Measurements of hard pellicles for 157nm lithography using Fourier transform phase-shifting interferometry.

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ABSTRACT

Though phase-shifting interferometry (PSI) is widely regarded as the method of choice for precision measurements of the surface and bulk characteristics of optical components, conventional PSI suffers from severe distortions in the presence of multiple reflections caused from co-parallel surfaces. The optical and physical characteristics of hard pellicles used for 157nm lithography mean that they are essentially parallel plates and the use of standard PSI techniques to evaluate the optical quality of these components will suffer from these problems.

We describe a measurement method called Fourier Transform phase-shifting interferometry (FTPSI) that can overcome the disadvantages of standard PSI by the use of wavelength tuning and special analysis techniques. The technique can measure several surfaces simultaneously without distortion from multiple interference effects and is applied to the measurement of mounted and unmounted pellicles. Additionally, bulk properties of the pellicle, such as index homogeneity, can be easily measured with high precision. By spectrally separating the interference produced by different surfaces in the cavity during a wavelength chirp, each surface is identified and measured individually. In this paper, we describe the technique and give examples of measurements of hard pellicles provided by International SEMATECH.

Keywords: Pellicles, 157nm lithography, photomasks, distortion, interferometry, metrology.

1. INTRODUCTION

The introduction of fused-silica pellicles in 157nm lithography affects the entire customer/supplier chain, from the manufacturer of the pellicles, to the mask maker, to the mask user. This is because the hard, fused-silica pellicles used for reticle particle protection have been identified as a potential cause of image placement error. Pellicle-induced distortions could add as much as 8nm image placement error on a wafer level, thus consuming one third of the 25nm error budget.[1] This stringent error budget for manufacturing semiconductor devices in the sub-100nm range demands that all reticle-related distortions be minimized or corrected. The main sources of these distortions are: temperature differences between the time of pellicle mounting to the time of reticle exposure; initially warped or distorted pellicles, and pellicle sag-induced refraction. Sources of pellicle attachment-induced distortion include initial frame curvature, reticle shape, attachment method, and initial hard pellicle bow. Bowed or sagging hard pellicles act as optical elements that induce image displacement and/or image degradation via refraction.

Before one can minimize or eliminate pellicle-induced distortion, one must first be able to measure and quantify the location and degree of distortion. To assess and quantify the optical quality of a pellicle and its contribution to image displacement errors on wafers, one must measure the pellicle for surface flatness, surface parallelism and optical uniformity and homogeneity – both before and after it is mounted onto the reticle. That is, global and local surface tilt (slope), peak to valley topography, sags and bows in the pellicle must be found and measured to determine whether these parameters are within specified tolerances for 157nm lithography processes.[2]

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Recently, Zygo has developed and introduced a new phase shifting interferometry technique that can measure multiple optical surfaces without distortion from multiple interference effects. Called Fourier transform phase-shifting interferometry (FTPSI)[3,4], the technique combines phase shifting via wavelength tuning with specific cavity geometries, and a flexible Fourier based analysis technique to identify and extract surface features from many surfaces simultaneously. FTPSI preserves the spatial relationships between the physically separated surfaces so that measurements of surface profiles, physical wedge between pellicle and reticle, pellicle physical thickness and homogeneity can be easily extracted. FTPSI is therefore a logical replacement for traditional phase shifting interferometry (PSI) as a general-purpose approach to interferometric surface profiling. FTPSI is the enabling technology imbedded in the Zygo Verifire MST1550, which was used to make the measurements presented in this paper.

2. METHODOLOGY

The basic Verifire MST1550 instrument--set up to measure the front and back pellicle surface topologies, the pellicle optical index homogeneity, and pellicle physical thickness--is shown in Figure 1. The analysis methodology adopted in this paper can be summarized as follows. The interferometer cavities are constructed so as to create unique 1st order optical path lengths for all of the elemental cavities (Figure 2), and the optical frequency is tuned over a wavelength range that is long enough to spectrally resolve the 1st order frequencies. Each elementary cavity produces a 1st order interference frequency proportional to the total optical path length and the optical frequency tuning rate. The spectral peaks corresponding to the elemental cavities are identified and the optical path lengths for each elemental cavity are determined. By using the appropriate cavity optical path length, the spatial phase variation for each elemental cavity of interest is then determined. Finally, surface and volume metrology results are determined from linear combinations of these phase profiles.

