Problem Solving Activity
MEMS (MicroElectroMechanical Systems) Process Problem
Instructor Guide

Note to Instructor – READ THIS FIRST!

This activity is intended to give participants additional practice in using a systematic approach to problem solving by solving a realistic problem that can occur in just about any MEMS photolithography process. Participants should follow the six steps to problem solving as close as this problem allows. As the instructor, you are to play the role of data provider and offer "limited" guidance.

Here's how the activity works

- Participants play the role photolithography technicians and other employees in a micro-fabrication process.
- The result of a quality check on photoresist thickness shows the photoresist thickness out-of-control.
- Participants follow the six-step problem solving process to determine the root cause of the problem.
- As the instructor, you already know what the root cause of the problem is and the details around the problem (see below). It is your job to facilitate getting the problem solving teams to learn what you know. However, you are to provide no information unless it is requested by the team. Below are what you know and what the problem solving team needs to discover.
- *What the instructor knows*
    - **The root cause of the photoresist thickness problem is** "an increase in photoresist viscosity due to a new batch of resist".
    - The resist was purchased from your regular supplier. All of the specifications that you use when purchasing the resist match what you have purchased before.
    - The only thing that you see is different is the lot number. The new batch of resist has a different lot number than the batch you have been using.
    - The problem with resist thickness occurred shortly after switching to a new bottle of resist from the newly purchased resist. (See additional information provided at the end of this Instructor Guide.)
    - Only the machine that has the new bottle of resist is showing the problem.
    - **The underlying root cause of the problem** is that the viscosity of the resist is on the high side of the supplier's acceptable control limit; however, since your company only orders resist based on a mean viscosity value, you, the buyer, are unaware that the resist may have a "little higher" viscosity than what you expect. **ALSO**, your resist storage facility AND the manufacturing facility are kept at temperatures at least 10° F

below your supplier's temperatures. Therefore, the viscosity of the resist can increase slightly in storage and during operation.
    - **Solution** – There are some obvious solutions to this problem; however, some are more time-consuming to implement and more costly than others. Your problem solving teams need to develop action plans that can be implemented quickly and at the lowest cost and that will resolve the current problem and prevent it from reoccurring. (More on this later.)
- Throughout this activity, you, the instructor, are to provide more information about the problem. However, do not give any of the information to the participants unless they ask for it.
- At the end of this Instructor Guide, you will find the following documents and information to provide the participants once, and if, it is requested.
    - Process Information and Process Flowchart for Microcantilever fabrication. (The wafers are which to problem occurred were for microcantilever arrays.)
    - A chart showing the relationship between resist thickness and spin speed, and resist thickness and resist viscosity.
    - Maintenance Records information
    - Personnel Information
    - Resist Thickness histogram
    - Control Chart for particle counts prior to photolithography
    - Control charts for silicon nitride layer
    - Control charts for metal deposition layer
- The teams present questions and data requests as part of Step 2 and Step 4.
- *Below is what the participants should do*:
    - Step 1: Write a Problem Statement.
    - Step 2: Develop a list of questions and requests for information and submit that list to the instructor. *You, the instructor, provide just what they ask for. If their questions are Yes/No questions, then answer ONLY with a Yes or a No. Charts and additional information are provided at the end of this Instructor Guide that include relevant data that the teams should request. You may have to add more information than provided here. So just make things up as you go, always keeping the root cause of the problem in mind.*
    - Step 3: Brainstorm for possible causes to the problem using a Cause & Effect (C&E) diagram.
    - Step 4: Analyze the possible causes against the data and information collected in Step 2. Submit more questions and requests for more data to the instructor.
    - Step 5: Using all of the information collected, identify the root cause of the problem. Develop an action plan.
    - Step 6: Identify how you will verify that the problem has been fixed.

This Instructor Guide helps you to facilitate this activity so that the participants can successfully use the six-steps and experience the effectiveness of this process. Participants need to have completed all of the previous units for this learning module in order to solve this problem effectively and efficiently.

The *Systematic Problem Solving Learning Module* consists of the following:

- Activity: Thinking Creatively
- A Systematic Approach to Problem Solving PK (Reading material)
- Brainstorming Activity
- Problem Solving Activity – The Lawn
- Problem Solving Tools PK
- **Problem Solving Activity – A MEMS Process Problem**

This companion Instructor Guide (IG) contains all of the information in the Participant Guide (PG) as well as answers to the activities.

Activity Description

In this activity you apply a systematic approach to problem solving to solve a problem in the photolithography aisle of a microfabrication facility. You and your team have been directed to solve the problem and fix it. You are to use the six-steps of problem solving to identify the cause of this problem, develop an action plan on how to fix it, and develop the plan to verify that the problem has been fixed.

You will be evaluated on how well you apply a systematic approach to solving the problem, how wel you communicate with your team members and those from which you gather information (your instructor), and how well you work together as a team.

<u>Time to Complete</u>
Approximately 45 minutes

Objectives

- Given a microfabrication problem, work with at least two other people to solve the problem using a six-step approach to problem solving.
- Develop an action plan that fixes the problem.
- Apply effective communication skills through the entire problem solving process.

