Invited Paper

Comparison of surface roughness measured with an optical profiler and a scanning probe microscope

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ABSTRACT

The surface topography of various samples has been measured using an optical profiler and a scanning probe microscope (SPM). Optical profilers offer fast and accurate measurements of surface topography but are limited in their lateral resolution by the wavelength of light used. SPMs extend the lateral resolution down to atomic dimensions. Topography measurements are used to obtain surface roughness data. We find that for a scan size of 50x50 μm, the roughness data obtained from the optical profiler agree with the SPM measurements. The roughness data do not vary significantly when higher magnification images are taken with the SPM on surfaces that lack high frequency components. But for surfaces that have rough features that are smaller than the resolution of the optical profiler, roughness data calculated from higher magnification images by SPM can vary significantly.

1. INTRODUCTION

Measurement and control of surface roughness are important in many fields, such as magnetic media, semiconductor processing and optics. Typical roughness measurements are performed using stylus profilers, non-contact optical profilers, or scanning probe microscopes (SPM). Stylus measurements are widely used for surface roughness, but they lack lateral resolution due to the tip geometry. They also may cause surface damage due to high forces exerted on the surface. Optical profilers offer quick measurement of surface features without surface contact, but they are limited in lateral resolution due to the wavelength of light used. The scanning probe microscope extends the lateral resolution to atomic dimensions and is non-damaging due to the very light forces used. In this paper, we present the surface topography measured on various samples using an optical profiler and a scanning probe microscope and discuss the roughness data calculated from the topographical data.

2. EXPERIMENTAL

All measurements were performed in air without any sample preparation. A commercially available optical profiler (WYKO HiRes) and scanning probe microscope (WYKO MicroProbe 3D) were used for all measurements.

2.1. Optical profiler

Figure 1 is a schematic representation of the optical profiler used for the measurements. The profiler uses a Linnik interferometer. The reference surface in the interferometer is mounted on a piezoelectric transducer that is used to move it at a constant velocity. This allows the use of electronic phase-shifting techniques to measure the phase of the interference pattern which is recorded by a CCD camera. Then the data are converted to give accurate height measurements.[1] A 100X magnification was used for all the measurements.

2.2. Scanning probe microscope

The scanning probe microscope used in these measurements was a force microscope as depicted in Figure 2.[2] The sample is mounted on a piezoelectric ceramic that is capable of scanning in x, y, and z directions. A thin cantilever (manufactured from silicon nitride) with an integrated sharp tip is brought near the surface of the sample. An optical deflection technique is used to measure the deflection of the cantilever during the scan. The deflection of the cantilever is kept constant by adjusting the z position of the sample using a feedback loop. The x, y, and z positions of the piezoelectric ceramic are recorded as the surface topography. 400x400 sample points were used for all the data.

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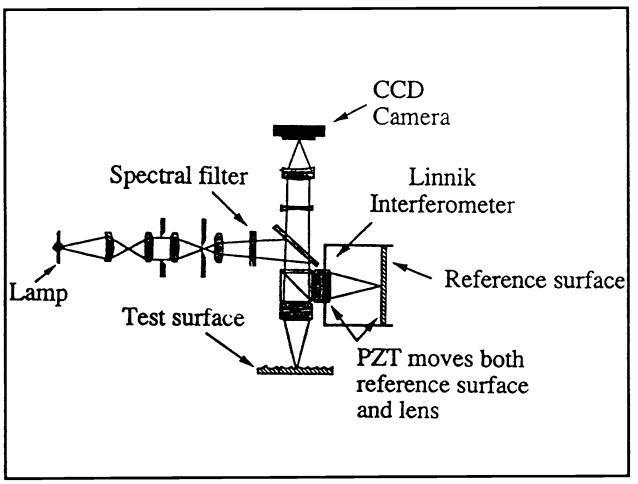

Figure 1. Schematic representation of an optical profiler.