3. MEASUREMENTS

Using the Verifire MST1550, we measured 300µ and 800µm thick fused-silica pellicles mounted on 6” square fused-silica mask blanks provided by International SEMATECH. The reticle/pellicle assembly was measured in a horizontal position with the Verifire MST1550 reticle-holding fixture with the pellicle face down, which is the orientation of the reticle in a lithography exposure tool. The reticle/pellicle assembly is a four surface geometry as depicted in Figure 3.

For an 800µm thick hard pellicle mounted on a mask blank, the four surfaces create a total of 6 cavities yielding a total of six 1st order peaks in the interference frequency spectrum, as shown in Figure 4. These six peaks correspond to the following optical path distances: (1) pellicle optical thickness; (2) pellicle back to reticle front; (3) pellicle front to reticle front; (4) reticle optical thickness; (5) pellicle back to reticle back; and (6) pellicle front to reticle back. The optical thickness variation of the 800µm pellicle (the first peak in Figure 4) is extracted from the spatial phase variation of each CCD pixel for that first order frequency peak with a digital filter. The optical thickness variation of the 800µm pellicle is shown in Figure 5. The measured variation of the pellicle to reticle separation (the second peak in Figure 4) is similarly extracted and is shown in Figure 6. Figure 7 shows the same pellicle gap with the global tilt removed to highlight nonlinear distortions. Figure 8 shows the range of local tilt (slope) in micro-radians of the mounted 800µm hard pellicle.

The 500GHz tuning range of the instrument used in this study produces high quality measurements of pellicles whose thickness exceeds 600µm. For thinner pellicles, spectral contamination from higher order interference frequencies produce measurement distortions. If the pellicle is too thin even the 1st order peaks cannot be resolved. With these limitations in mind, we attempted to measure a 300µm thick hard pellicle mounted on a chrome mask blank, and were moderately successful after applying some non-standard spectral filtering. Figure 9 shows the measured reticle-pellicle gap variation in microns between a 300µm hard pellicle and chrome blank. With the global tilt of 42 µradians removed, the measured sag of approximately 19µm in the pellicle center matches closely with the predicted 16µm gravity sag. Finally, figure 10 shows that the maximum local tilt for a 300µm hard pellicle is over four times steeper (800 vs.

200μradians) than the maximum local tilt for an 800μm thick pellicle. It should be noted that lasers with phase continuous tuning ranges over 12.5THz are available, allowing high quality measurement of pellicles as thin as 50μm.

4. CONCLUSIONS

The data accumulated thus far by both Zygo and International SEMATECH confirms that the Zygo Verifire MST1550 wavelength shifting interferometer provides the very high quality surface, volume, and relational measurements needed to verify that manufactured hard pellicles and pellicle/reticle assemblies conform to the stringent error budgets required by the ITRS technology nodes for 157nm lithography. The measurements also confirm that the use of 800μm thick hard pellicles significantly reduces mounting distortions compared to using 300μm thick pellicles.

Additional Verifire MST1550 options include a laser with a wider tuning range capable of measuring more complex surface arrays and thinner optical elements, and a higher pixel count CCD camera to enable finer spatial resolution for generating higher resolution maps of local tilt and optical thickness variations. The Verifire MST1550 has proven to be a versatile tool for measuring the characteristics of a large variety of complex optical components and systems.