Activity – MEMS Process Problem

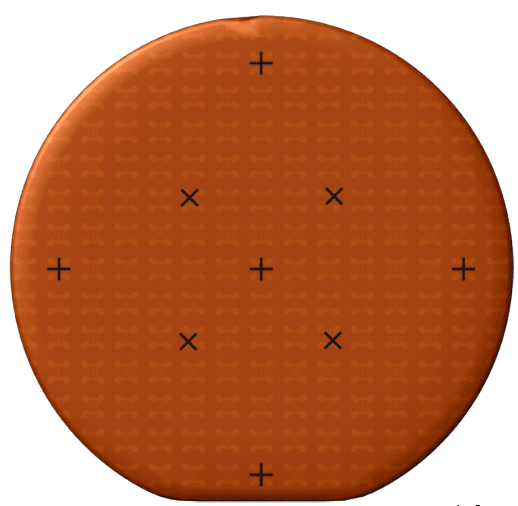
1. Assign the following roles:
    a. Recorder - Writes necessary information on the board, flip chart or computer screen for all to see and keeps a written accounting of the team's process. Recorder is also a participant in the problem solving process.
    b. Facilitator – Keeps the team members on track during the activity and the activity moving forward. Mediates the exchange of information and ensures that all team members participate and understands before moving forward. The facilitator is also a participant; however, the facilitator has to be able to ensure that ALL participants participate and should be careful not to dominate nor control the conversation. An effective facilitator usually waits to contribute until all other participants have contributed. Choose this person wisely.
2. The team – The team consists of employees with different roles from within photolithography (e.g., an engineer, technician, supervisor). However, your job title is not important within the team, but what you know about the process, equipment, and other aspects of the business are important. Within the team you work equally and together to solve the problem.
3. The Problem – A photolithography technician has reported that, after randomly testing several wafers from the last processed batch and plotting the results on the control chart, the resist thickness of this batch of wafers is out-of-control (OOC). The technician consulted the Out-of-Control Action Plan (OCAP) which told her to run another batch of wafers and retest. After retesting she found that the resist thickness was still OOC.

    NOTE: *The OCAP is an action plan that technicians are required to following when an OOC situation is identified. This is the first step that a technician makes. If, after following the OCAP, the process is still OOC, then the problem might require a problem solving team, which is the case presented here.*

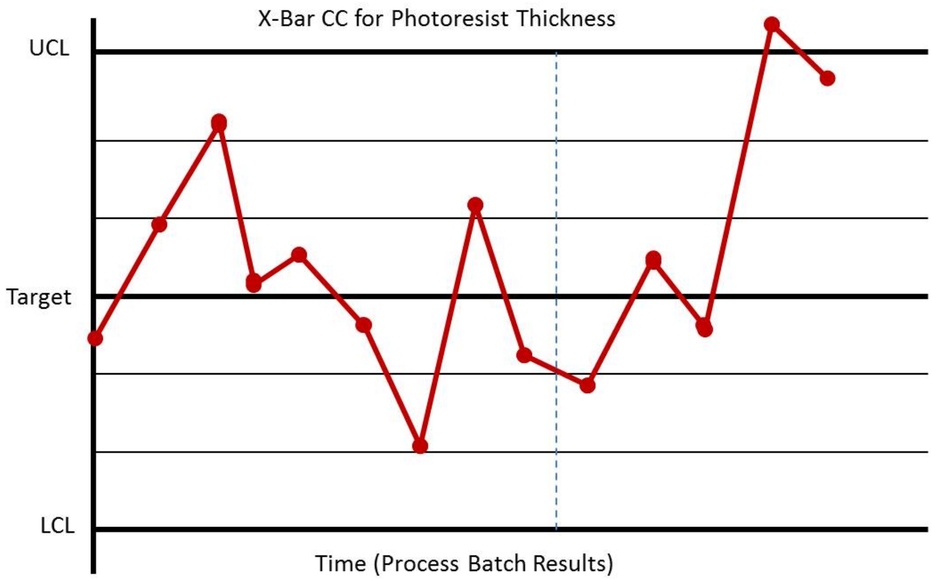
    Following is the company's quality control (QC) procedure for measuring photoresist thickness and uniformity. After the QC procedure are the current control charts for photoresist thickness (x-bar chart) and uniformity (R-chart).

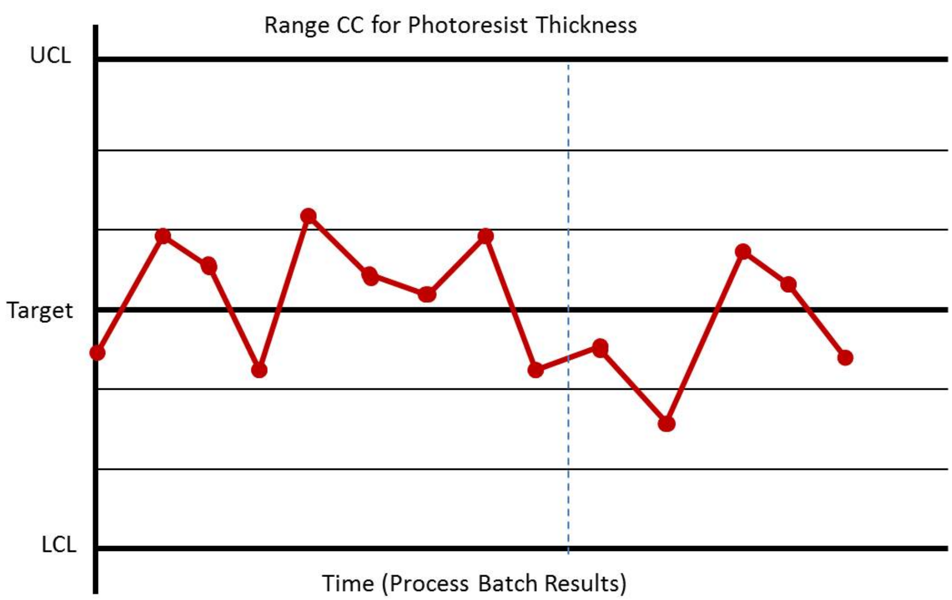
Company's Quality Control Check Procedure

The quality control procedure for resist thickness and uniformity is to randomly select 5 wafers from each processed batch of 24 wafers, and measure the photoresist thickness at 9 points on the wafer. This diagram illustrates those nine points. The *mean* resist thickness for all measurements is calculating and plotted on an x-bar control chart. The mean *range* of thicknesses for the 5 wafers is calculated and plotted on the R control chart.