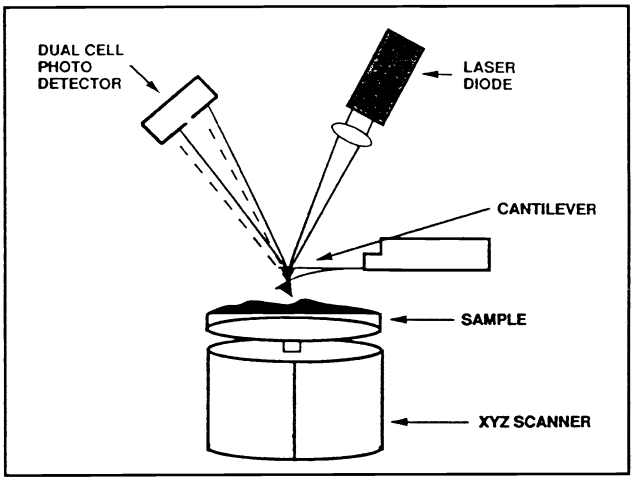

Figure 2. Schematic representation of a scanning force microscope.

3. RESULTS

A 50x50 μm image taken on a magnetic disk with the optical profiler is shown in Figure 3. The calculated R_{rms} and R_a are 11.0 nm and 8.6 nm, respectively. A 50x50 μm image taken on the magnetic disk measured with the SPM is shown in Figure 4. The calculated R_{rms} and R_a are 12.9 nm and 8.9 nm, respectively. Higher magnification images taken with the SPM on the magnetic disk are shown in Figures 5 and 6, and the calculated R_{rms} and R_a are summarized in Table 1. As can be seen from the data in Table 1, R_{rms} and R_a values do not vary significantly as the magnification is increased. This indicates that the surface roughness is uniform and no significant features with high frequency components are present on the surface. Similar results are obtained on a magnetic tape sample (Figures 7 through 10 and Table 2)

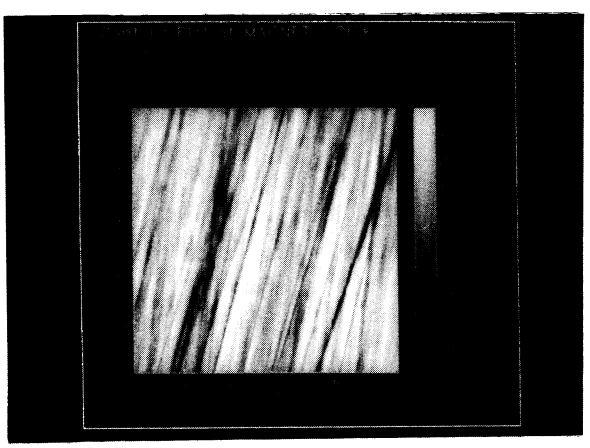

Figure 3. A 50x50 μm image taken on a magnetic disk with the optical profiler.

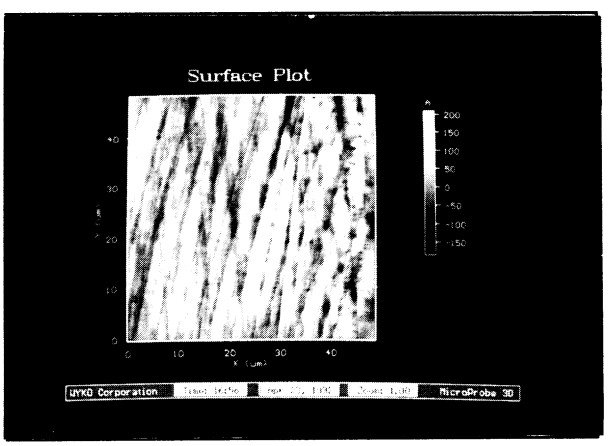

Figure 4. A 50x50 μm image taken on a magnetic disk with the SPM.

