## 3.2 A Metrologist's Core Activities

Before discussing the new metrics and methodologies, consider the core activities performed by a metrology engineer, as shown in Fig. 3.1. Each activity requires the use of a particular metric(s), as indicated by the possible criteria. All of the criteria mentioned under each activity are ideally used, but in reality, time constraints and resources may limit how many of the criteria are used in a given situation. The first box describes the process of bringing a new toolset to a fab. This process is typically executed at a given supplier's demo facility, or else a tool can be brought into the fab for evaluation to ensure that it meets key requirements before making a decision to purchase. Regardless, the typical criteria used would be precision, accuracy, and matching.

Once a decision is made to bring in a new toolset, the next step is to qualify the first tool. In this case, the primary criteria would be precision because there is only one toolset in the fleet at this point. Matching is sometimes used to compare against other similar types of tools already in the fab, e.g., a different model from the same supplier or a similar tool from a different supplier (this is defined as heterogeneous matching). After the first tool passes qualification, the long-term monitoring strategy is invoked to ensure that the tool is stable over time. More tools are then added to the fleet, and each must be qualified and monitored for long-term stability.

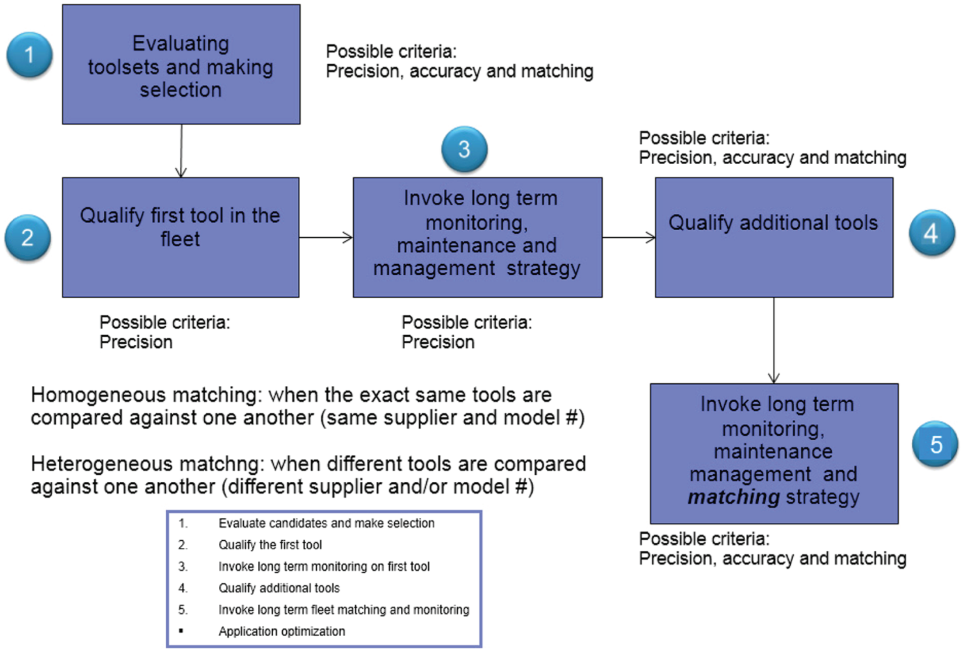

**Figure 3.1** General list of activities and flow performed by a metrology engineer.

Each subsequent tool must match the other tools and is called homogeneous matching because all of them are from the same model and supplier. Each of the criteria listed for each step is critical to ensure that the tools meet requirements when released and over the life of the toolset.

## 3.3 Roadmap and Specifications

A roadmap is a document that describes the requirements that various metrology solutions need to meet. It is typically a function of technology node and the requirements listed are typically for the most demanding applications. This is published annually by the International Technology Roadmap for Semiconductors (ITRS). This document does not teach how to assemble the measurement data to compare it against the requirements; it simply communicates the needs. The following sections clarify new metric definitions and how to assemble the data so it can be used to compare against either the roadmap requirements, supplier specifications/requirements, or the needs of a given process step, as defined by the gaugemaker's rule.

The specification or requirement must be determined for the precision, FMP, or TMP metrics to be compared against. If there is no explicit requirement, then the requirement will generally be derived using the following methodology:

- The metrology tool(set) precision or FMP will not exceed 2% of the target value. For example, if the target CD for a 14-nm gate is 25 nm, then the precision or FMP will be no larger than 0.5 nm.
- Note that for overlay tool(set)s the target is zero, in which case 20% of the process tolerance is used. For example, if the overlay process tolerance for the 14-nm gate lithography is ±10 nm, then the precision or FMP will be no larger than 2 nm.