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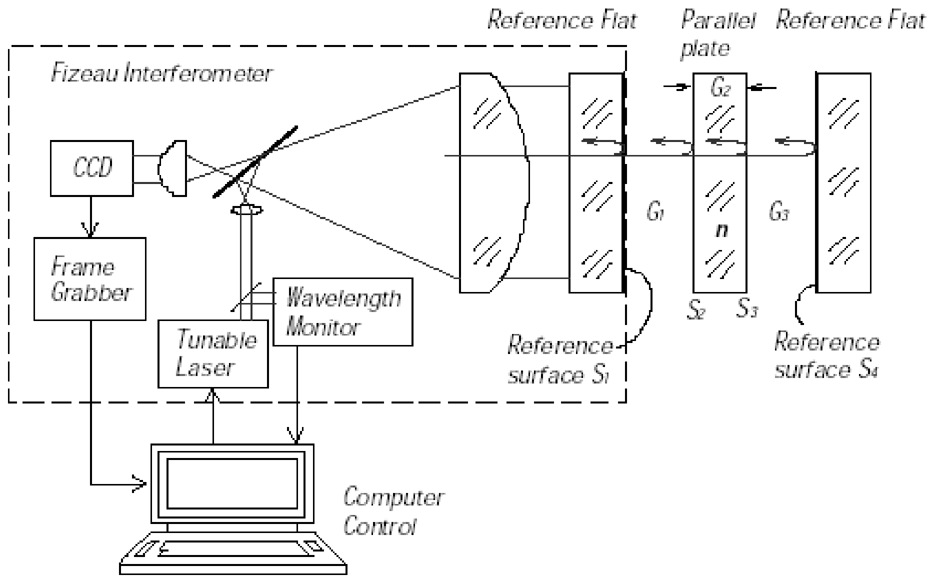

Figure 1: Basic Verifire MST1550 instrument set up to measure the flatness of surfaces S_2 and S_3, and the optical homogeneity and physical thickness of pellicle G_2

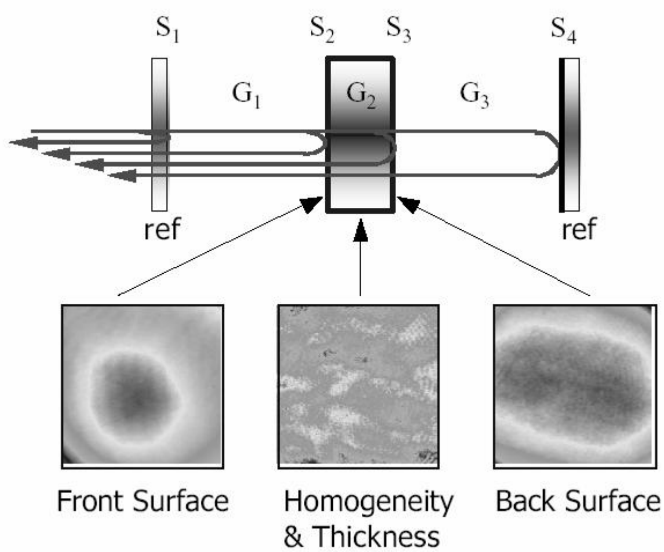

Figure 2: The 4-surface Fizeau cavity geometry used to measure the optical properties of hard pellicle G_2. S_1 and S_4 are reference surfaces used to measure the pellicle surfaces S_2 and S_3. The cavities are set up to create unique 1st order optical path lengths. The linear combinations of spatial phase variation profiles for interferometer cavities S_1-S_2, S_1-S_3, S_2-S_3, S_2-S_4, and S_3-S_4, and the cavity S_1-S_4 with the hard pellicle G_2 removed, are used to determine optical and physical properties of pellicle G_2.

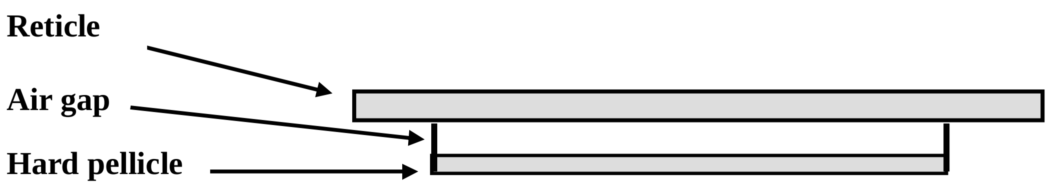

Figure 3: The pellicle/reticle assembly consists of a 6.35 mm thick mask blank with mounted 0.3mm or 0.8mm hard pellicle, and 3.3-4.0mm gap between pellicle and mask surface. The Verifire MST1550 can measure all four surface shapes, the air-gap thickness variation, and the global and local tilt of the hard pellicle