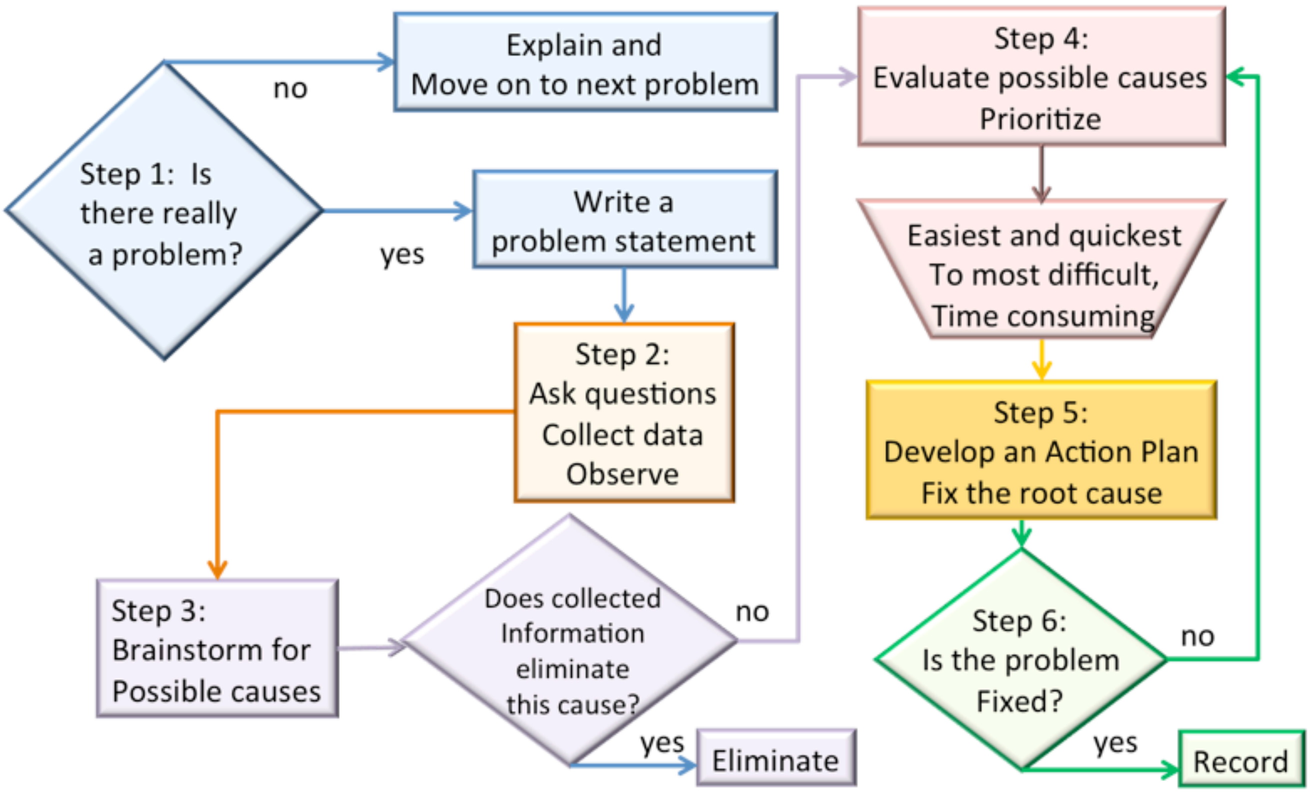


Below are the x-bar and R control charts for photoresist thickness for the last 14 batches of wafers. (**Dashed line indicates shift change**.)





As a team, you are to use the Six Steps of Problem Solving to solve this problem. Direct all analysis and evaluation questions to your instructor.



Let's get started!

Step 1: *Write the problem statement*. Make sure that the whole team agrees with the problem statement before moving forward.

Step 2: *Analyze the problem:* Make a list of questions that you would ask other employees that might know more about the problem, as well as a list of data or other information that you need to know more about the problem. Make sure that any requests or questions are relevant to the problem and in helping to solve the problem. Be sure to word your questions in a manner that yields the most information.

Note to Instructor: Require the teams to provide you with a list of questions and data needed. Give them ONLY what they ask for and nothing more. If a question is a YES/No question, answer Yes or No. The answers to the questions should support the information provided in the first "Notes to Instructor" and the additional information provided at the end of this Instructor Guide.

Some data charts are attached to this Instructor Guide that you can use to provide some of the data that they request. You may need to generate (make-up) other data, depending on what the teams ask for. If a request is for data that has absolutely nothing to do with the problem or is data that is normally not collected or is not available, ask them how such data will contribute to solving the problem.

Examples of data that have absolutely nothing to do with the problem: Training records of employees, cost related data (i.e., how much does resist costs?), control charts for diffusion furnace temperatures

Example of data that are not available: control charts or any data from the suppliers or customers, cost related data

Additional information for the instructor:

- This OOC occurred in the middle of a shift. A photoresist bottle change was made after the second batch of wafers was run on the current shift.
- After the photoresist bottle was changed out, the resist line between the equipment and the bottle had enough of the previous resist to complete well over half of the wafers in the batch (batch 3) ; therefore, even though a few of the wafers in batch 3 could be OOC, the mean of the batch was not OOC. The OOC did not show up until batch 4 of the shift.
- None of the other equipment for resist coating are showing an OOC situation.

Step 3: Brainstorm for possible causes to the problem. Record your results on a C&E diagram.

Step 4: Analyze the possible causes and identify the root cause of the problem. Use the data that you have already collected to eliminate some of the items on your C&E. If you need additional information, submit another set of questions and request for more information to your instructor. You want to end up with only 1 or 2 possible causes to the problem.

Note to the Instructor: The team will submit you additional questions and requests for data in order to reduce the possible causes down to one to two probable causes. Again, only give them what they ask for. You may need to generate more data for them, but only if it is data that they truly need to solve the problem.

At this point in the problem-solving procedure, the instructor may need to offer more guidance on process and procedure as well as to the types of questions that the team should have asked and didn't or the type of data that the team should have asked for and didn't. If the team is off track, provide a hint or two that will direct them in the right direction to identify the root cause of the problem.

