Absolute Measurement of Surface Roughness

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Abstract

In an interferometer which uses a reference surface, the measured surface heights correspond to the difference between the test and reference surfaces. To determine the rms roughness of supersmooth surfaces accurately, the effects of the reference surface roughness need to be removed. One technique for doing this involves averaging a number of uncorrelated measurements of a mirror in order to generate a reference surface profile which can then be subtracted from subsequent measurements so that they do not contain errors due to the reference surface. The other technique provides an accurate rms roughness of the surface by taking two uncorrelated measurements of the surface. These two techniques for measurement of supersmooth surfaces are described, and results of the measurement of a 0.7 Å rms roughness mirror are presented. The expected error in the rms roughness measurement of a supersmooth mirror due to instrument noise is 0.02 Å.

Subtraction of a Generated Reference Surface

A profile of the reference surface can be generated by averaging a number of measurements N of a smooth mirror. The mirror surface used to do the averaging does not need to be supersmooth, but the smoother it is, the fewer measurements will need to be averaged. Between measurements, the mirror is moved by a distance greater than the correlation length of the surface.[1] Once the reference surface profile is generated, it can then be subtracted from subsequent measurements of test surfaces to measure the surface profile minus the reference surface. The generated reference surface becomes invalid if the reference surface is moved. Using this procedure, supersmooth surfaces with rms roughness values of less than an Ångstrom can be measured.

The rms roughness of the actual test surface profile measurement σ_{test} is[2]

$$\sigma_{test} = \sqrt{\sigma_{meas\text{-}genref}^{\,2} + \frac{\sigma_{mirror}^{\,2}}{\sqrt{N}}}\,, \tag{1}$$

where $\sigma_{meas\text{-}genref}$ is the rms roughness of the calculated test surface profile (a single measurement of the test surface minus the generated reference surface) and σ_{mirror} refers to the rms roughness of the mirror surface used to produce the generated reference profile. Thus, the error (second term in Eq. (1)) in the measurement of the test surface rms roughness is reduced by using a smoother mirror to generate the reference and by increasing the number of measurements averaged to generate the reference.

Absolute RMS Roughness Measurement

For an absolute rms roughness measurement, two uncorrelated measurements of the test surface are made. To get an uncorrelated measurement, the test surface is moved by a distance greater than the correlation length of the surface between measurements. The reference surface effect on the measured profile should not change from the first to the second measurement. This means that the reference surface should not be tilted relative to the optical axis between measurements. (Focus can be adjusted between measurements.) When the difference of these two measurements is taken, the effects of the reference surface profile cancel out. The rms roughness of the test surface is given by

$$\sigma_{test} = \frac{\sigma_{diff}}{\sqrt{2}}\ . \tag{2}$$

Thus, the rms roughness of the test surface can be easily determined by making two measurements of the surface. When this measurement is made, the effects of the reference surface cancel, and the surface statistics are derived. However, the calculated surface profile does not represent the actual test surface.

Results

Figure 1 shows a single measurement of a supersmooth mirror made without using any absolute measurement techniques. The rms roughness of this measurement is 5.6 Å (0.56 nm). When a reference is generated using 16 measurements of this supersmooth mirror, an rms roughness of 5.3 Å is obtained. This generated reference corresponding to the Mirau reference mirror is shown in Fig. 2. The difference between Fig. 1 and Fig. 2 is shown in Fig. 3. This corresponds to the actual surface without effects due to the reference surface and has an rms roughness of 0.71 Å.

The absolute rms roughness technique was used to produce the results shown in Fig. 4. The rms roughness obtained using this technique is 0.70 Å. The profile obtained represents the test surface statistically but does not correspond to the profile at the measured location. The rms roughness obtained using this technique only differs by 0.01 Å from that obtained using the generate reference technique.

These rms roughness values can be measured repeatedly to within ±0.05 Å. A more detailed derivation of these techniques is given in reference 2.

References

1. Correlation length is defined as the distance over which the autocovariance function falls to 0.1 of its maximum value. (ANSI Standard B46.1-1978, Surface Texture, p. 34) It can be calculated from a measured profile of the surface.