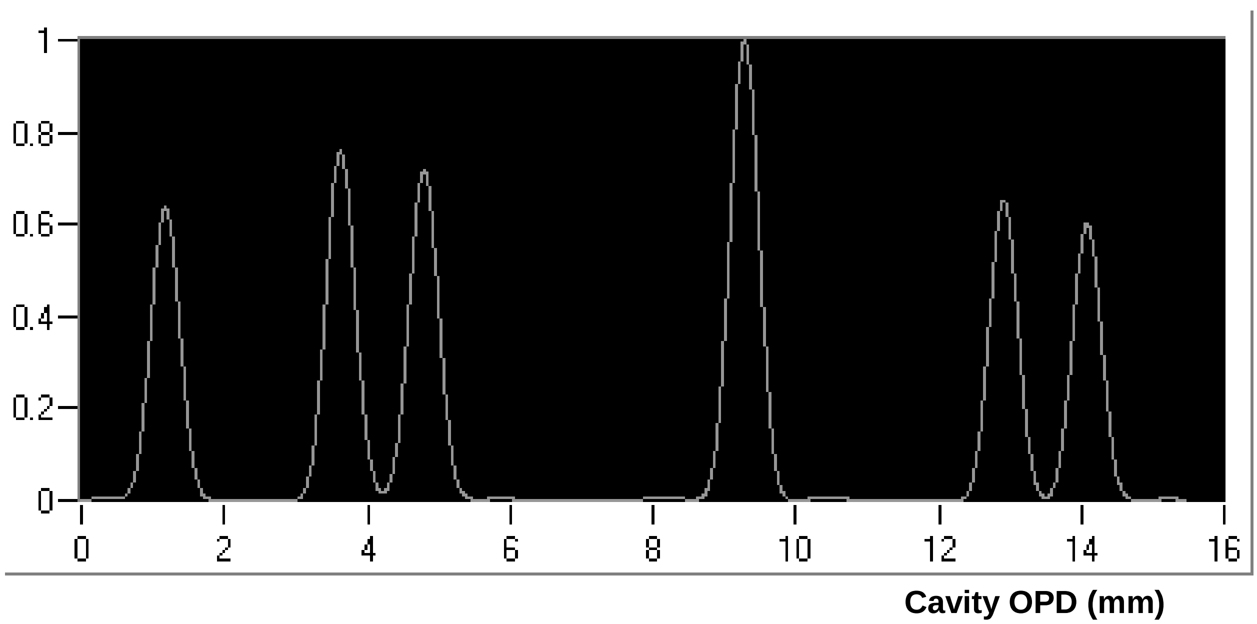

Figure 4: The optical path distance spectrum for an 800µm hard pellicle mounted on a 157nm reticle blank. From left to right, the six peak positions correspond to the optical path distances: (1) pellicle optical thickness; (2) pellicle back to reticle front; (3) pellicle front to reticle front; (4) reticle optical thickness; (5) pellicle back to reticle back; and (6) pellicle front to reticle back.