Allow the team to ask more questions that will guide to the root cause of the problem.

Step 5: Develop an action plan on how to fix the problem. At this point you should be confident that you know the cause of the problem. Now it's time to fix it. You may find that there are several ways to fix this problem. As a team, discuss the possibilities and develop an action plan for the most effective and efficient solution to the problem.

Note to Instructor: As mentioned earlier, there is more than one way to solve this problem. Some solutions include adjusting the spin speed to compensate for the new viscosity, applying a heater blanket around the bottle to lower its viscosity, trading out the last purchase of photoresist for photoresist from a different lot number and retesting. In all cases, part of the action plan should include working with the supplier to tighten up their controls so that the viscosity of future resist purchases is more in-line with what is needed.

Step 6: State how you will verify that the problem has been fixed.

Present your action plans for Step 5 and Step 6 to the instructor and to other teams. Compare the plans of the different teams and discuss the differences.

Post-Activity Questions

Below are the objectives of this activity.

- Given a microfabrication problem, work with at least two other people to solve the problem using a six-step approach to problem solving.
- Develop an action plan that fixes the problem.
- Apply effective communication skills through the entire problem solving process.

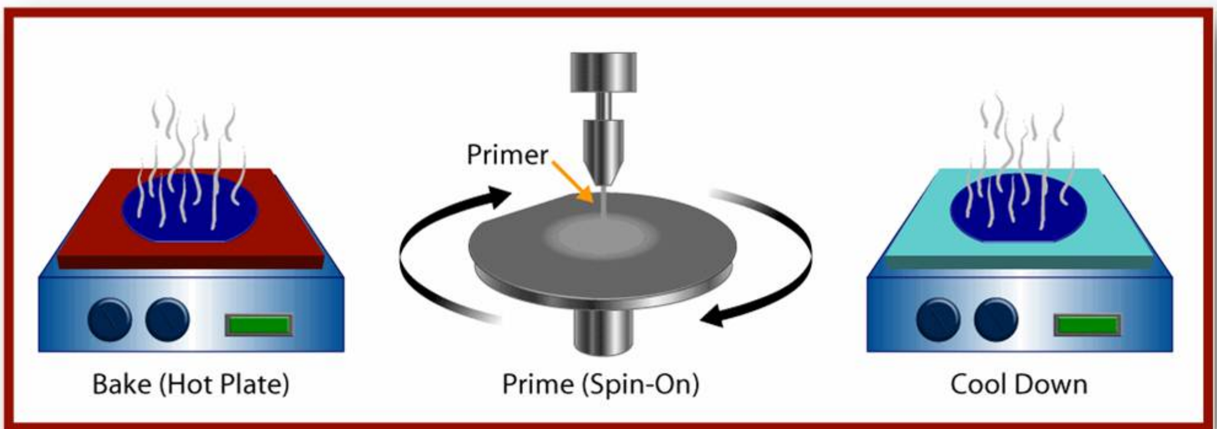
Answer the following questions based on how well you satisfied the objectives.

1. How easy/hard was it to following a systematic approach for solving this problem?
2. Take a look at the questions you developed in Step 2 and identify what you would consider a “weak” question and a “strong” question. Which one of your questions was “weak”? What was one of your “strong” questions? How could the team have improved upon the questions they asked?
3. When selecting and analyzing the “data”, what criteria did you use to determine what was relevant and what was NOT relevant to the problem?
4. What criteria did you use in developing your action plan?
5. As a team, what were your strengths?
6. As a team, what areas could be improved upon?
7. What behaviors helped the team to complete its task?
8. What behaviors hindered the team from completing its task?

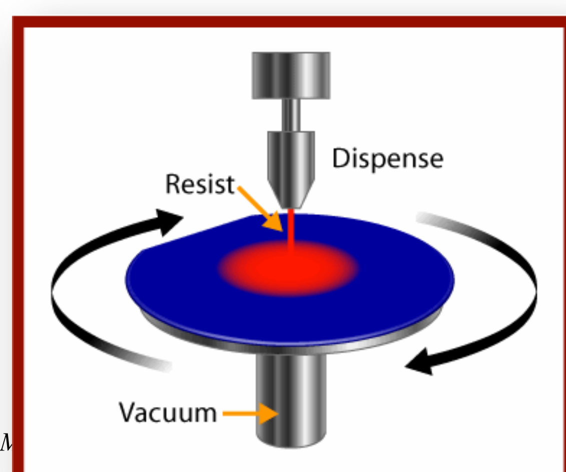
Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).

Review of Photoresist Process

Prior to applying the photoresist, the wafer is conditioned. It is heated to remove any surface moisture, then a layer of HMDS (hexamethyldisilazone) is spun on the surface of the wafer to act as a primer for the photoresist. After the HMDS is applied to wafer, the wafer is cooled prior to applying the photoresist.



Below (left) is a spin coat chamber for applying photoresist (resist) to the surface of a wafer. The wafer sits on a wafer chuck through which a vacuum is applied. The vacuum holds the wafer on the surface of the chuck keeping it from flying off during the spin coat process. Depending on the program, the resist can be deposited onto the center of the wafer prior to the wafer starting to spin or immediately after the wafer starts to spin. Once the resist is deposited, the speed accelerates to its casting speed (the final spin speed).



