The Design and Construction of an Interferometer for the measurement of Strain in Thin Metal Films.

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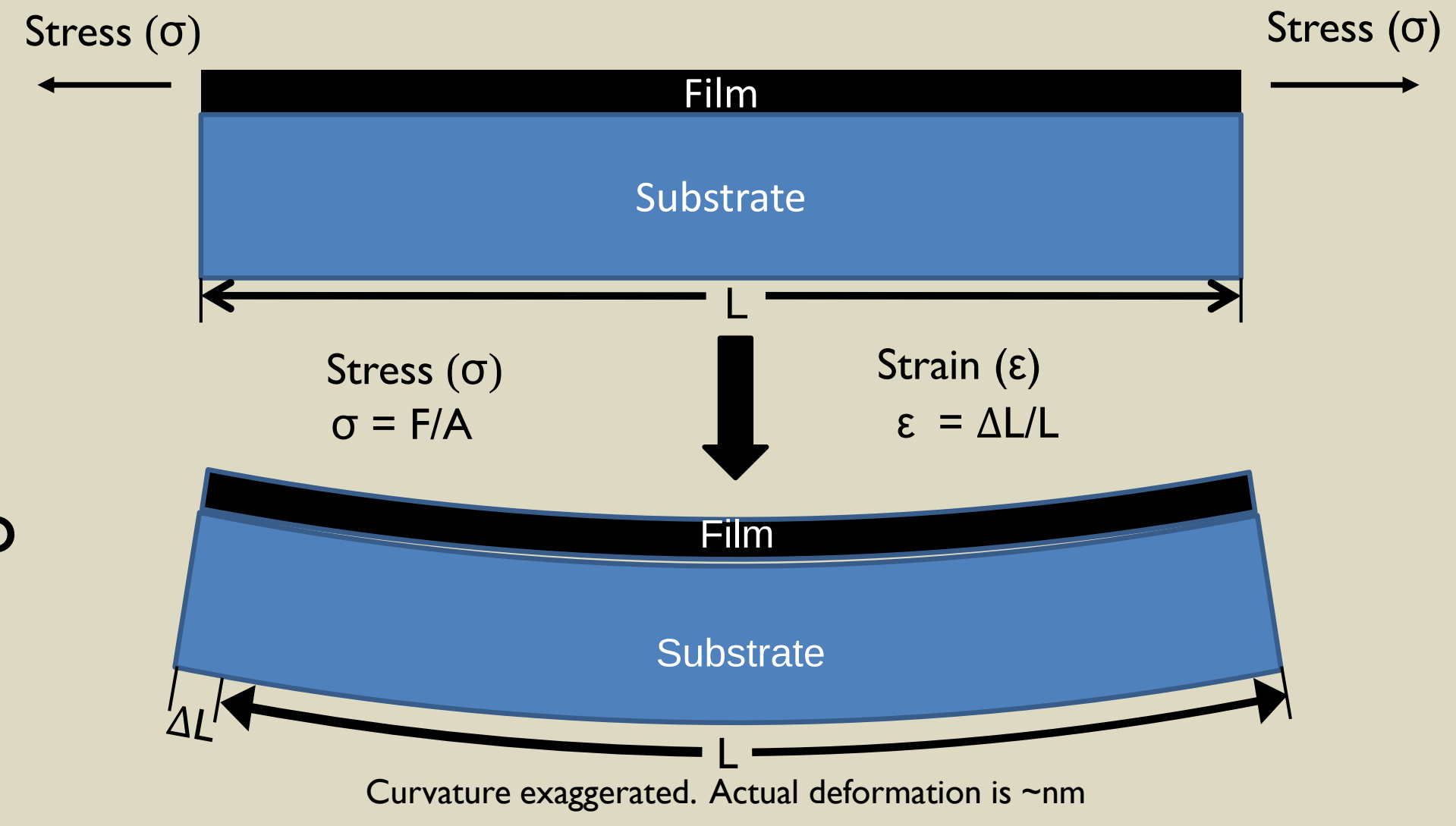
I. Abstract