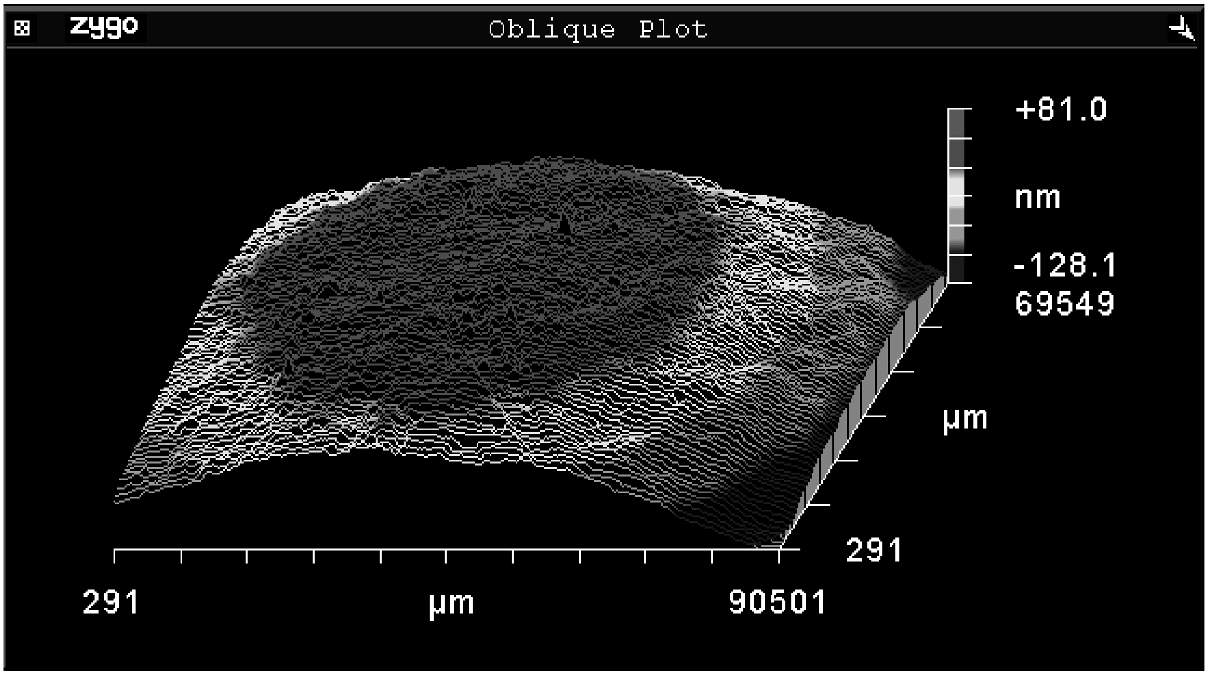

Figure 5: The optical thickness variation of the 800 µm pellicle measured from the internal Fizeau peak (1st peak in Fig. 4).