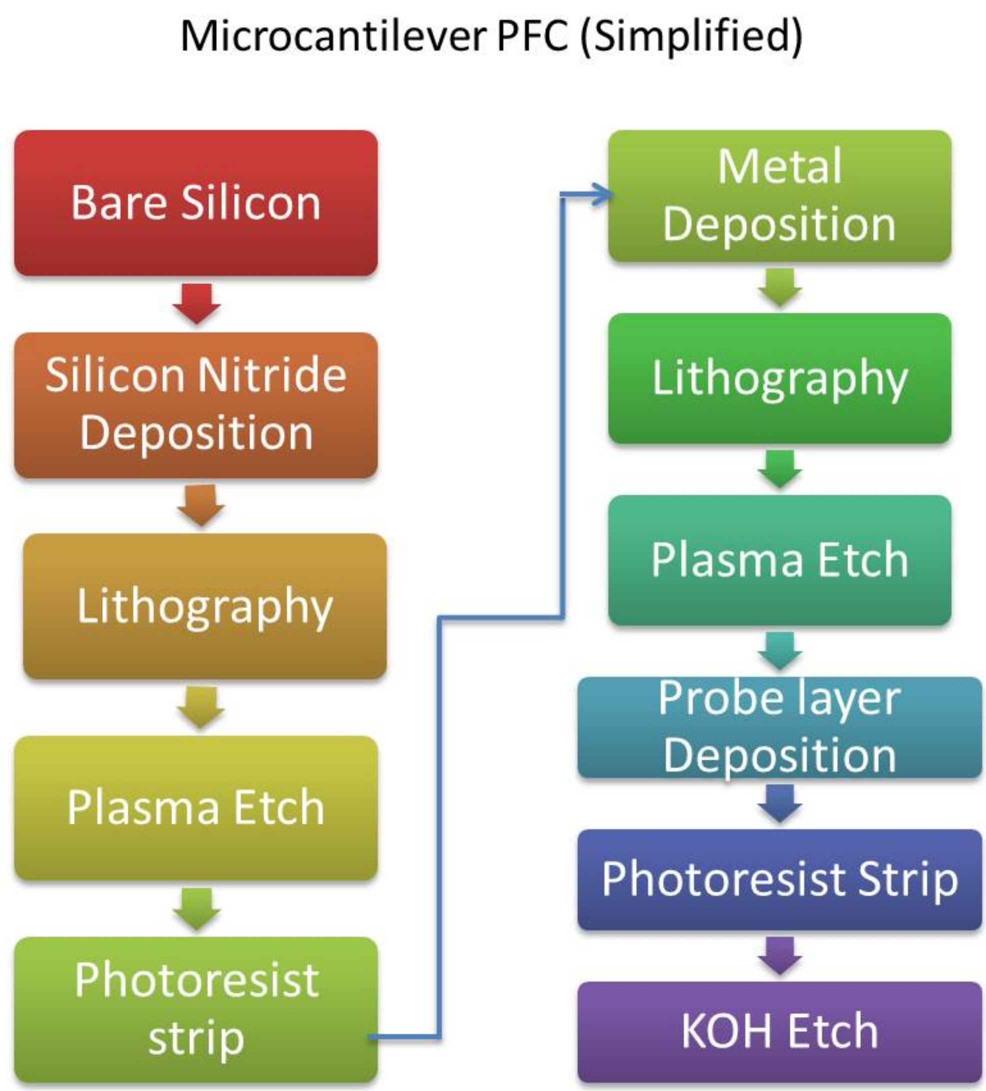
After conditioning, the photoresist is applied followed by a softbake to remove residual solvents from the photoresist. After the softbake then wafer is cooled.

Following is data for the problem solving team AS IT IS REQUESTED

Process Information

Where are the wafers in the process? – The last four batches of wafers are post-metallization wafers. The last four batches are microcantilever arrays. The previous batches were post-silicon nitride wafers for micropressure sensors.

Process Flow for MicroCantilever Fabrication



Maintenance Records

Ellipsometer Calibrations- All ellipsometer calibrations have been completed according to the preventative maintenance schedules. (The ellipsometer is a tool used to measure photoresist thickness)

Coating equipment maintenance –

- The photoresist coat equipment was cleaned at the end of the last shift as required by the equipment maintenance schedule. It is schedule for another clean at this end of the current shift.
- Spin speed calibrations are schedule for all coat equipment after the 50th run. This equipment has completed 22 runs since the last calibration.
- All other preventative maintenance (PM) procedures have been performed as required by the PM schedule.

Resist Bottle Replacement – The photoresist bottle was changed out after the third run of the shift. It was changed on this one piece of equipment only. All other equipment are operating with resist from the previous purchase.

Resist Bottle Information – All of the specifications on this new bottle of resist are the same as the previous bottle except for the lot number. This new bottle is part of a recent purchase from the regular supplier.

Personnel

Technicians/Equipment Operators – There is one new technician in the photolithography aisle. All other personnel have been working this aisle for months. The new technician has been operating the machine with the OOC situation for two days. The new technician was trained by a senior technician for 2 weeks before being released to operate the equipment alone.

Supervisors/Engineers – No changes within the past 6 months.