An interferometer is being constructed at Houghton College which will be used to measure the pattern of interference created by the superposition of light waves incident on a thin metal film and a reference mirror. A uniform wavelength 4" collimated beam of light will illuminate an entire sample and the interference pattern will be captured by a CCD. The position of the reference mirror will oscillate via piezo-electric ceramic. Each pixel will be processed individually to produce a topographical image of the sample surface. The resulting superposition data can be used to calculate the curvature of the thin film and from that the stress of the film in real time.

II. Motivation

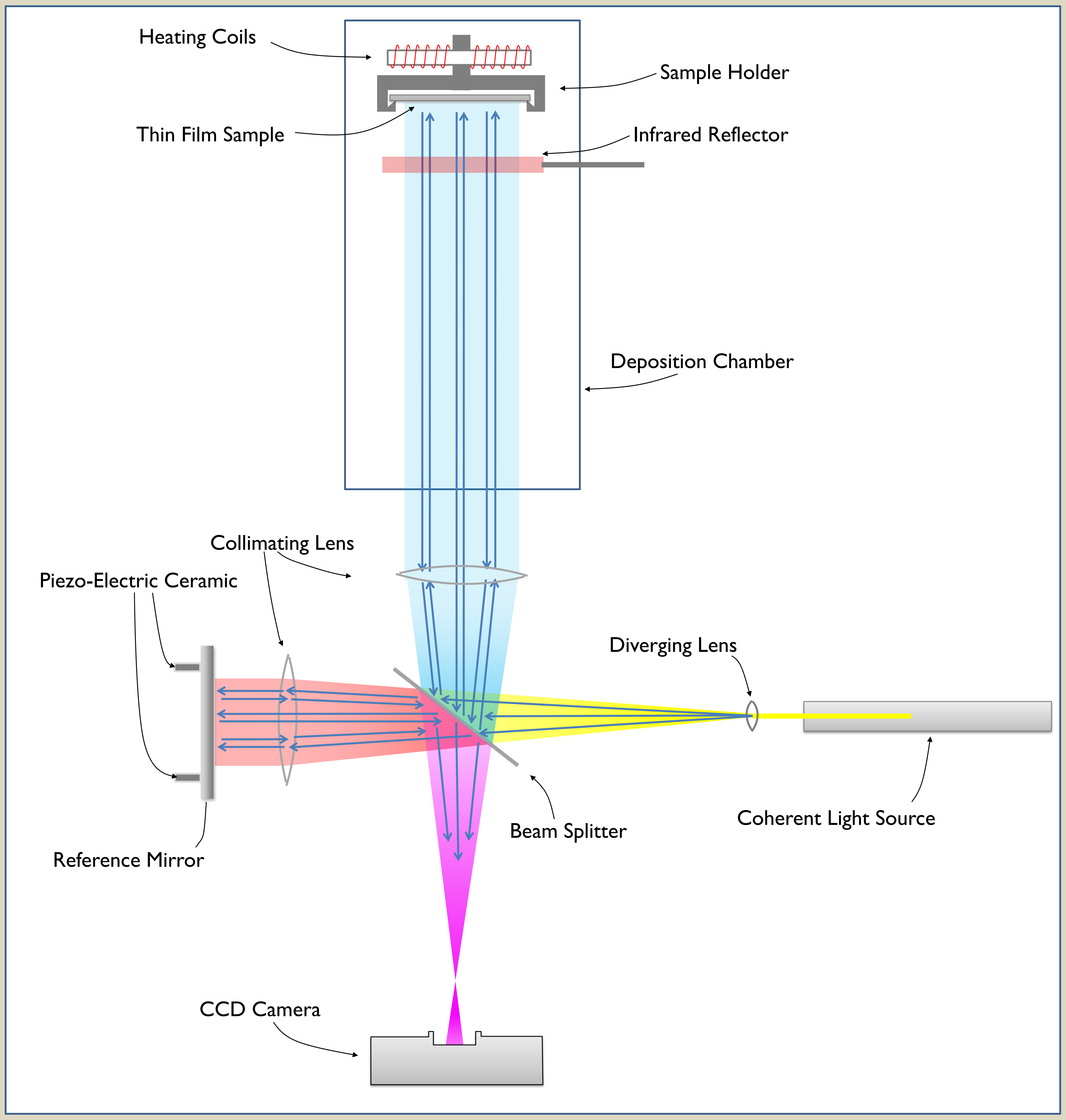
When thin films are composed of materials with different coefficients of thermal expansion, varying temperature causes stress at the interface of the materials. This stress causes a thermal strain displacement which will cause the film to deform and curve an amount proportional to the stress. To measure the curvature, a topographical map can be used which can be supplied by an interferometer.