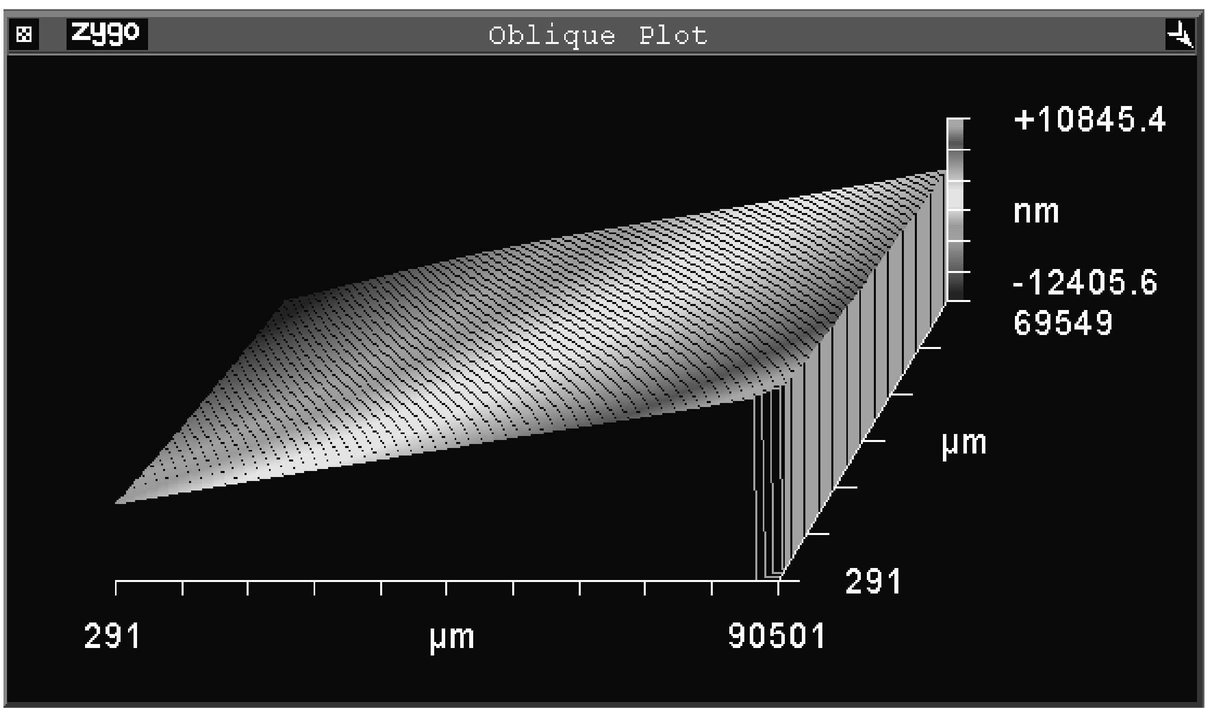

Figure 6: The measured variation of the 800µm hard pellicle to reticle separation (second peak in Figure 4). Note the wedge between the pellicle and reticle.

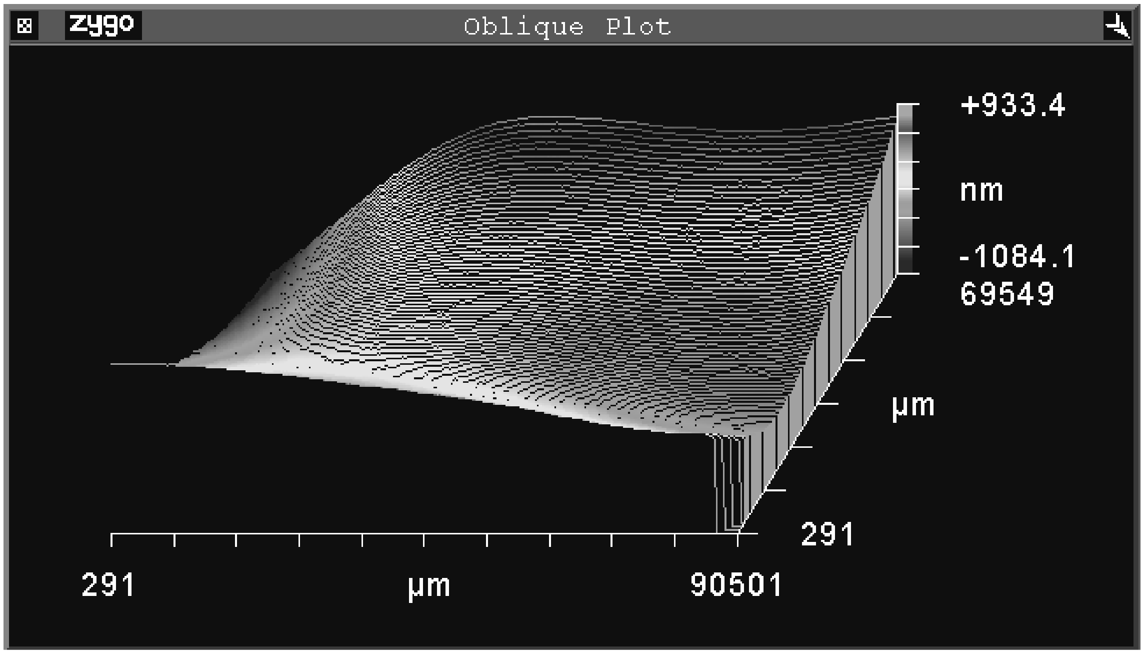

Figure 7: Measured variation of the pellicle to reticle gap with the 42 µradian wedge removed.