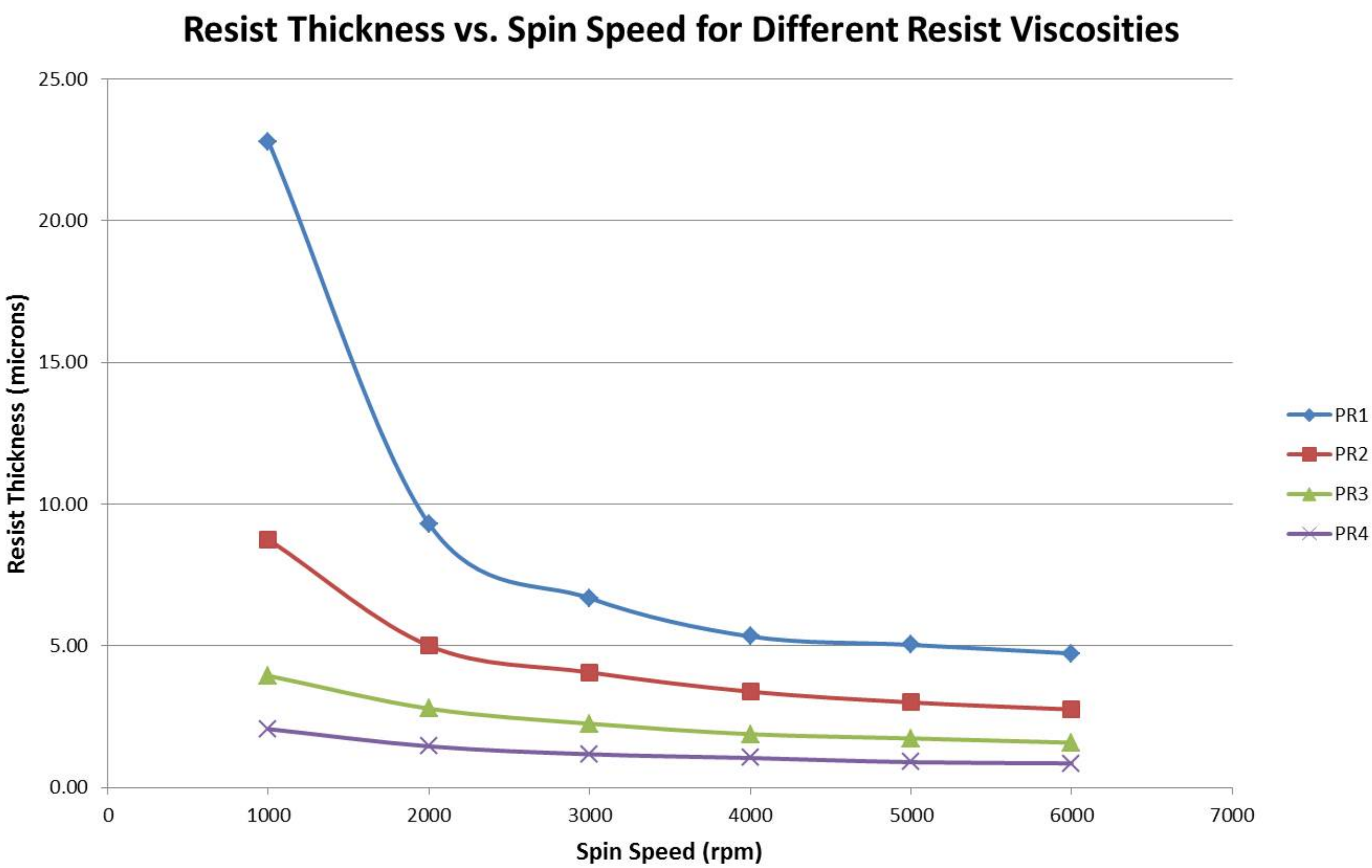
Who measures the resist? – The same person who runs the process performs the QC checks.

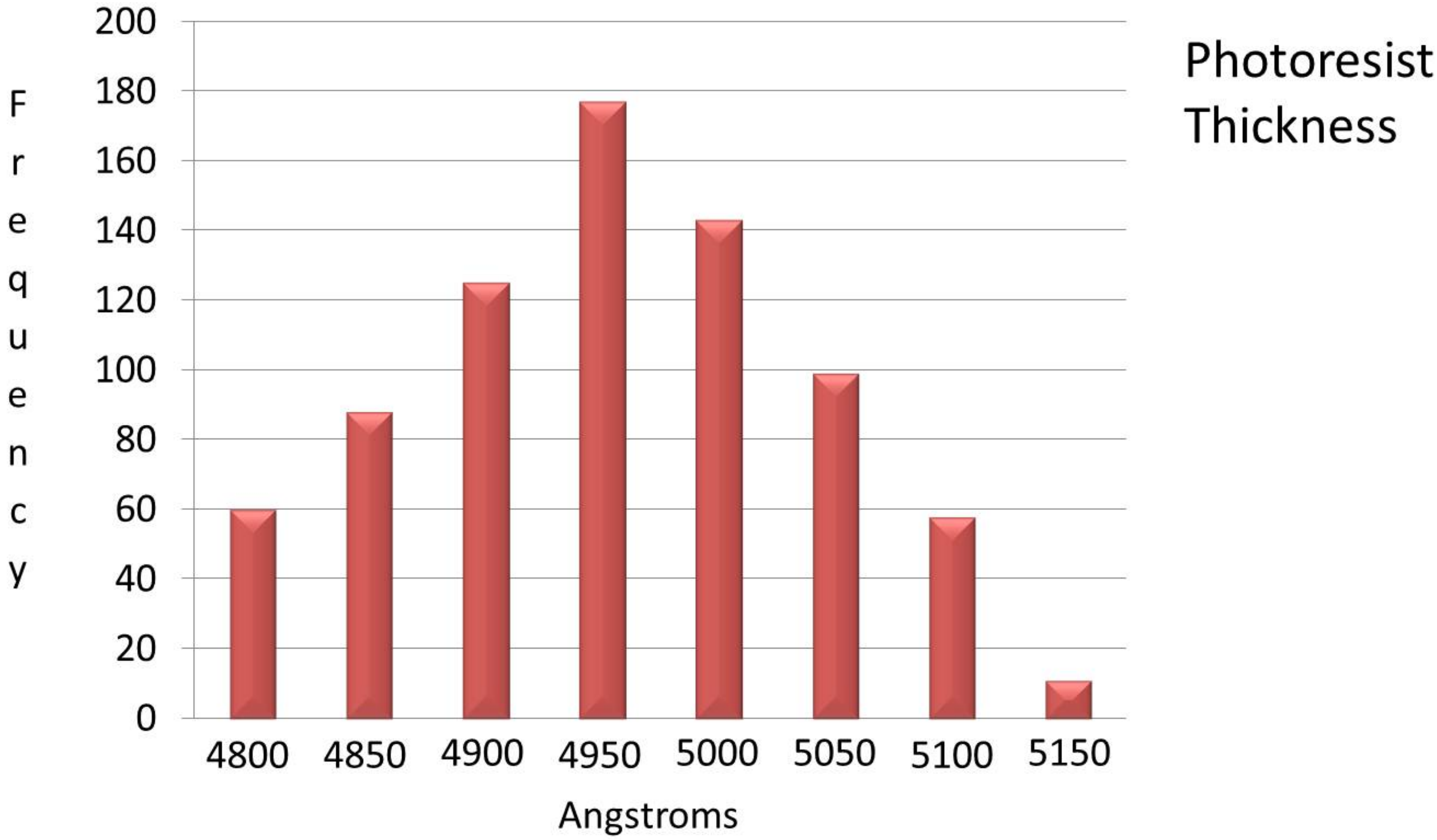
More on personnel – There is one operating technician per equipment. This person runs the process batches, performs all daily PMs (i.e., cleaning and wipe downs), and performs all QC checks on the product leaving the equipment. An equipment technician performs all corrective maintenance, PMs that are not daily (i.e., spin speed calibration, pump maintenance) or any maintenance on the service aisle side of the equipment.