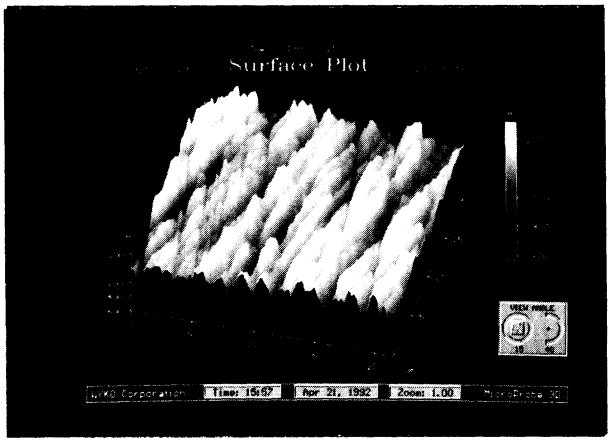

Figure 5. A 21x21 μm image taken on a magnetic disk with the SPM.

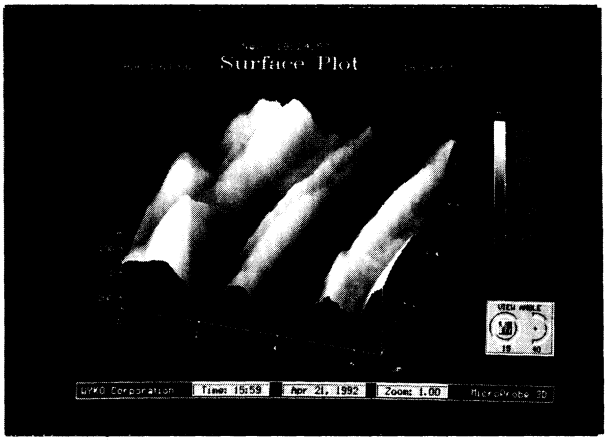

Figure 6. A 6.5x6.5 μm image taken on a magnetic disk with the SPM.

Table 1. Calculated R_{rms} and R_a values from the SPM measurements on a magnetic disk.

	SPM		HiRes	
Scan size (μm)	R_{rms} (nm)	R_a (nm)	R_{rms} (nm)	R_a (nm)
50x50	12.9	8.9	11.0	8.6
21x21	10.9	8.7		
14x14	9.3	7.5		
6.5x6.5	10.8	8.8		

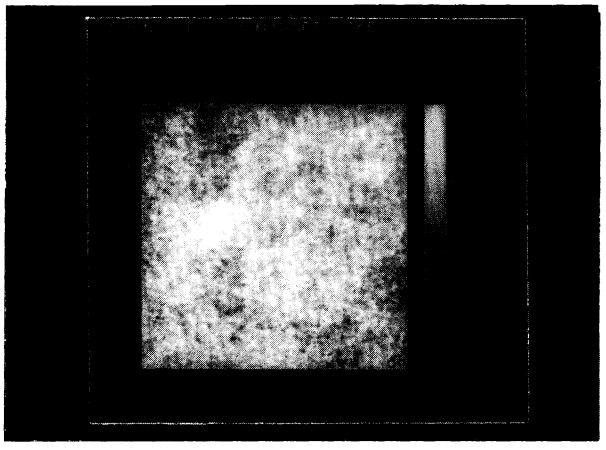

Figure 7. A 50x50 μm image taken on a magnetic tape with the optical profiler.

Figure 8. A 50x50 μm image taken on a magnetic tape with the SPM.

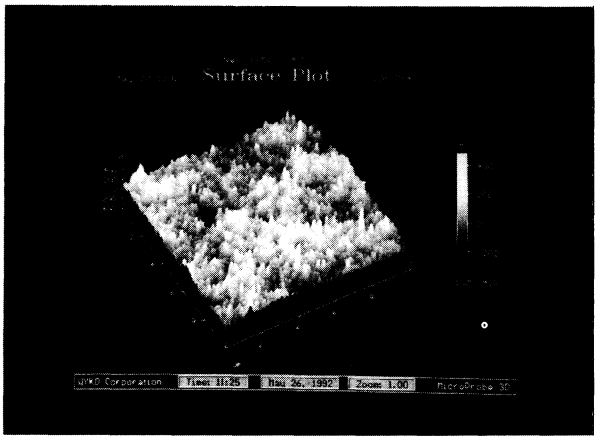

Figure 9. A 20x20 μm image taken on a magnetic tape with the SPM.

