Fundamentals of Micro and Nanofabrication
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Lecture – 32
Optical Lithography: Stepper and Scanner

The last lecture discussed contact lithography and proximity lithography, where wafer and mask are in contact or with a small gap. In this session on optical lithography, we are going to look at projection lithography. In the case of projection lithography, there will be a large gap between mask and wafer, and the gap consists of complex projection optics.

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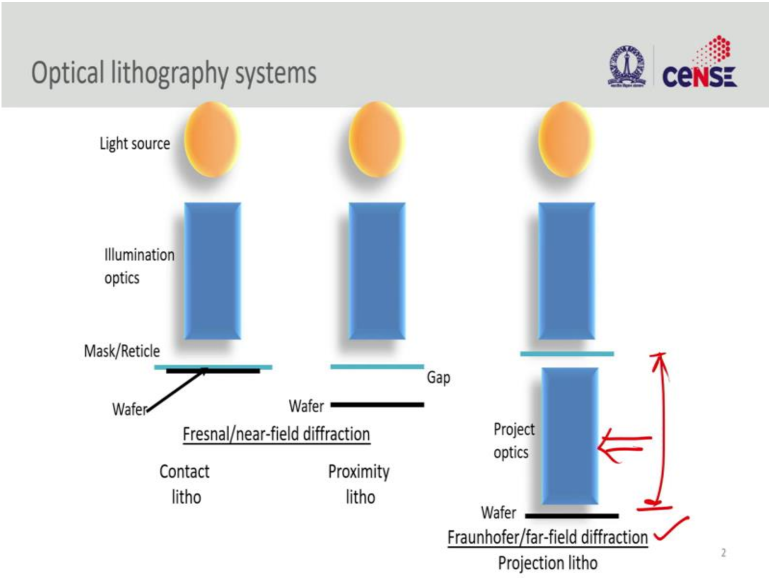

The above slide shows three different types of systems. All three systems have similar source and illumination optics, and projection lithography has in addition projection optics between mask and wafer, to project the image onto the wafer.

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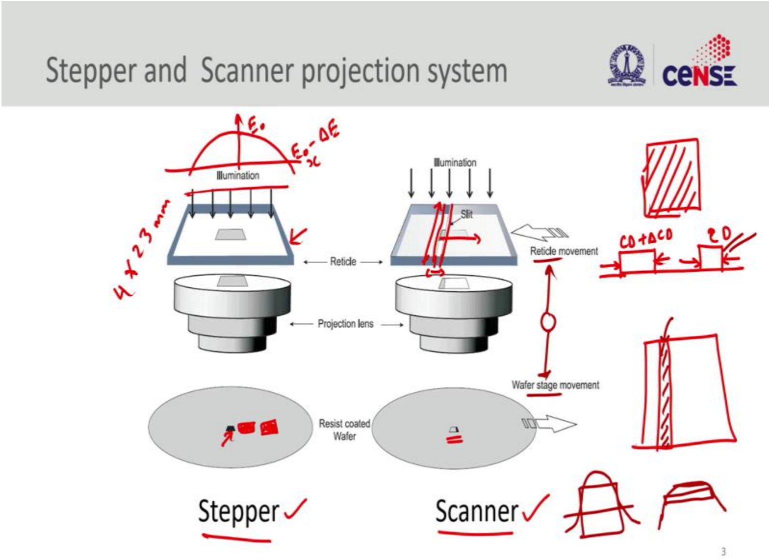

There are two types of projection lithography systems; stepper and scanner. Stepper works with the following principle. The mask is flood illuminated, so the illumination is uniform across the mask, and all the structures in the mask are patterned in one go. So the whole circuit is imaged at a time. It will then move in step to expose the next whole path of the circuit, hence called stepper.

A scanner is evolved from a stepper. The scanner consists of a slit that allows light to pass, and the slit is moved to image the entire wafer. So, unlike stepper, scanner illuminates only a part of the circuit. On one full movement across the reticle, the whole circuit is realized on the wafer. Here each mask is scanned hence called scanner.

In stepper, we expect high throughput because we are illuminating the whole mask. And the in scanner, we have to move both reticle and wafer to image complete circuit. Still, the scanner is preferred over stepper. The reason being, the illumination should have uniform intensity to get the right critical dimension; in the case of stepper, we are illuminating a big mask, say 23 mm x 4, and if the intensity of illumination is not uniform, the dose will vary across the wafer, changing the dimension. At center, the intensity will be high, and away from center intensity decreases, the dose will reduce. Hence patterns will be underexposed, and line width will increase. To illuminate the whole region with the uniform intensity, it needs complex illuminating optics, costly.

Instead, if we create a slit and uniform intensity within the slit- we can create optics to get uniform illumination in a reduced area. The smaller the slit dimension, the intensity profile will be more flat. This allows a uniform exposure, and this uniform exposure will guarantee that all my CDs are uniform, with no CD gain or CD loss. This is why scanners became popular and are the industry standard for illumination systems in projection lithography.