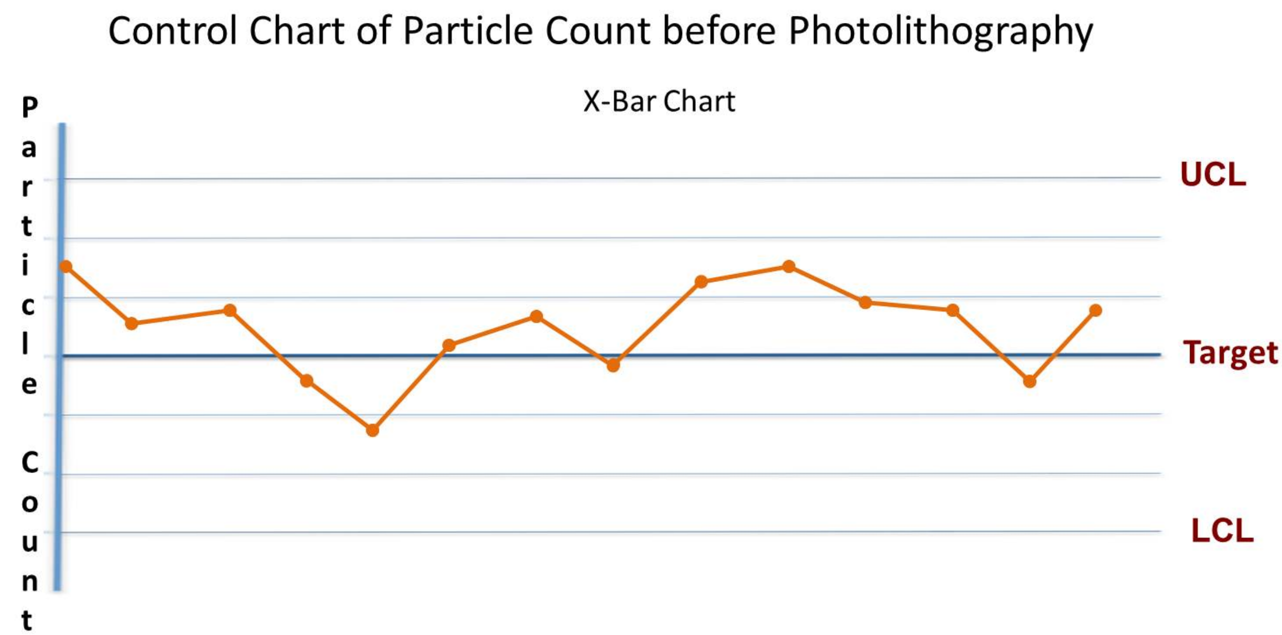
Suppliers – No new suppliers

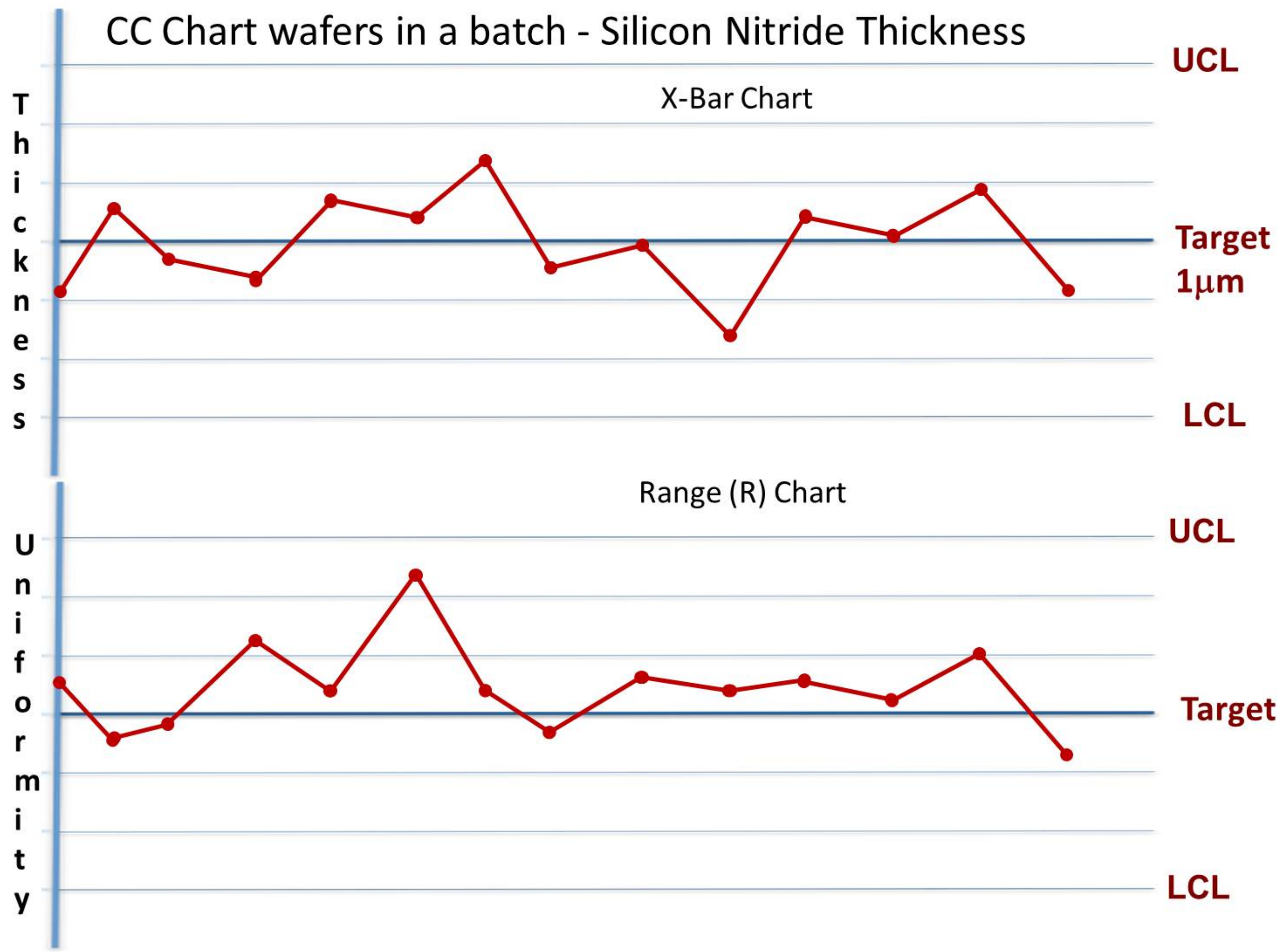
DATA

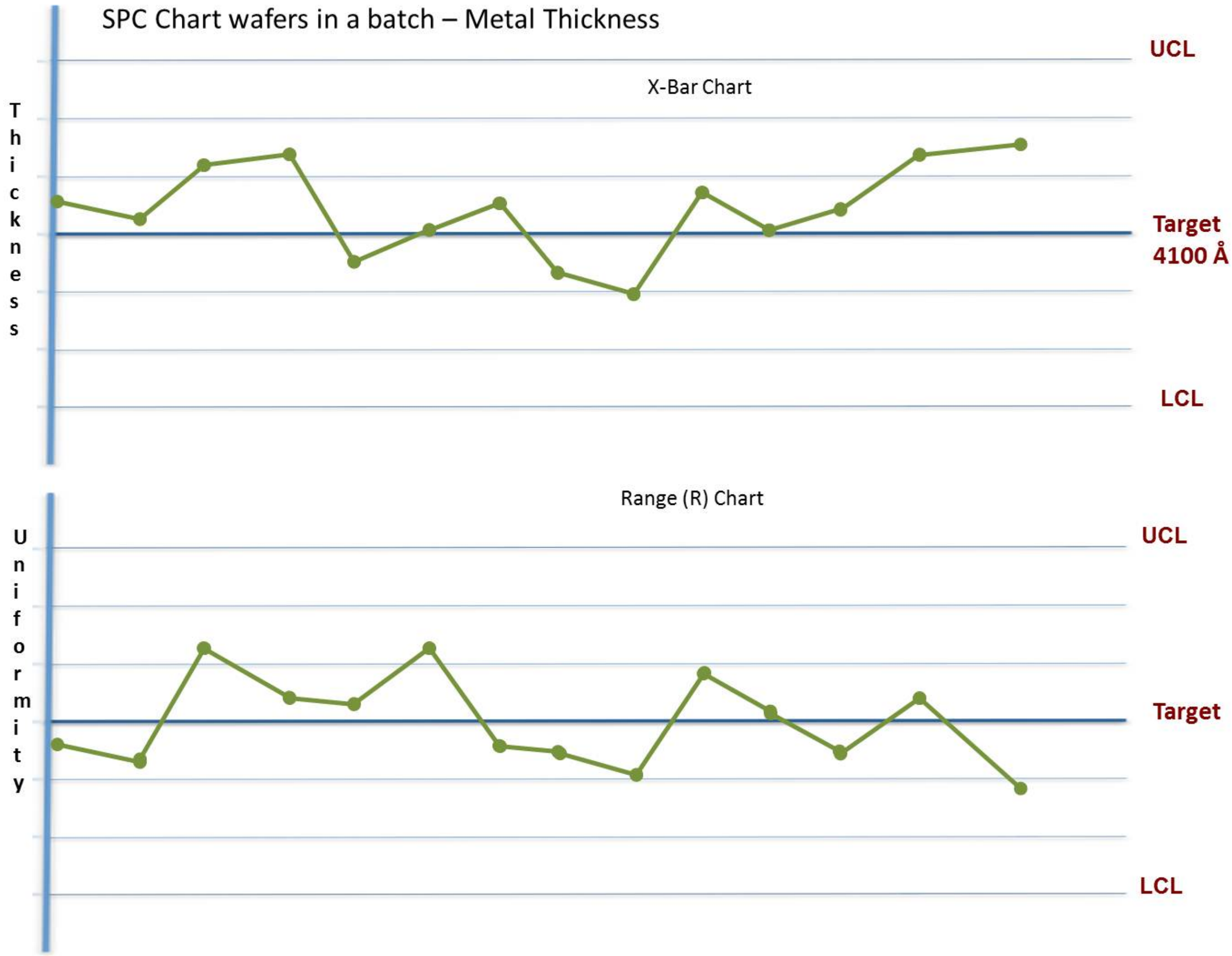
Below is a chart that shows the relationships between photoresist thickness and spin speed, and photoresist thickness and resist viscosity.




Photoresist Thickness
Frequency
200
180
160
140
120
100
80
60
40
20
0
4800
4850
4900
4950
5000
5050
5100
5150
Angstroms


Control Chart of Particle Count before Photolithography
X-Bar Chart
Particle Count
UCL
Target
LCL


CC Chart wafers in a batch - Silicon Nitride Thickness
X-Bar Chart
Thickness
UCL
Target 1µm
LCL
Range (R) Chart
Uniformity
UCL
Target
LCL



SPC Chart wafers in a batch – Metal Thickness
X-Bar Chart
Thickness
UCL
Target
4100 Å
LCL
Range (R) Chart
Uniformity
UCL
Target
LCL