Film Stresses – Thermal Strains



Curvature exaggerated. Actual deformation is ~nm

IV. Apparatus



A single incoming beam of coherent light will be spread by a lens and then collimated into a 4 inch diameter beam. This beam will be split with one path incident on a reference mirror and the other path incident on a thin metal film. The reference mirror will be controlled by piezo-electric ceramic which will oscillate under a saw-tooth wave a distance of one wavelength. The reflected beams will return to the beam splitter and recombine at an altered phase to be captured by a CCD. This system is designed for taking measurements during heating experiments and to measure film thickness that is less than half a wavelength, post deposition.

III. Theory

Light waves have the property of superposition which causes interference patterns when they combine. The phase difference of waves with identical wavelength determines whether the resulting pattern undergoes either constructive or deconstructive interference. The interference pattern can be used to determine the phase shift between two incoming identical wavelength beams of light.

Two light waves of equal amplitude and frequency can be defined by

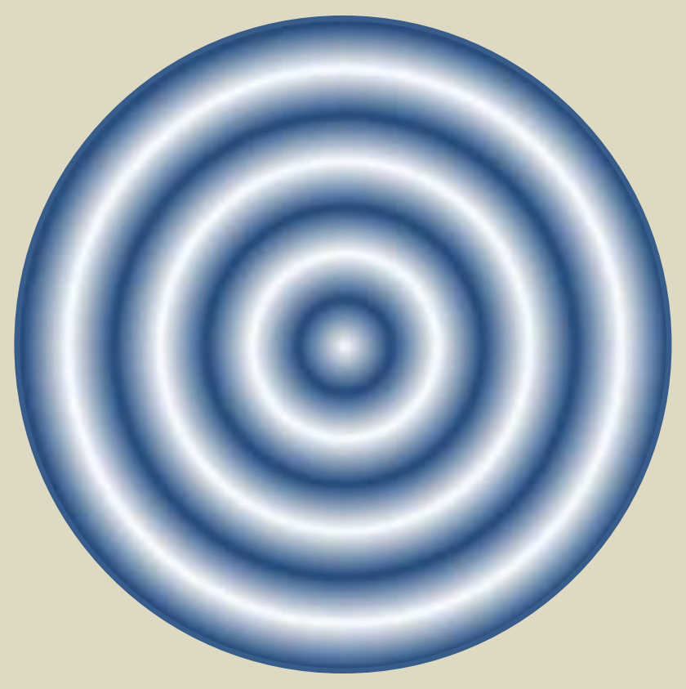
$$y_1 = A\sin(kx - wt) \qquad y_2 = A\sin(kx - wt + \phi)$$

where the phase shift is given by $\phi = \Delta r\left(\frac{2\pi}{\lambda}\right)$.
The combined wave can be given by

$$y = y_1 + y_2 = 2\cos\left(-\frac{\phi}{2}\right)\sin\left(kx - wt + \frac{\phi}{2}\right).$$

The amplitude of the wave is proportional to the intensity squared, therefore the measured intensity can be fit to a curve to determine the phase shift for each pixel.