Scanners are also expensive because the system needs to be controlled. The moving stages and the moving masks should be controlled accurately with a control system because the speed dictates whether we have continuity or not. Any delay in the movement, the circuits will not yield the way we expect.

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The above slide shows a typical ASML, which is a commercial lithography tool manufacturer, and PAS 5500 system. This has an Argon Fluorite illuminated system. The cartoon shows the tool, the configuration, and parts inside the tool.

Behind the monitor, we see a laser source, Argon Fluoride laser, with a cavity for Argon Fluoride gas. It is then connected to the refection optics that brings the light into the illuminating tool. Then we have illuminating optics, consisting of various beam shaping optics, for uniform illumination. In the cartoon, we can see a large uniform light falling on the mask. This mask is illuminated from the top with illuminating optics.

Below the mask is the complex projection optics. In later lectures, we will see how these projection optics works and what are the requirement for projection optics. Below this projection optics wafer is placed. The whole system is complex and very bulky.

Since the mask and wafer are far away, it is important to understand how to align the structures, as we can have multiple layers to form a final circuitry.

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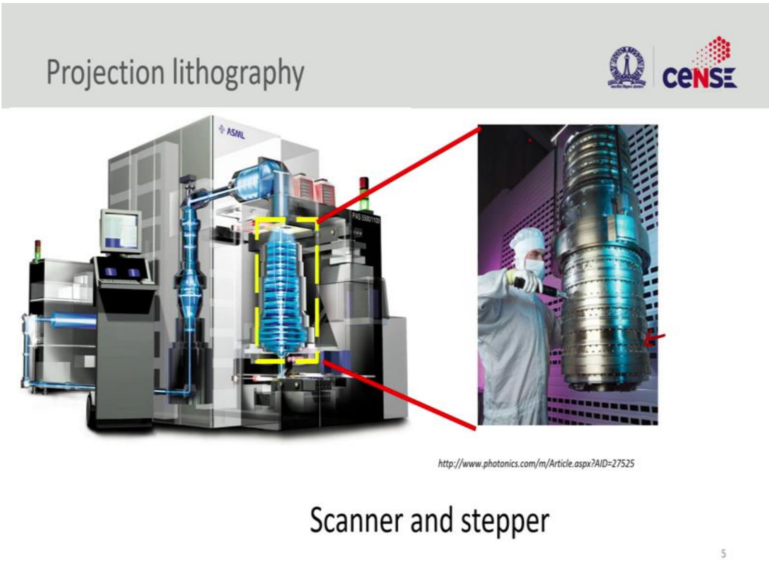

The above slide shows the lens assembly of the projection lithography system. We can see a massive metal handler containing all the lenses. It is all stainless steel, but inside we have all the optics. There are large lenses inside, and the lens system should be appropriately aligned to expose the wafer without any misalignment, to achieve the required resolutions.

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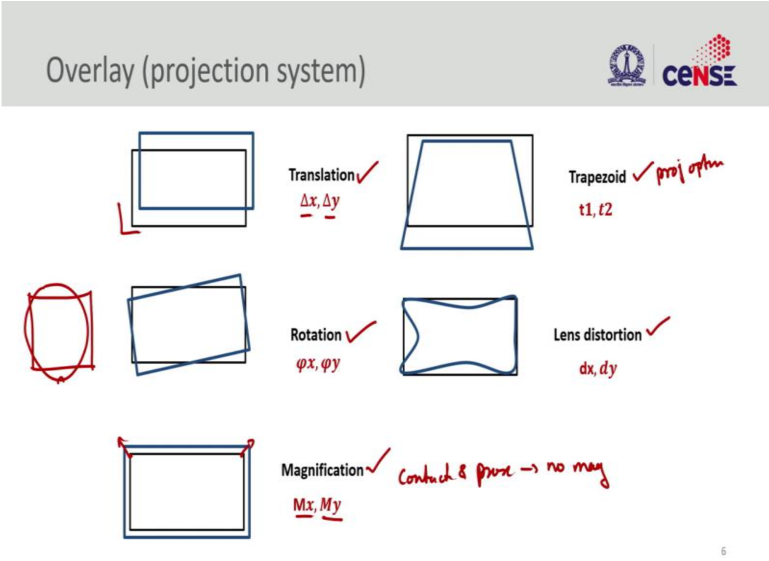

The above slide shows various possible overlay misalignments between 2 layers in the projection system.

Translation misalignment: the two layers can misalign x and y direction. So, Δx and Δy will result in translational misalignment.

Rotational misalignment occurs because of the circular wafer and rectangular or square mask. So, now, we should make sure both the wafer and mask are properly aligned. In the case of a non-ideal situation, the size is the same but will have some rotation.

Magnification: This doesn't occur in contact or proximity systems. The reason for this is the presence of projection optics, which normally downscales the feature size, hence brings in some magnification issues.

Trapezoid effect: This is again a result of the projection of optics.