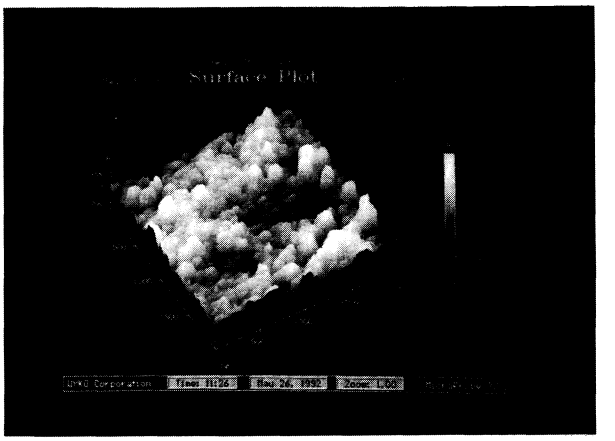

Figure 10. A 2x2 μm image taken on magnetic tape with the SPM.

Table 2. Calculated R_{rms} and R_a values from the SPM measurements on magnetic tape.

	SPM		HiRes	
Scan size (μm)	R_{rms} (nm)	R_a (nm)	R_{rms} (nm)	R_a (nm)
50x50	8.2	6.2	10.1	7.9
20x20	7.4	5.6		
10x10	7.4	5.8		
2x2	6.8	6.0		

In contrast, measurements made on chemically etched glass have rough features that are smaller than the resolution of the optical profiler. A 50x50 μm image taken on a glass sample with the optical profiler is shown in Figure 11. The calculated R_{rms} and R_a are 4.1 nm and 3.1 nm respectively. A 50x50 μm image taken on the glass sample with the SPM is shown in Figure 12. The calculated R_{rms} and R_a from this image are 3.9 nm and 2.8 nm, respectively. Higher magnification images taken with the SPM on a magnetic disk are shown in Figures 13 and 14 and the calculated R_{rms} and R_a are summarized in Table 3. As can be seen from the data in Table 3, R_{rms} and R_a values increase significantly as the magnification is increased. This indicates that at higher magnification, features that were too small to be imaged are now observable (Figure 13). At still higher magnifications, the roughness data vary depending on the area scanned. This indicates that the roughness is not uniform.

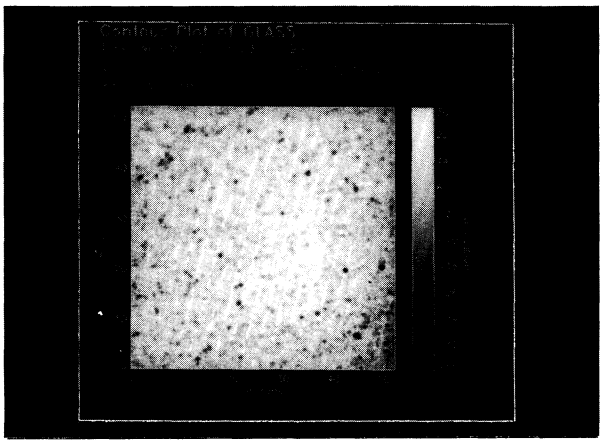

Figure 11. A 50x50 μm image taken on a glass sample with the optical profiler.

