MetroBoost

Traceability of Sample Pitch

Recently, one MetroChip sample was certified at NIST. The results were exceptional and indicated deviation of 5 ppm from ideal length scale. In this document, we elaborate on the significance of that certification for other MetroChip samples. While in principle the same certification process can be carried out on other samples, the practice would be costly and offering little value to customers. Rather than establishing traceability of accuracy of other MetroChip samples by means of direct measurements, control limits in sample manufacturing process are employed to establish the traceability limits. In this manner, we can claim deviation of less than 100 ppm from ideal length for the same features on other samples. This provides customers with compelling value for any MetroChip sample.

1. The Certified Sample

"**Is the sample NIST certified?**" This question is commonly asked about MetroChip.

The short answer is that ONE MetroChip sample has been certified by NIST.

The detailed answer requires elaboration. There are hundreds of features on each MetroChip sample. Each feature has several attributes such as linewidth, height, sidewall angle and possibly pitch. In theory, each attribute of each feature can be certified.

Since the sample is intended to function as a magnification calibration standard, the attribute of primary concern is pitch (repeating distance between periodic structures). The pitches of two features on one sample were certified by NIST. Height, linewidth or sidewall angle were not certified for any of the features on that sample.

The NIST calibration report is also referred to as the calibration report and is available in a separate document. It quantifies the deviation of average length scale in that particular sample from the ideal unit of length to approximately 5 parts per million. Because the line scale interferometer uses an optical microscope for feature placement detection, only gratings having rather large dimensions (CD and pitch) can be certified with this technique. The certified features were two long gratings with 6 micron pitch, one horizontal and one vertical. These gratings were designed specifically for certification using the line scale interferometer at NIST. The certification was carried out for displacement measurements (pitch) at every 120 micron interval over a length of 4.44 mm. The results for deviation from the ideal of the average length over the span of the gratings are about a thousand times more precise than the pitch uncertainty of other certified samples commonly available in the industry.

While other MetroChip samples can be similarly certified at NIST for any customer, in practice the certification process is costly and takes a rather long time.

2. Traceability of the Same Features on Any MetroChip Sample

The topic for the rest of this document concerns the following question: **Does the certification of pitch for the pair of gratings on that one sample have any bearing on the same pair of features on other samples?**

The short answer is "Yes"! And the long answer quantifies the variation. From the certification of pitch measurements of one particular sample, the traceability of accuracy of pitch for the same features on other samples can be established. The traceability limits can be derived from manufacturing process tolerances, even though no other sample has yet been measured in the same manner.

To develop the details, consider the collection of MetroChip samples made over time. Each feature on each sample will have a particular value for one of its attributes. The collection of those values for the particular attribute of the copies of the particular feature on different samples will have a distribution with a mean and a width (sigma). The width of the distribution represents sample-to-sample variations resulting from acceptable operating windows in the manufacturing process.

Specifically, as a feature we key on high-precision long gratings consisting of repeating lines. Two attributes of such a feature are linewidth (or CD) and pitch. Linewidth refers to the local width of the line while pitch refers to the (periodic) distance between successive lines (either edge-to-edge or center-to-center distance between adjacent lines) as shown in Fig. 1 below.

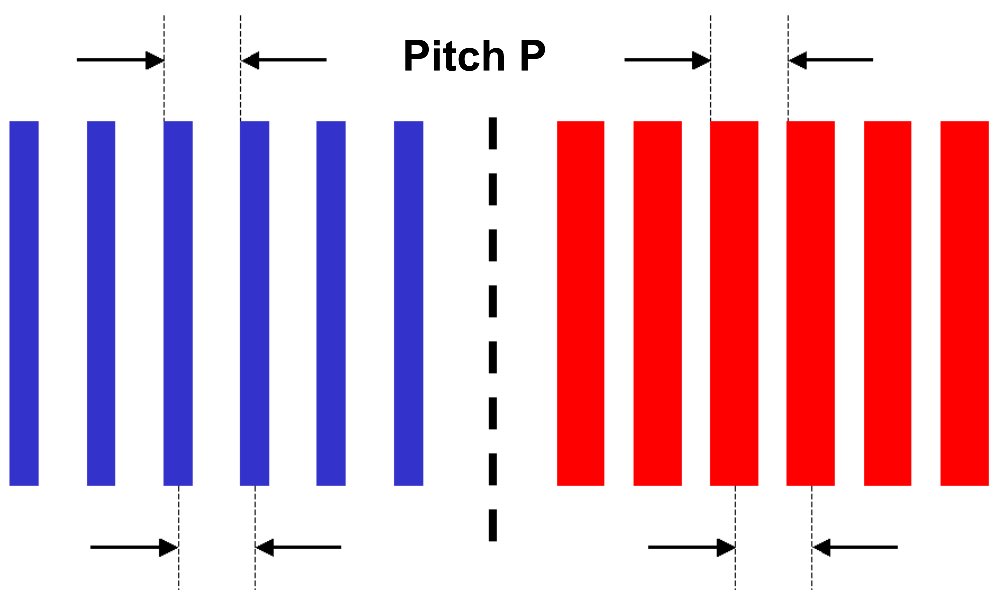

Figure 1 – Schematic of portions of two grating with same pitch but different CD

Samples are manufactured using common steps in semiconductor processing. All samples are produced from 200mm silicon wafers having deposited on them a layer of polysilicon on top of a grown gate oxide. A single binary mask is used for patterning the wafers. Patterns on that mask are transferred to the wafers using scan and repeat exposure tools. There is only one copy of each horizontal or vertical grating of a certain nominal pitch on the master mask.