Lens distortion: The lens system should be extremely stable. To put the lens in place, stainless steel liners are used. But sometimes, there can be some misalignment or vibrations that create lens distortion, using which it difficult to image or any kind of corrections.Translation or mask alignment rotation can also be handled with the movement of either wafer or mask. But the lens distortion is impossible to attain without attending the projection optics and the illumination optics; so, one needs to open up the system and solve this. In contrast, other kinds of distortion could be handled in a more automated fashion.

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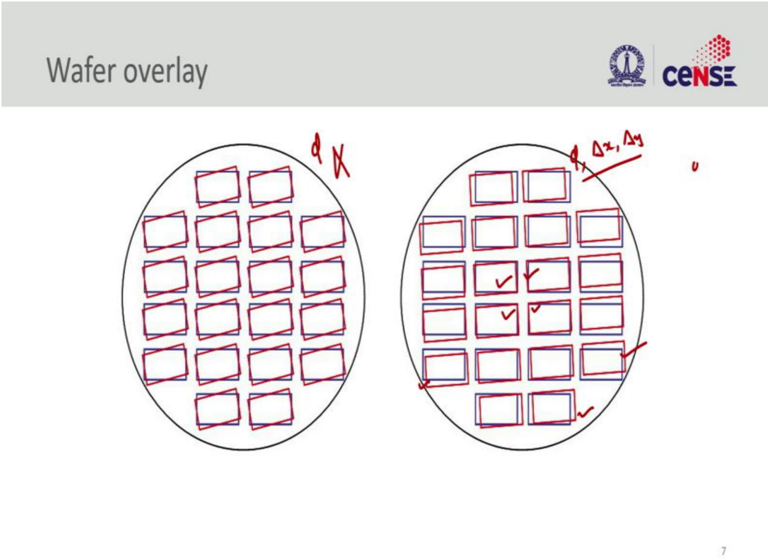

In the above slide, blue structures are in the first layer, and the structures in red are in the second layer. The left image shows structures with rotational misalignment. All the chips on the wafer are rotated, hence unusable. But then, on the right side, we see a different type of misalignment; it is a combination of both translational and rotational misalignment. In this case, we see certain dice at the center with low overlay error and then the outer edge with significant overlay error. So, these are all the ways one would probe this non-uniformity's in either performance or non-uniformity in alignment with respect to the different types of misalignments.

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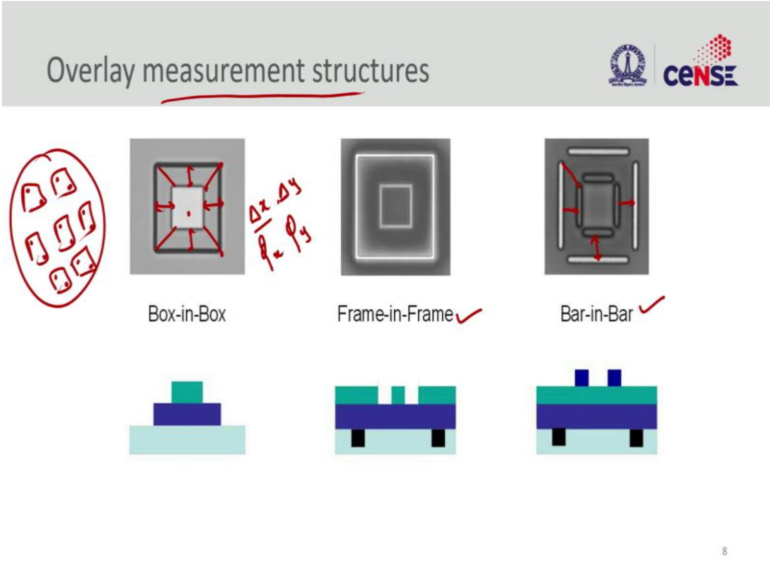

To tackle the misalignment, we need to have overlay structures and then overlay measurement structures to see the extent of misalignments. The above slide shows three types of overlay measurement structures typically used; there are more sophisticated ones too.

Box-in-Box structures have a box inside another box. We will measure distance between the edges using some kind of image processing, which gives the Δx and Δy, i.e., the translational misalignment, and the corners will give the rotation error. Using these, we can even measure magnification errors resulting from a discrepancy in Δx in one direction compared to the other. A similar thing can be done with a Frame in Frame and then Bar in Bar. Here again, we will be looking at the distance between these edges and so on. So, this will tell us the translational misalignment and rotational misalignments.

Once the wafer is out, and we see some anomalies between the center and edge and nonuniformities. With these measurements, we will be able to point out the type of misalignment.

In a wafer with multiple dies, we should have these measurement structures in each die. Sometimes we can place more than one to have more data to validate the argument. So, by measuring all these overlay structures, we can identify the contributions of different overlays.

We have learned projection lithography systems and how they work. We saw, stepper and scanner working. And how the scanner is preferred over the stepper because of the uniformity in the illumination using a slit to get good CD uniformity. So, we saw alignment measurement strategies and saw how active alignment is done.