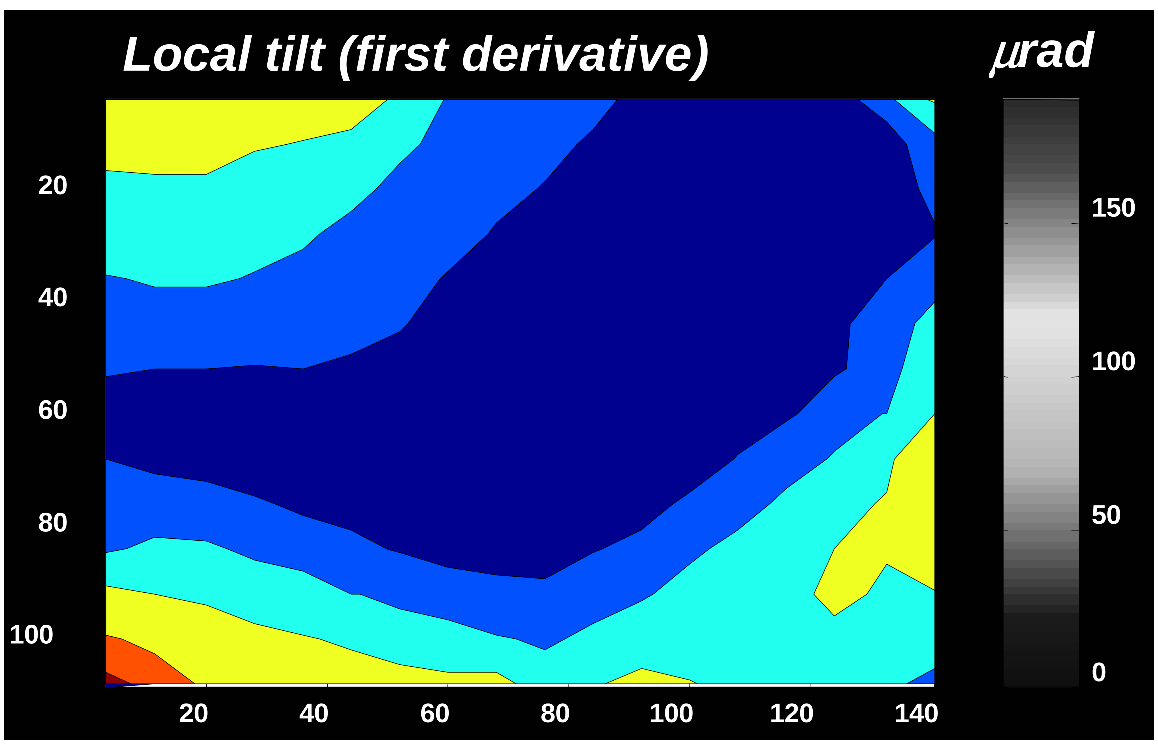

Figure 8: Local tilt (slope) in micro-radians of an 800µm hard pellicle mounted on a 157nm clear blank reticle.

