# Surface Quality

## SQ-1

a) How is surface profile data obtained using the FECO interferometer? Your explanation should include diagrams with the appropriate quantities defined.

b) Can resolutions of less than 10 angstroms in height be obtained? What are the major resolution limitations?

c) Why do the reference and test surfaces need to be coated?

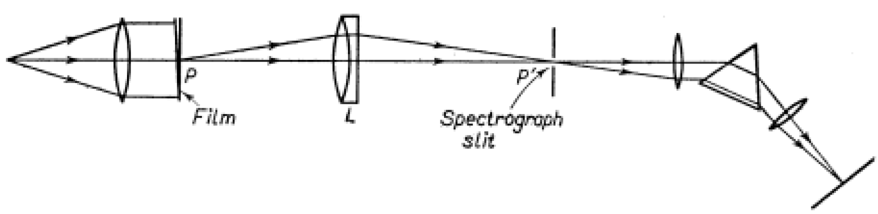
d) How does this interferometer compare to a Fizeau interferometer? Is it better or worse? Explain.

e) It is also possible to measure surface profiles by dragging a stylus over the surface. Does a stylus yield higher resolution? Consider both lateral and height resolutions.

### Solution

#### a)

The interferometer is a Fabry Perot etalon composed of coated reference and test surfaces. One strip of surface is tested at a time. Multiple beam fringes are obtained using a white light source. The surface under test is imaged onto the entrance slit of a spectrometer. Due to multiple beam interference and high finesse fringes, the wavelengths passing through the entrance slit depend upon the etalon thickness. When the images of the entrance slit (fringes) are plotted versus wavelength, variations in wavelength for a given fringe correspond to variations in cavity thickness variations. If the reference surface is flat and smooth, cavity thickness variations give test surface height variations.




#### b)

Yes, resolution down to a few Angstroms is claimed. The reference paper shows 8 Angstroms height resolution limited by the roughness of the reference surface.

#### c)

The coatings are needed because a high resolution requires a high finesse. The finesse depends upon the reflectance of the test and reference surfaces.

### d)

Some FECO advantages are

1) No walk-off of beam due to wedge
2) The interference order number is ambiguous
3) Never a question about whether a surface error is high or low
4) Measured irregularities are independent of surface figure
5) Better height resolution

Some Fizeau advantages are

1) Can look at entire area at once rather than line
2) No need to coat surface
3) Less expensive and easier to use

### e)

A stylus can give better lateral resolution and some people say better height resolution.

| | Stylus | FECO |
|---|---|---|
| Lateral | 1 micron | 2 micron |
| Height | 1 Angstrom | 3 Angstrom |

However, the stylus may damage the surface and because of its shape it may not follow the surface exactly.

# SQ-2

I have a Nomarski interference microscope that uses a 20X objective lens. I do not know the material or the prism angle of the Wollaston prism. However, I do know that if I illuminate the Wollaston prism with a linearly polarized collimated HeNe laser beam and if after the prism I place a properly oriented analyzer I obtain fringes with a spacing of 5 mm. What shear do I have in the Nomarski microscope? How does the shear compare with the resolution of the microscope? (If you need to make any assumptions, state them.)

## Solution

Let $\alpha$=angular shear produced by Wollaston

$$\text{Assume, focal length of objective} = \frac{160\ \text{mm}}{20} = 8\ \text{mm}$$

$$(5\ \text{mm})\ \alpha = \lambda = 0.633 \times 10^{-3}\ \text{mm};\quad \alpha = 0.0001266$$

$$\boxed{\text{Lateral Shear} = (8\ \text{mm})\left(1.266 \times 10^{-4}\right) = 1.01\ \mu\text{m}}$$

Resolution of microscope

Assume NA=0.5

$$\text{AiryDiskRadius} = \frac{1.22\ \lambda}{2\ \text{NA}} = \frac{1.22\ (0.63\ \mu\text{m})}{2\ (0.5)} = 0.77\ \mu\text{m};$$

The shear is slightly larger than the Airy disk radius.