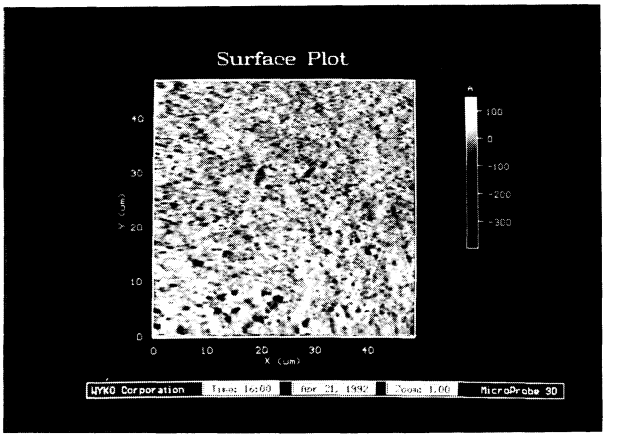

Figure 12. A 50x50 μm image taken on a glass sample with the SPM.

Figure 13. An 11x11 μm image taken on a glass sample with the SPM.

Figure 14. A 1.7x1.7 μm image taken on a glass sample with the SPM.

Table 3. Calculated R_{rms} and R_a values from the SPM measurements on a glass sample.

	SPM		HiRes	
Scan size (μm)	R_{rms} (nm)	R_a (nm)	R_{rms} (nm)	R_a (nm)
50x50	3.9	2.8	4.1	3.1
30x30	4.8	3.5		
11x11	6.7	4.9		
3x3	5.8	4.4		
1.7x1.7	3.4	2.7		

Other measurements made on an air bearing surface (ABS) of a magnetic head and a chemically etched silicon sample are shown in Figures 15 through 22. The calculated Rms and Ra are shown in Tables 4 and 5, respectively. In each case, the data from the optical profiler agree well with the SPM measurements. But in contrast to the glass sample, images taken at higher magnifications with the SPM on these samples have lower values of R_{rms} and R_a. This indicates that these surfaces have low frequency components.

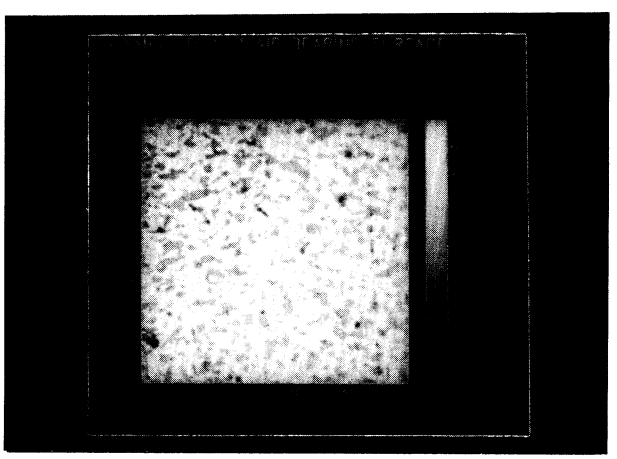

Figure 15. A 50x50 μm image taken on an ABS of a magnetic head sample with the optical profiler.

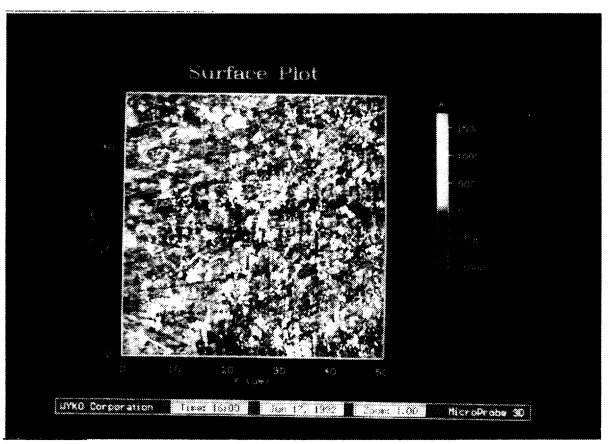

Figure 16. A 50x50 μm image taken on an ABS of a magnetic head sample with the SPM.