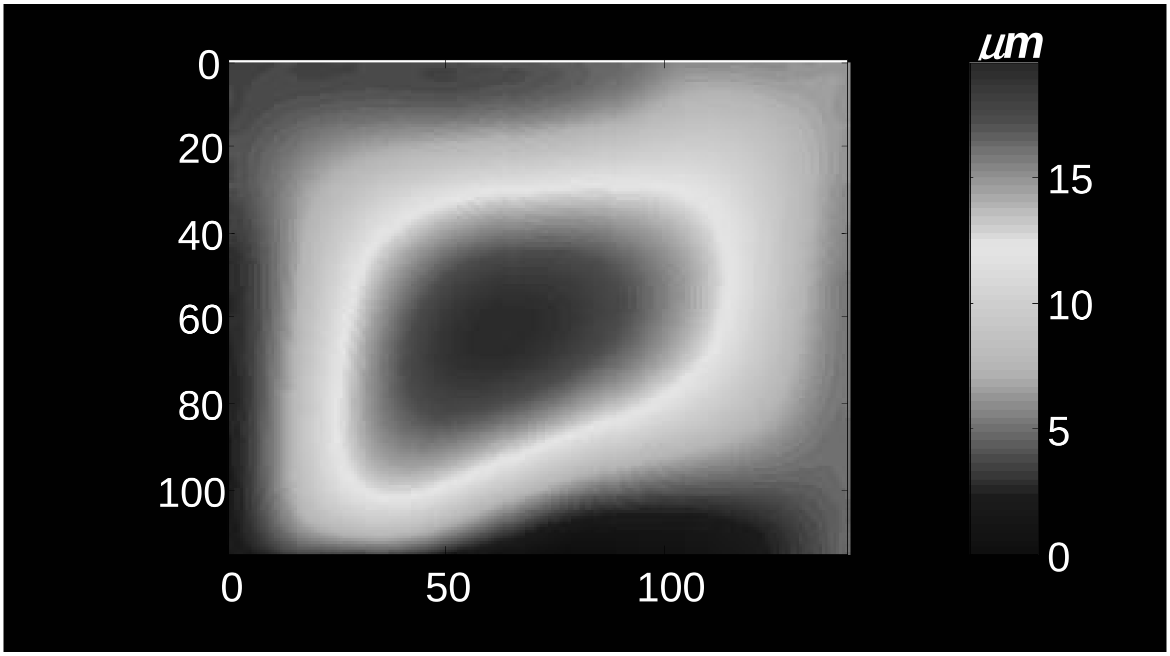

Figure 9: Reticle-pellicle gap variation in microns between a 300µm hard pellicle mounted on a chromed blank reticle. The global tilt has been removed. The measured sag of ~19µm in the pellicle center matches closely to the 16µm predicted sag due to gravity.

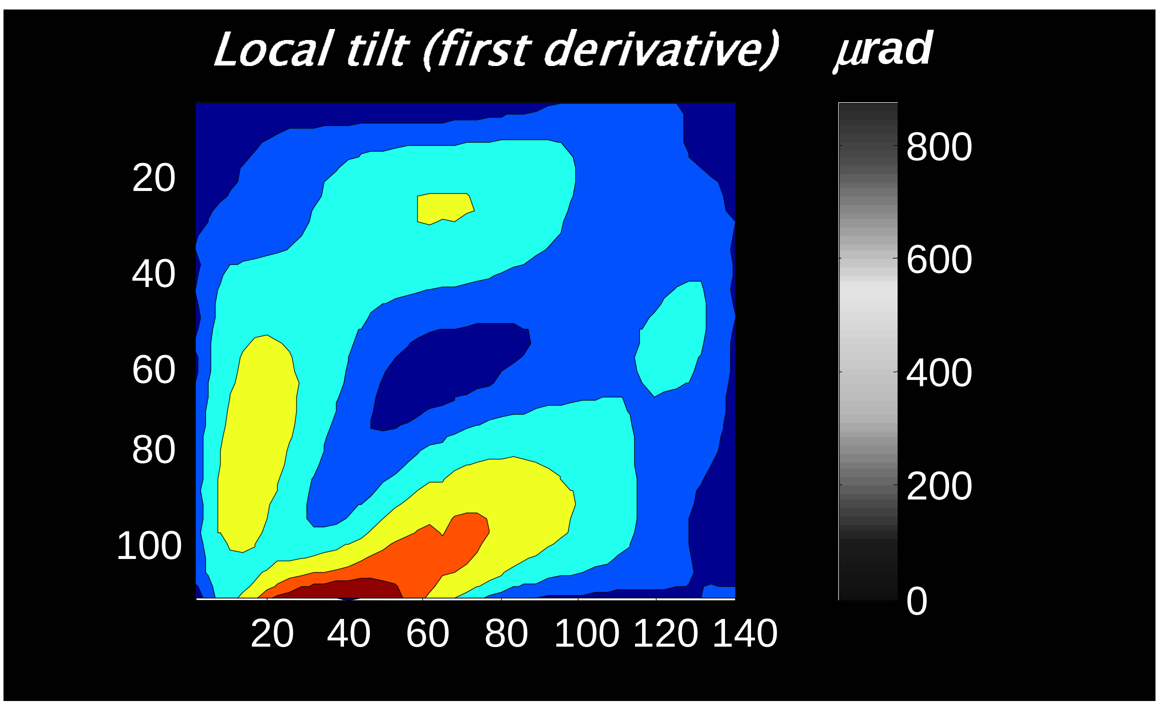

Figure 10: Local tilt (slope) in micro-radians of a 300µm hard pellicle mounted on a chrome blank reticle.