# SQ-3

I have a Mirau interferometer attachment with a microscope. The light source used with the microscope is a tungsten source with a 40-nm wide bandpass filter centered at a wavelength of about 600 nm.

a) I am using the Mirau to measure the surface roughness of some magnetic tape. It is hard to keep the tape flat, so I put a thin piece of glass on top of the tape to keep it flat. I find I have much difficulty getting good fringe contrast. Why? Approximately how thick can the glass (with a dispersion of $4\text{x}10^{-6}$/Å) be before the fringe contrast is unacceptable? State any assumptions you make.

b) I am now using the Mirau interferometer to measure the radius of curvature of a spherical surface. If I am looking at a sample 0.5 mm in diameter, approximately how small can the radius of curvature be before I lose fringe contrast at the edge of the sample? How do I determine if the surface is concave or convex?

c) If I am using a 20X objective and a detector array with 50 $\mu$m spacing to detect the fringes, would I be able to resolve the fringes at the edge of the mirror in part b)? With this detector array, what is the smallest radius of curvature I can measure? For this radius of curvature what width is needed for the bandpass filter to obtain high contrast fringes?

## Solution

$$\text{Coherence length} = l_c = \frac{\lambda^2}{\Delta\lambda} = \frac{(600\ \text{nm})^2}{40\ \text{nm}} = 9\ \mu\text{m}$$

### a)

The fringe contrast is reduced because the paths are not matched when the tape is in focus. Even if the Mirau interference objective is adjusted to correct for the defocus the dispersion of the glass makes it impossible to match the paths for all wavelengths unless a compensating glass plate is put in the interferometer.

Let t be the thickness of the glass plate of index n. The OPD between test and reference beam is given by

$$\mathbf{opd = 2\left((n-1)\,t + \frac{n-1}{n}\,t\right);}$$

where $\frac{n-1}{n}$ t is due to the defocus

If $n = 1.5$, $\text{opd} = \frac{5}{3}\,t$

Assume that maximum opd for acceptable fringe contrast is $l_c / 2$ then

$$\frac{5}{3}\,t \le \frac{l_c}{2} \quad \Rightarrow \quad t \le 2.7\ \mu\text{m}$$

However, if the reference plate is raised by (5/3) t, then only dispersion of glass will cause the bad contrast. Assume that acceptable spread due to dispersion is $\lambda/2$, then

$$2\,\text{Abs}\left[\frac{dn}{d\lambda}\right]\Delta\lambda\, t \le \frac{\lambda}{2} \Rightarrow t \le 94\,\mu\text{m}$$

## b)

$$\text{sag} = \frac{\rho^2}{2\,r};\ \text{opd} = \frac{\rho^2}{r} \le \frac{l_c}{2} \Rightarrow r \ge \frac{2\,\rho^2}{l_c} \approx 13.9\text{ mm}$$

Could gain factor of 2 by matching OPD's half way down the sag, rather than at top or bottom of sphere. Therefore, $r_{min}$=6.95 mm.

To determine sign push sphere away from Mirau and for circular fringes the fringes will expand for a concave sphere and shrink for a convex sphere.

## c)

To resolve fringes need 2 detector elements per fringe. Effective detector spacing at sample is 2.5 $\mu$m.

For fringes

$$\frac{\rho^2}{r} = m\,\lambda;\quad \frac{2\,\rho\,\Delta\rho}{r} = \lambda;\quad \text{fringeSpacing} = \Delta\rho = \frac{\lambda\,r}{2\,\rho}$$

$$r_{min} = \frac{2\,\rho\,\Delta\rho}{\lambda} = \frac{2\,(0.25\text{ mm})\,5\,\mu\text{m}}{0.6\,\mu\text{m}} = 4.2\text{ mm}$$

Match OPD's half-way down sag

$$\frac{\text{opd}}{2} = \frac{\rho^2}{2\,r} = \frac{l_c}{2} = \frac{\lambda^2}{2\,\Delta\lambda}$$

$$\Delta\lambda = \frac{\lambda^2\,r}{\rho^2} = \frac{(600\text{ nm})^2\,4.2\text{ mm}}{(0.25\text{ mm})^2} = 24.2\text{ nm}$$

# SQ-4

The Lyot test is used to measure a sample at normal incidence and a wavelength of 633 nm. The Lyot filter has no absorption. The sample is illuminated uniformly and there is no reflectance variation across the sample. The irradiance of the image varies from 1 to 1.04. What is the maximum height variation across the sample?

## Solution

$$e^{i\,\phi} \approx 1 + i\,\phi;\quad \text{intensity} = \text{Abs}[1+\phi]^2 \approx 1 + 2\,\phi;$$

$$1.04 = 1 + 2\,\phi_{\text{max}}$$

$$\phi_{\text{max}} = 0.02 = \frac{2\,\pi}{\lambda}\,2\,h$$

$$\boxed{\mathbf{h = \frac{0.02\,\lambda}{4\,\pi}\;/.\;\lambda \to 633\,nm = 1\,nm}}$$