The resulting two dimensional picture of the interference pattern will show the intensity varying with respect to the position of the sample which will shift as the reference mirror moves.



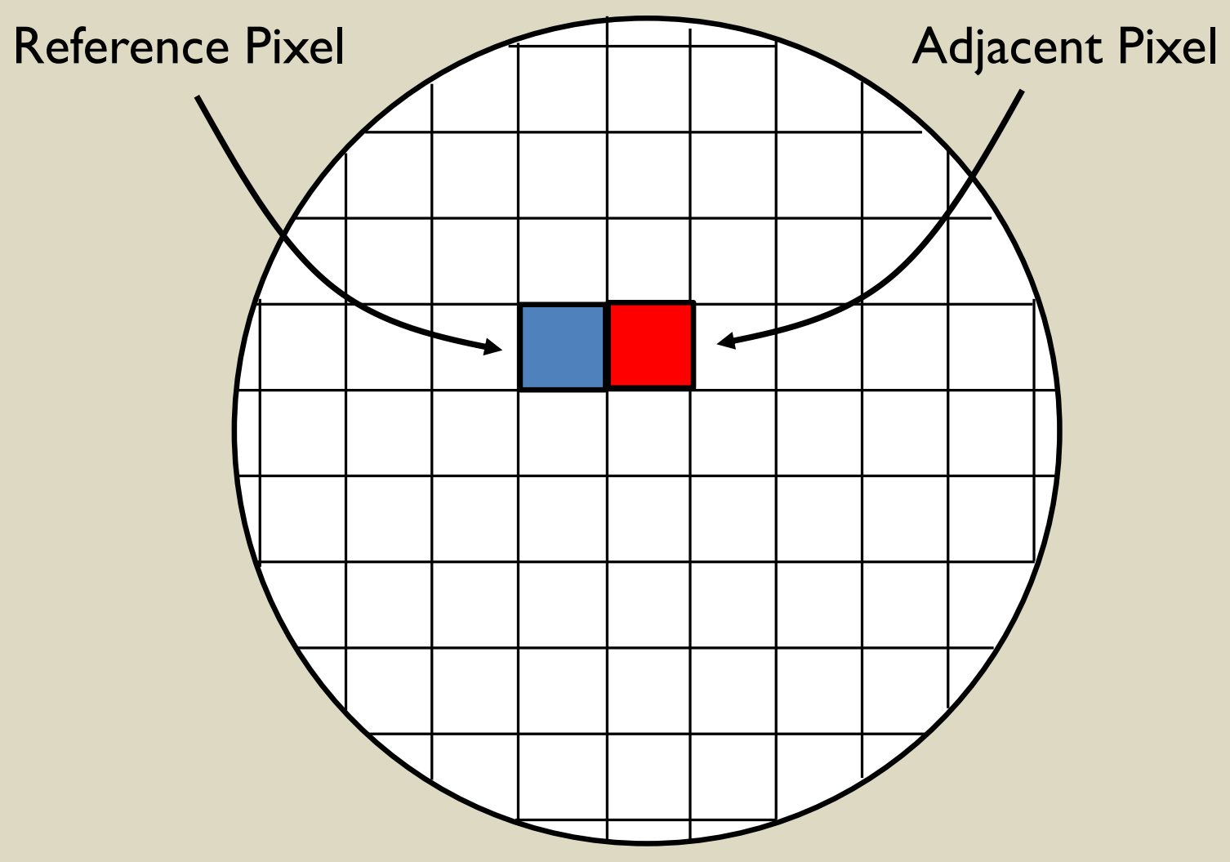
Ideal Sample Interference Pattern

V. Image Analysis

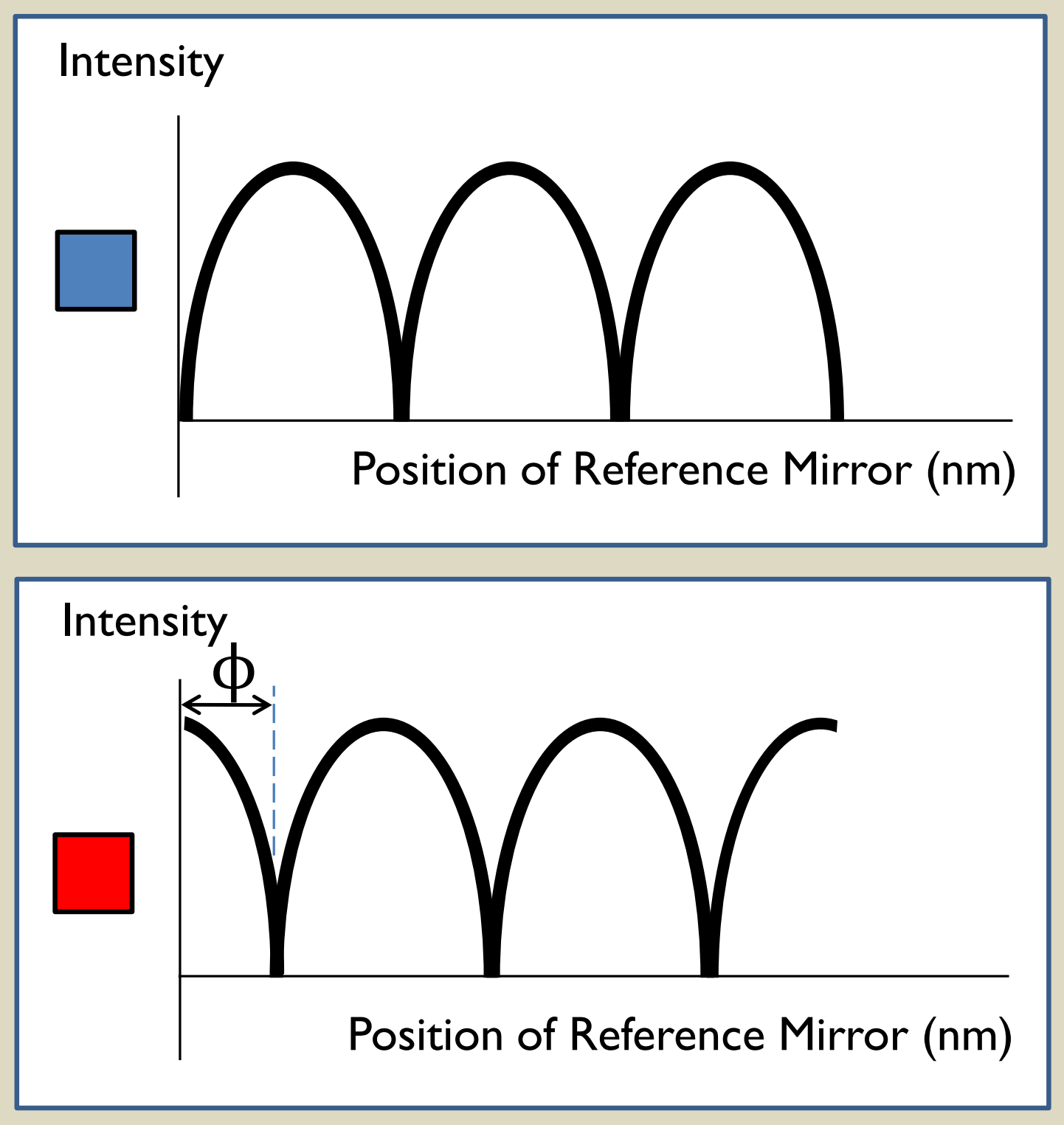
Motivation of Analysis: The purpose of using this system is to provide high resolution with the ability to analyze each pixel individually, rather than analyze the surface as a whole. The height difference due to curvature may be small, but it can still be measured easily through the use of an oscillating reference mirror.

