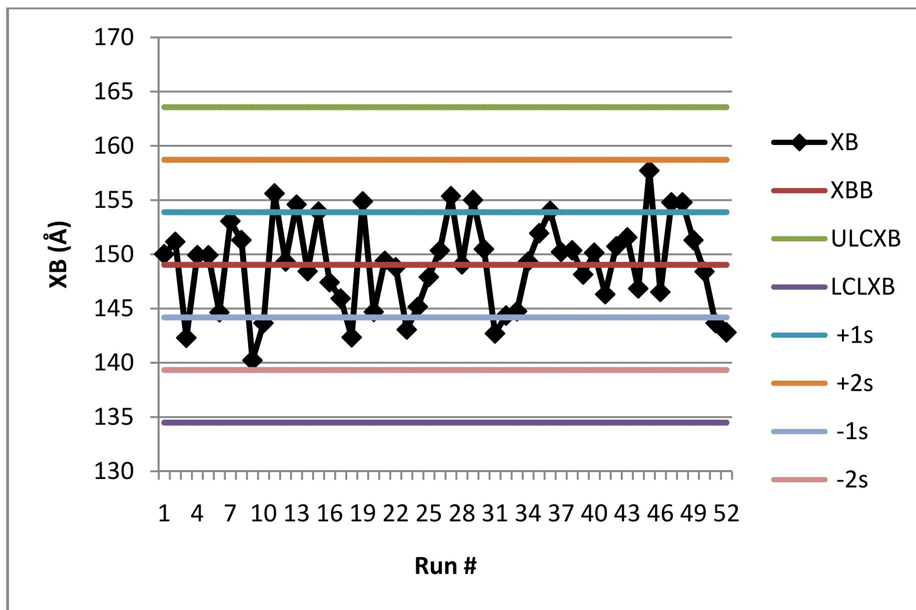

Figure 7: XB chart with additional 2s violation removed. XBB=149Å, RB=25Å, UCLXB= 164Å, LCLXB=134Å.

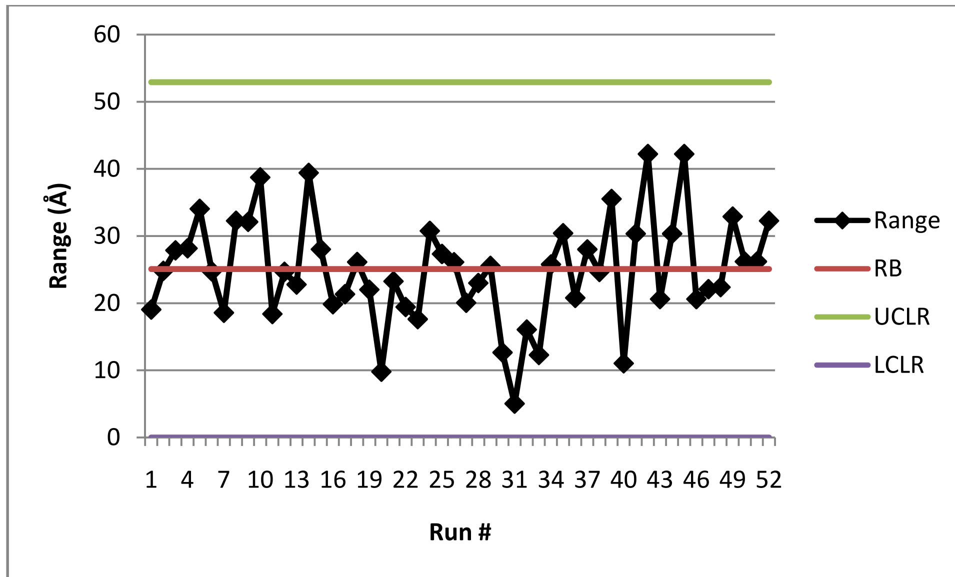

Figure 8: Range chart with all violations removed. XBB=149Å, RB=25Å, UCLR= 53Å, LCLR=0Å.

Recommendations and Conclusions:

It is recommended that while the data received from the testing house showed some areas of concern about the process, that the following control limits should be used to monitor the gate oxide thickness: XBB=149Å, RB=26Å, UCLXB= 164Å, LCLXB=134Å, UCLR=54Å and LCLR=0Å. These control limits were taken from the first twenty runs of the process, and matched closely with the control limits generated by the whole data set, with the SPC violations removed, (Figure 7 and Figure 8 with XBB=149Å, RB=25Å, UCLXB= 164Å, LCLXB=134Å. XBB=149Å, RB=25Å, UCLR= 53Å, LCLR=0Å.) It is further recommended that resources be dedicated to determine the causes of the observed violations.

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[1] S. M. Sze and K. K. Ng, Physics of Semiconductor Devices, third edition John Wiley, New Jersey, 2007.
[2] G. S. May and C. J. Spanos, Fundamentals of Semiconductor Manufacturing and Process Control, John Wiley, New Jersey, 2006.