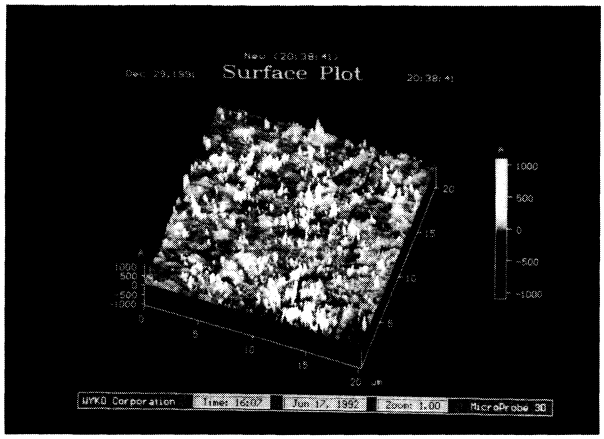

Figure 17. A 20x20 μm image taken on an ABS with the SPM.

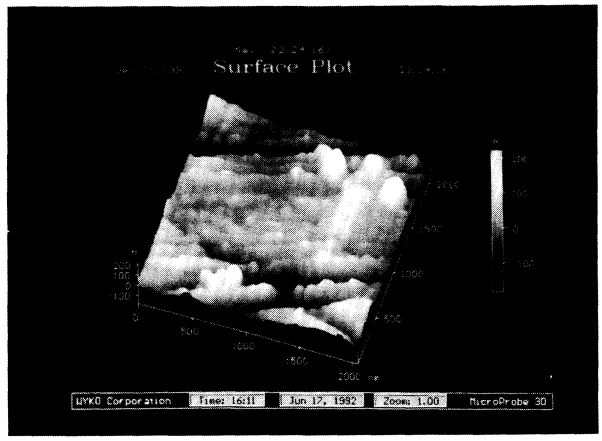

Figure 18. A 2x2 μm image taken on an ABS with the SPM.

Table 4. Calculated R_{rms} and R_a values from the SPM measurements on the ABS.

	SPM		HiRes	
Scan size (μm)	R_{rms} (nm)	R_a (nm)	R_{rms} (nm)	R_a (nm)
50x50	8.0	4.8	8.0	6.5
20x20	7.0	4.5		
10x10	6.6	4.9		
2x2	4.0	2.8		

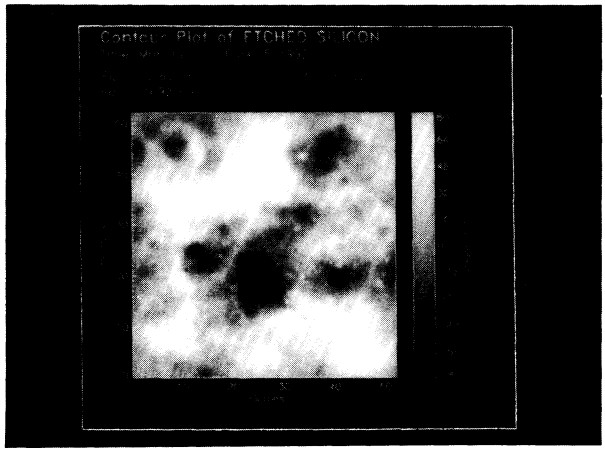

Figure 19. A 50x50 μm image taken on a chemically etched silicon sample with the optical profiler.

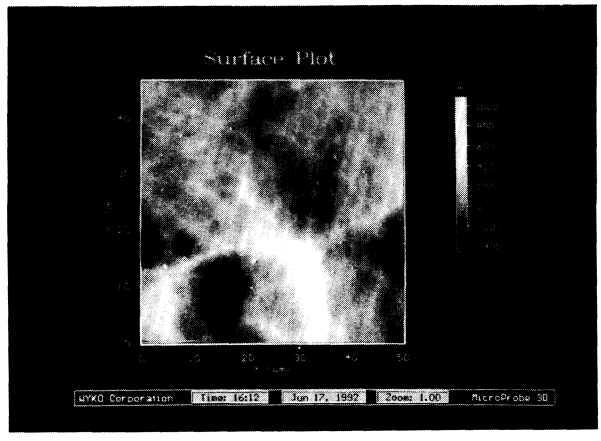

Figure 20. A 50x50 μm image taken on a chemically etched silicon sample with the SPM.