## 3.4 Standards

Ideally, accuracy (or bias) compares measurements with known values on a NIST-traceable standard; however, this is often not possible. An International SEMATECH Manufacturing Initiative (ISMI) response (2) to the Automotive Industry Action Group (AIAG) MSA Guidelines states the following:

> In almost all meaningful cases, traceable semiconductor metrology standards are not available. The modern wafer fab's requirements have surpassed the traceability expectations described in the AIAG MSA. Today's fabs routinely employ many gauges costing millions of dollars, including state-of-the-art wavelength, interference comparators, and scanning electron microscopes. In most cases, reference standards simply do not exist. If reference standards were to be created, by the National Institute of Standards and Technology for

> example, the best gauges available to them at any price would be the very same gauges in hourly use in our member company wafer fabs. This eliminates the possibility of using MSA to ensure gauge accuracy. In any case, for most internal metrology needs, accuracy is least important. Only customer-measurable qualities need to be accurate, and for these cases we have and use traceable standards. Gauge matching is more important. The disparity between gauges used to measure the same characteristic must be minimal compared to the business decision limits used for product or process control.

Dimensional standards do not exist for the IC industry. Therefore, dimensional metrology systems such as a CD-SEM cannot be evaluated by the standard calibration procedure. A reference measurement system with nontraceable, manufacturer-specific standards is needed. Fortunately, the absolute accuracy (which needs a standard to calibrate) is not as important as relative accuracy (which does not need standards) because ultimately IC manufacturers care about device performance and device yield. So long as the measured CD values in IC process control have good correlation with the device performance and yield, then tightly reproducing those CD values in IC processes will produce good results. Additionally, because metrology tools are also used for process control, the measured values should be sensitive to the relevant process changes that need to be controlled.

The fact that IC device scaling follows Moore's law means that developing any CD standard is nearly impossible; however, it also has built-in tolerance for "absolute inaccuracy." Certified standards are desirable when they are available, but for the purpose of judging tool matching, golden parts, golden tools, or PSAs are sufficient.

## 3.5 Monitor Samples and Process Stressed Artifacts (PSAs)

A monitor is defined as a wafer or set of wafers used to ensure that a particular characteristic of the toolset maintains its desired performance. The characteristic of interest in this section is measurement stability. Monitor wafers are typically generated by removing them from a specific product lot at a particular process step and then placing them on a monitor route that continuously cycles at some frequency through the toolset being tested. The limitation of this method is that the removed wafers represent the process only at a single point in time. Meanwhile, other wafers from similarly processed lots moving through the fab at the same process steps will likely measure higher and lower. A better practice for generating monitor wafers incorporates this expected variability in one wafer or a wafer set, which are called process stressed artifacts (PSAs). When this wafer or wafer set is used to monitor the toolset, it better represents the process situations that the measurement tool is expected to see over time and serves as a more demanding and realistic test for the measurement toolset.

Most metrology tools are used for a wide variety of applications. It is not possible to monitor the performance of each one via monitors, so the following guidelines must be used:

1. Group similar applications together.
2. Rank the importance of application groups.
3. Create monitors for each of the most important groups to monitor all critical application groups with a minimum number of monitors.
4. Monitors should be PSAs whenever possible.

PSAs must be carefully chosen so that, ideally, all parameters of interest are monitored across the entire range of process variation. However, due to tool availability constraints, one must be careful to monitor the critical parameters in as few wafers/sites as possible. The order of preference when generating and using monitor wafers is as follows:

1. Single-wafer PSA, with intentional variation in one or more parameters of interest;
2. Multiple-wafer PSA, with intentional variation in one or more parameters of interest, changing wafer to wafer; and
3. Monitor wafer with normal process variation.

Some processes, such as lithography, can generate a wide range of process conditions on a single wafer, which allows for the preferred single-wafer PSA to be generated for toolsets such as a CD-SEM. Other processes, such as film deposition or etch, are not capable of generating variation across a single wafer, so toolsets such as ellipsometers must resort to one of the other options.

The following are the general guidelines for generating PSAs:

- Parameters of interest must be stable over time (feature dimensions or material composition). Unstable PSAs require additional work to monitor the true performance of the fleet, as well as periodic generation of new PSAs.
- Range of variation for parameters of interest should exceed the process tolerances by at least 10%, i.e., the artifact(s) should capture the entire expected process window expected over time.
- Data should be evenly distributed across the range of variation.

If it is not clear which parameters of interest a PSA must include and what the amount of induced variation should be, a set of wafers may be generated with broad variation across a multitude of parameters. Data can then be collected to determine which parameters correlate to true measurement problems and should therefore be monitored. This information can then be used to generate an improved version of a PSA that can become a sector monitor.