2. Katherine Creath and James C. Wyant, "Absolute measurement of surface roughness," to be published in Appl. Opt. **29**, 1990.

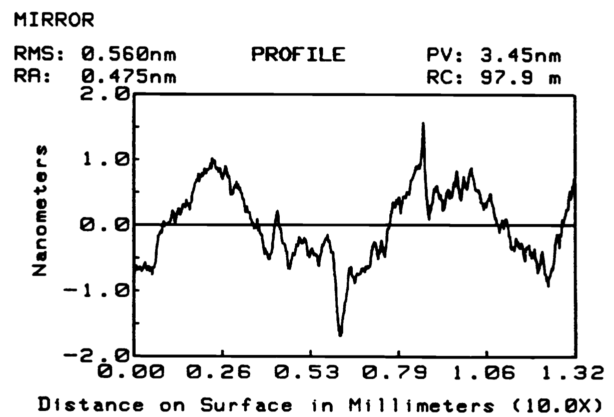

Figure 1. Measurement of supersmooth mirror including the reference surface.

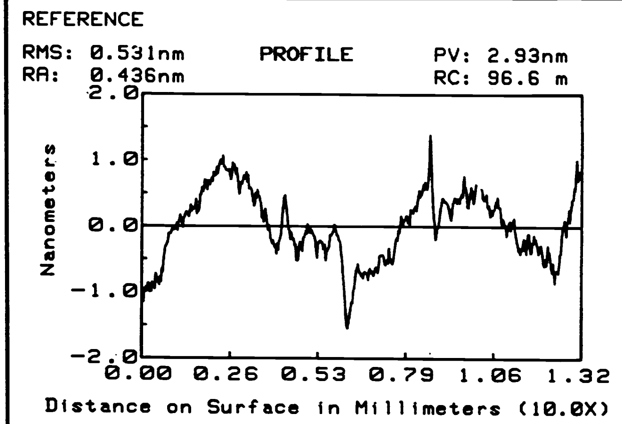

Figure 2. Profile of reference surface generated by averaging 16 uncorrelated measurements.

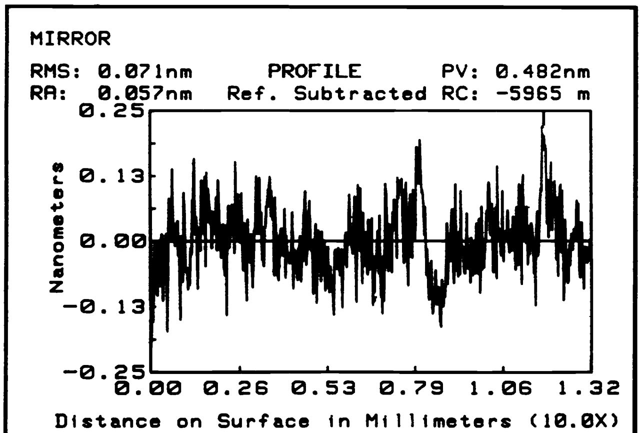

Figure 3. Supersmooth mirror without effects of the reference surface.

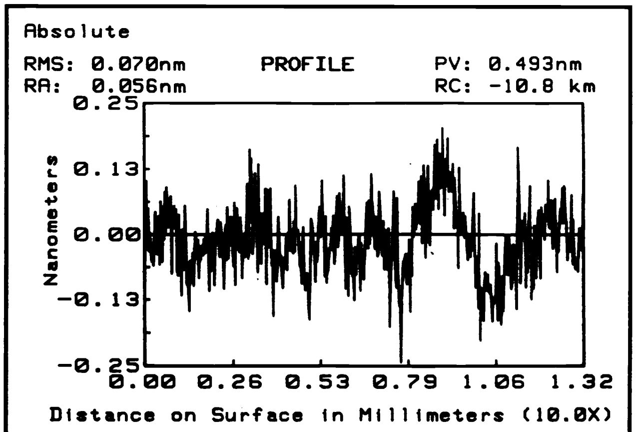

Figure 4. Absolute measurement of supersmooth mirror made with two uncorrelated measurements.