For each pixel collected by the CCD: Plot intensity vs. position of the reference mirror which should yield a full wavelength of the resulting beam. Fit a $\cos^2$ curve to the data to find the phase shift between the beams. Plot the phase shifts for every pixel on a topographical map where each pixel represents a corresponding position on the sample.

CCD Pixel Display

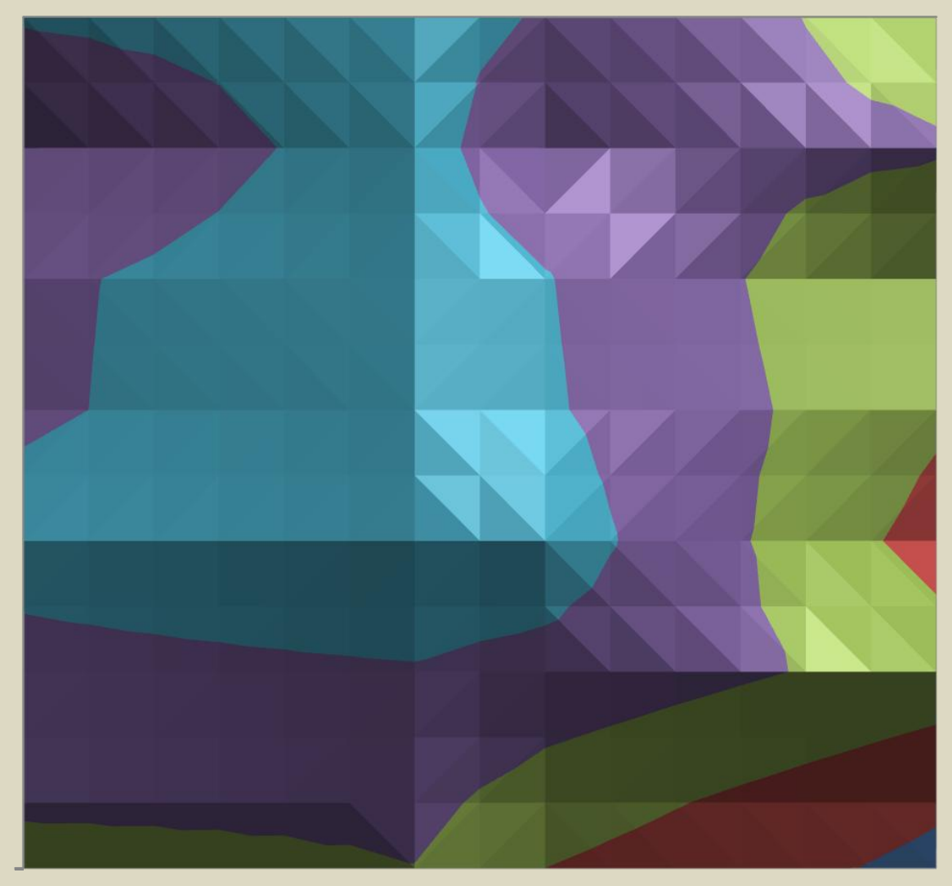


To correlate phase shifts to thickness: Begin with the assumption that the actual thickness variation between pixels is less than a quarter of a wavelength. Starting with a reference pixel near the center of the sample, look at each adjacent pixel and add or subtract the phase shift distance ϕλ/4π to be the relative thickness of the sample at the corresponding position of each pixel. Specifically,



Difference between phase shifts. (radians)	Relative height of adjacent pixel. (nm)
If between 0 – π	+ϕλ/4π
If between π – 2π	-ϕλ/4π

Sample Thickness Map



After all pixels are calculated, construct a thickness map of entire sample which can be used to calculate the curvature relative to the initial state.