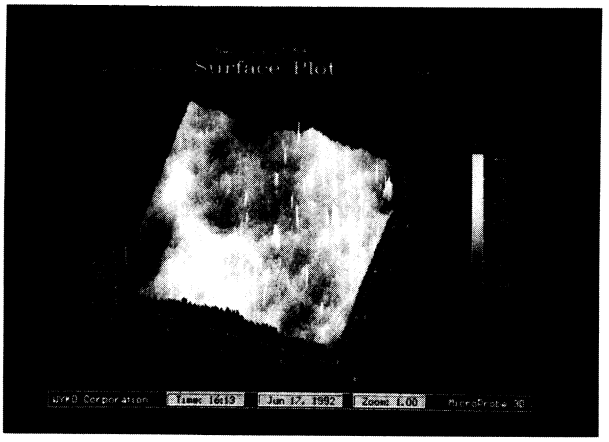

Figure 21. A 20x20 μm image taken on a chemically etched silicon sample with the SPM.

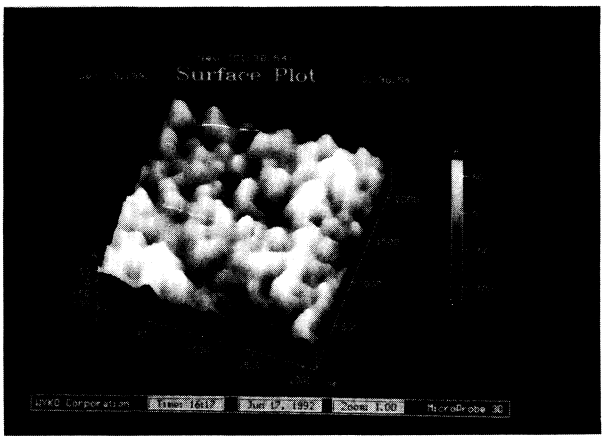

Figure 22. A 2x2 μm image taken on a chemically etched silicon sample with the SPM.

Table 5. Calculated R_{rms} and R_a values from the SPM measurements on a chemically etched silicon sample.

	SPM		HiRes	
Scan size (μm)	R_{rms} (nm)	R_a(nm)	Rms (nm)	R_a (nm)
50x50	13.0	10.4	12.6	9.9
20x20	6.7	5.4		
10x10	4.2	3.2		
2x2	2.4	1.9		

Optical profilers can also measure surface topography of thin films, only if the film thickness and the index of refraction are known. SPM measurements are independent of the properties of the thin film. SPM images taken on a thin film of polycrystalline silicon (unknown thickness) on a silicon substrate are shown in Figures 23 through 26, and the calculated R_{rms} and R_a are summarized in Table 6.

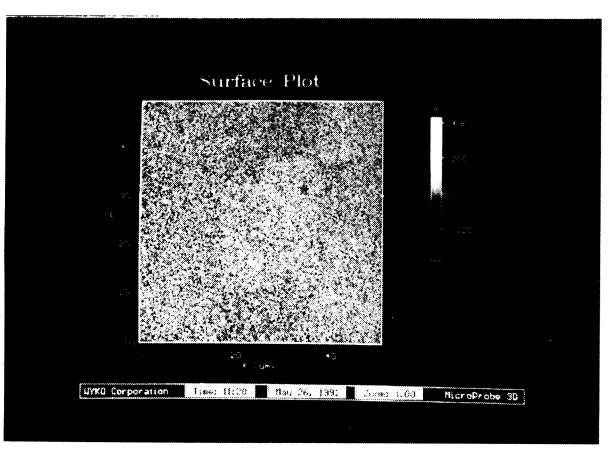

Figure 23. A 50x50 μm image taken on a thin polycrystalline silicon film on silicon with the SPM.

