Optical Requirements

- **Transmission vs. Film Thickness**

A pellicle needs a good light transmission and long term transmission stability. Transmission depends on the film thickness, film material and any anti-reflective coating on the film. Transmission stability depends on the material used, the light wavelength and intensity used for the optical system.

The transmission of a thin film is dependent on the film thickness, light wavelength, incident angle and light absorption of the film. For a normal incident of light on a non-absorptive thin film, the maximum transmission of the film happens when a film thickness is an integer multiple of an optical half wavelength, i.e., the half wavelength of the light divided by the refractive index. That is

$k\lambda/2n$, where $k = 0, 1, 2, \dots$, λ is the wavelength, n is the refractive index.

The transmission minimum happens when the film thickness is at the optical quarter wavelength from a transmission maximum. That is

$k\lambda/2n + \lambda/4n$

The minimum transmission is $(1-4((n-1)/(n+1))^2)$. For $n=1.5$, the minimum transmission is 0.84. From a transmission spectrum of a thin film, one can calculate the thickness and the refractive index.

For a projection aligner or a wafer stepper using multiple wavelengths, the film thickness selection is dependent on the light source intensity and photoresist sensitivity at different wavelengths. A film thickness is usually chosen to have a stable transmission over some thickness range. For a multiple wavelength system, the transmission vs. film thickness shows a “beat” pattern and stabilized to a constant transmission when the thickness is high. Ronald S. Hershel has published a good introduction paper on pellicle in 1981.[2]

For example, for a thin film used at g-line (wavelength 436 nm), with a refractive index of 1.5, a 0.72 µm film thickness is chosen with a small tolerance of +/- 0.01 µm. While for a broadband system from g-line to i-line (365 nm), a thickness of 2.85 µm is chosen with large thickness tolerance of +/-0.2 µm. It has to be noted that for a broadband system because photoresist sensitivity is wavelength dependent, each system with different photoresist can have a different optimal thickness.

Anti-reflective coating was introduced to improve the transmission and reduce the sensitivity of transmission to the film thickness variation. At the beginning, vacuum deposition with metal fluoride such as calcium fluoride was used. Anti-reflective coating with fluoropolymer was first used by Micro Lithography, Inc. (MLI) in 1984. Multiple layer anti-reflective coating was also introduced later.[3]

Some transmission curves of different films were shown in Figure 3.

- **Particle Size vs. Frame Height**

The pellicle film is kept at a fair distance from the photomask so that any particle on the film will only give a blurry shadow on the wafer. However, if the particle is large enough the shadow can reduce enough intensity of the light on the wafer to cause a defect. Therefore, the particle size and distance between the film and photomask surface, i.e., frame height or standoff, need to be considered. The standoff is dependent on the maximum expected particle size and allowable light intensity reduction in the process and should be proportional to particle size and reduction ratio, and inverse-proportional to numerical aperture and partial coherence of the illumination system. For an opaque particle in a single lens system, the following calculation can be used to determine the minimum standoff D required for an opaque particle with diameter P,

$$D = P\,(M/NA/\sigma)\,[R^{-0.5} - 1] / 2$$

where M is the reduction ratio, R is the percentage of intensity reduction, NA is the numerical aperture of the projection optics on the wafer and σ is the partial coherence of the illumination system. The particle image diameter is P/M and the distance from the particle image to the photomask image on the wafer is D/M^2. The diameter of the shadow is $(2NA \bullet D/M^2 + P/M)$. Examples of the reduction ratios and numerical aperture values are shown below:

First Perkin Elmer wafer aligner, 1973: M=1, NA=0.167

First GCA stepper, 1976: M=10, NA=0.28

Most current wafer stepper, 2003: M=4, NA=0.6

Assuming the partial coherence σ from the illumination system is 1, the following examples show the different calculations used in determining standoff with different reductions in intensity on the wafer plan:

For R = 4% reduction in intensity: D = (M/NA) x P x 2

For R = 1% reduction in intensity: D = (M/NA) x P x 4.5

For P = 0.1mm = 100 µm, the calculated standoff is presented in Table 1.

	M	NA	M/NA	D @ R = 4%	D @ R = 1%
Perkin Elmer	1	0.167	6.0	1.2 mm	2.7 mm
GCA	10	0.28	36	7.2 mm	16 mm
4:1	4	0.6	7	1.4 mm	3.2 mm

Table 1: Standoff for Different Wafer Steppers and Aligners

For particles on the glass surface, the apparent distance from particles to the pattern surface is D/n, where D is the thickness of the glass and n is the refractive index of the glass.

For a real system, the minimum standoff is also dependent on the partial coherence of the illumination system, wavelength of the light and size of the pattern, i.e., the diffraction pattern. Pei-Yang Yan, et. al. have published a paper on the printability of pellicle defects for deep UV lithography in 1992.[4]

- **Focus Change vs. Film Thickness**

In addition, the film thickness of the pellicle on the pattern side can change the depth-of-focus by $t/n/M^2$, where n is the refractive index of the pellicle film and t is the thickness of the film. For a 1:1 broadband projection wafer aligner using a pellicle with 2.85 µm film thickness and refractive index of 1.5, , there is a 1.90µm depth-of-focus correction, while for a 4:1 stepper the depth-of-focus change is only t/24. For a film thickness of 1 µm, this is a shift of only 0.04 µm.