Chromeless Phase Lithography (CPL)

Chromeless Phase Lithography or CPL is a recent development in the area of phase shifting technology that is extending the perceived $k_1$ limits and has the potential to be the multi-layer enabling technology for the 65nm node. CPL uses chromeless features on the mask to define patterns that have nearly 100% transmission and are phase shifted by 180 degrees. (Figure 1). The phase shift is created by etching the quartz substrate to a depth that is dependent on the wavelength of the imaging system. Using the etched quartz to induce a phase shift, it is possible to build the desired 100% transmission phase structures for any given wavelength (248, 193, 157nm) using standard chrome on quartz substrates.

**Figure 1:** Four examples of how a poly layer for an SRAM cell could be defined as phase shifted patterns and opaque areas on the mask for imaging with CPL.
As its name implies, CPL is a lithography technology that is more than just a type of phase shifting mask. It includes mask making technology, imaging technology, and the full-chip implementation software. CPL is as dependent on the wafer imaging system (scanner) as it is on the phase shifting mask. It is only when the chromeless phase patterns are exposed with higher NA and strong off-axis illumination (OAI) that the high contrast aerial images are formed. (Figure 2.) By using strong OAI, CPL becomes a two beam imaging system similar to alternating PSM and chrome-less phase edge PSM. (Figure 3.) Therefore, in order to obtain the resolution enhancement of CPL, it is necessary to have wafer exposure tools with the capability of high numerical aperture settings (>0.70) and strong off-axis illumination (e.g. Quasar, annular, double dipole).

**Figure 2:** Aerial image simulation of a 100nm chromeless phase feature when exposed with conventional and Quasar illumination at 0.80NA. Using off-axis illumination, a smaller aerial image is formed by the phase line. Simulation performed using LithoCruiser™ v1.0.
Benefits of Chromeless Phase Lithography

- **No special material is required.** The standard chrome on quartz material used for binary reticles can be used for CPL at any exposure wavelength. The portions of the drawn design geometry become phase structures that transmit nearly 100% of the light with a 180-degree phase shift. This results in phase shifting structures that are symmetric i.e., the aerial image is formed by two symmetrical phase edges. (Figure 3.) And just as with att-PSM, there are no phase conflicts that must be resolved by redefining the 0 and 180-degree phase regions or by placing design restrictions on the device layout.

**Figure 3:** Comparison of three quartz etched phase shift mask technologies. All three techniques have the advantages of 2-beam imaging.
- **Single reticle/single exposure technology.** Unlike alt-PSM, there is no need for a second exposure of a trim mask to remove unwanted phase edges or to image patterns that cannot be imaged with the phase shift reticle. This has many implications on the entire lithography flow from pattern decomposition to OPC to reticle manufacturing to exposing the wafer. For example, using alternating phase shift masks requires dealing with two separated patterns imaged with two different reticles (phase shift layer and trim layer), adding complexity to all of the steps. Plus, with alt-PSM, applying OPC requires that the software be able to predict the imaging behavior of the two separate reticles being exposed at two different times, with two very different imaging conditions. With CPL there is one reticle, one exposure, and one illumination condition, greatly simplifying the design implementation. (Figure 4.)

![Diagram of single reticle/single exposure technology compared to alternating PSM](image)

**Figure 4:** Comparison of double exposure alternating PSM to Chromeless Phase Lithography, illustrating how the process complexity is greatly reduced with a single reticle / single exposure system.
- **Can be used for multiple layers.** CPL is an optical extension technology that can be applied to multiple device types and multiple layers - making the economics of using CPL in high volume manufacturing much more viable compared to the other phase shift techniques. It is not just a poly or contact layer phase shift technique. Figure 5 shows the wafer resist image of several different device patterns illustrating the versatility of CPL.

![Figure 5: Examples of different device layers patterned with CPL](image)

**Summary**

CPL is a patented and innovative technology developed by ASML MaskTools that combines the advantages of high NA imaging systems, custom illumination, and phase shifting masks into a powerful resolution enhancement solution for the 65nm technology node. As compared to other optical extension technologies, CPL also offers the advantages of being a single reticle, single exposure technology, and is more versatile since it is applicable for most layers on most device types. Consequently, as CPL matures, it will extend the limits of optical lithography and provide a viable solution for very low $k_1$ manufacturing.