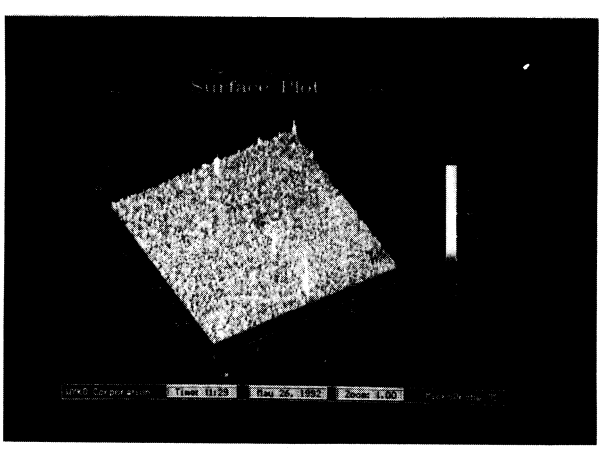

Figure 24. A 20x20 μm image taken on a thin polycrystalline silicon film on silicon with the SPM.

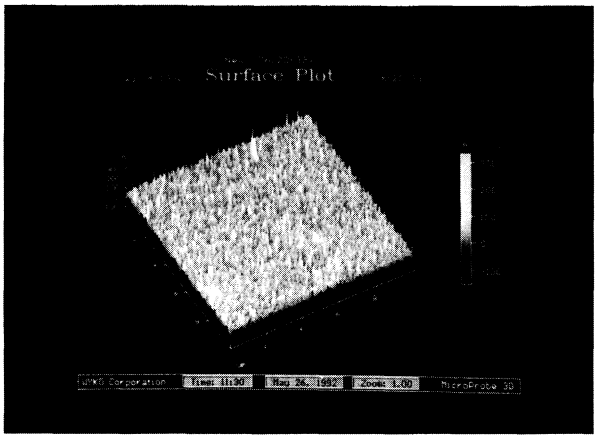

Figure 25. A 10x10 μm image taken on a thin polycrystalline crystalline silicon film on silicon with the SPM.

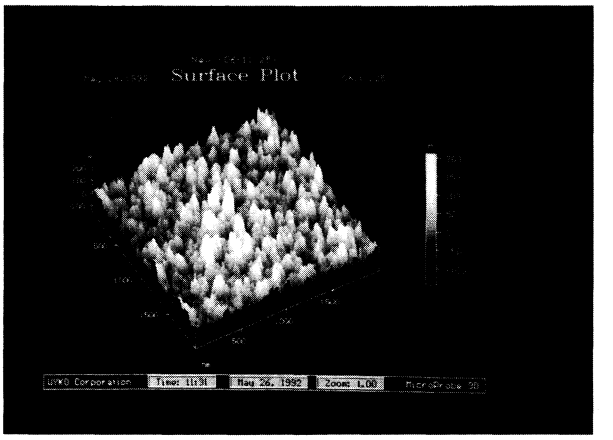

Figure 26. A 2x2 μm image taken on a thin polysilicon film on silicon with the SPM.

Table 6. Calculated R_{rms} and R_a values from the SPM measurements on a thin polycrystalline film on silicon.

Scan size (μm)	R_{rms} (nm)	R_a (nm)
50x50	3.9	3.1
20x20	3.5	2.7
10x10	3.4	2.7
2x2	4.0	3.2

4. CONCLUSIONS

Surface roughness data obtained on various samples indicate that in cases where the surface topography does not have features smaller than the nominal resolution of the optical profilers, measurements obtained with the optical profilers are indicative of the true surface roughness. In cases where the microfeatures are present, a complementary technique such as the scanning probe microscope should be used to provide accurate roughness data.

5. ACKNOWLEDGMENTS

We would like to thank Lisa Merrill for HiRes optical profiler measurements.

6. REFERENCES

1. J.C. Wyant, C.L. Koliopoulos, B. Bushan, and D. Basila, "Development of a Three-Dimensional Noncontact Digital Optical Profiler," J. Tribology, pp. 1-8, 1985.
2. J. Jahanmir, B.H. Haggar, and J.G. Hayes, "The Scanning Probe Microscope," J. Microscopy, to be published.