The mask from which features are produced contains one long horizontal or vertical grating of a specific pitch. Copies of the same grating produced in each exposure field can have different CD (linewidth) and in theory, different pitch. But the distribution of pitch is much narrower, within a few parts per million, to be precise. In other words, feature linewidth and pitch exhibit very different distribution widths. For two attributes of the same feature, the characteristic difference in the widths of the two distributions is that linewidth can vary rather widely (as much as +/- 10% from the targeted mean) while pitch remains nearly constant (to within a few parts per million) at the mean value.

The latter should be emphasized since it is the basis for forming the answer to the question in bold. Once any feature on one sample is certified, all other samples ever produced with the same mask and the same exposure tool will have similar features with identical pitch to within a few parts per million. A similar statement can be made about grating CD, but with an uncertainty that is larger by about four to five orders of magnitude!

Consider again the population of long gratings on MetroChip samples ever produced. The previous paragraph narrows the sources of process variation for the pitch of the gratings to mainly the pattern placement accuracy of the exposure tool. Distortion errors in the mask patterns do not contribute to pitch variations within our sample population, but can manifest as deviation of mean and local displacement (pitch) from the ideal. For good quality masks, those deviations are small. And at any rate, all these errors combined are rather small relative to CD variations. Pattern placement accuracy variation for scan and repeat exposure tools used for wafer manufacturing is specified in terms of layer-to-layer overlay that is well below 50 nm for any location in the entire exposure field of more than 20mm by 20mm.

By contrast, linewidth of high-precision gratings (or any other feature for that matter) produced from the corresponding master feature on the single mask can vary by large amounts compared to pitch variations. The sources of CD variation are mainly exposure dose variations, and secondarily other effects such as resist bake temperature variations, etch bias variations, etc. Typical CD process control specifications are +/-10% of target CD. A +/-5% CD range is considered a tight window for process control.

Stated differently, it would be easy to deliberately produce a 10% CD variation in different samples, whereas even a 0.1% variation in distortion (magnification, skew, or rotation) is a very large amount and not easy to generate, since magnification control for scan and repeat tools is in the parts per million range.

This claim regarding the level of control of overlay in general and magnification in particular is readily accepted by semiconductor industry lithography personnel. Once the pitch of any feature on one sample is certified, all other samples ever produced with the same mask and the same exposure tool will have similar features with identical pitch to within a few parts per million. When the logic employed in the statement is applied to linewidth, the uncertainty that is arrived at is larger by about four orders of magnitude!

To better convey this point, Fig. 2 below schematically depicts three gratings with the same pitch but different CD side by side. It is easy to produce such CD variation from the same master on the mask by changing the exposure energy dose from one field of exposure to another. If portion of the images of those gratings produced with different exposure doses are cut and placed side by side, one would obtain what is depicted in the image below.

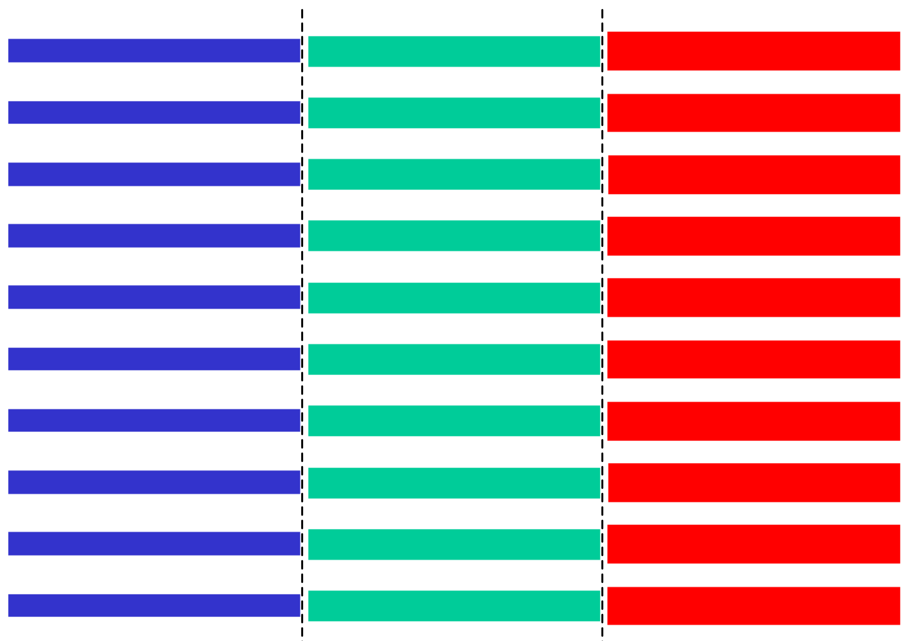

Figure 2 – Schematic of portions of three different copies of the same grating

Because of the way the wafers are manufactured, the variation of pitch on any feature from field to field and from wafer to wafer is well below 10 parts per million (ppm). Therefore, once that one sample was certified, all of the other samples made from that mask are traceable to within those limits. To be conservative and allow for possible higher order changes of the lens resulting from calibrations, a conservative limit of 100 ppm in claimed for traceability of pitch accuracy from wafer manufacturing tolerances.

In other words, using the same mask that was used for printing the certified features, the traceability chain for accuracy of pitch from any sample to the certified sample can be established based on limits of pattern placement accuracy as 100 ppm for wafer-to-wafer variations in semiconductor fabrication. This level of accuracy for pitch (displacement) is still superior to those of commercially available certified samples.