S.P. Schneider, Purdue University, School of AAE, 765-494-3343, 19 August 1999
Measurements by Chris Tieche, Purdue University, School of AAE.

Note: This document is best accessed as a Word file, since the images are in color, and the original electronic version allows magnified views of the images.

Zygo Optical Profilometer Measurements of Test Mandrel: Sample Tests for Mach-6 Quiet-Flow Nozzle Throat

1. Introduction

An electroform was made by GAR using hard and soft nickel, on the test mandrel. Earlier measurements were made by Chris Tieche on two coupons cut from the electroform, prior to any heating. These are reported elsewhere.

After the preheating measurements, the two samples were placed in the oven at ASL by Schneider for 67 hours at 196-198C, or about 385F. This was done 12 July. Unfortunately, Chris was not available to measure them at that time, and then the Zygo interferometer stopped working for some time. Ca. 12 August, Chris made measurements of the heated samples and these are reported here.

Chris reported the following general comments: *"All of the samples showed the preferential ridges in the longitudinal direction of the sample. Sometimes I put in notes on what the max peak to valley value is because they differ than what is in the .bmps. This is because I feel that an isolated spike is an artifact and so I don't include that in the PV number. The Zygo, however, does. I didn't filter the data to get rid of it because I didn't want to lose any topography."*
I asked him whether these preferential ridges had been present prior to the heating. He replied that: *"I can't say whether the ridges look better or worse than last time because it has been so long since then. The ridges were pronounced, however, and I don't recall seeing that before. I have down in my notebook that the samples were very smooth last time, so I would say that they had less topography last time than this time."*

Area 2 of sample 2 shows a substantial spike which indicates that for best performance we will need to polish the electroform after heating to get best performance. Also, the many ridges shown in the heated sample may possibly generate Gortler vortices, since they are aligned with the flow, although they have small amplitude. The spacing is roughly 20-100 micrometers, or 0.0008-0.004 inches. At the throat, the circumference is roughly 4 inches, so these are spaced 1000-5000 ridges around the circumference. Since the most amplified Gortler vortices are spaced at roughly 300-400 waves, starting well downstream of the throat, direct coupling is unlikely, but indirect nonlinear effects seem possible.

2. Measurements on Sample 1.

Figures 1 and 2 show area 1 on sample 1. The preferential ridges are very evident, the P-V amplitude is about 92 nm or 3.6 microinches. Ra is 14 nm or 0.55 microinches. Despite the ridges, the finish quality is still more than sufficient.

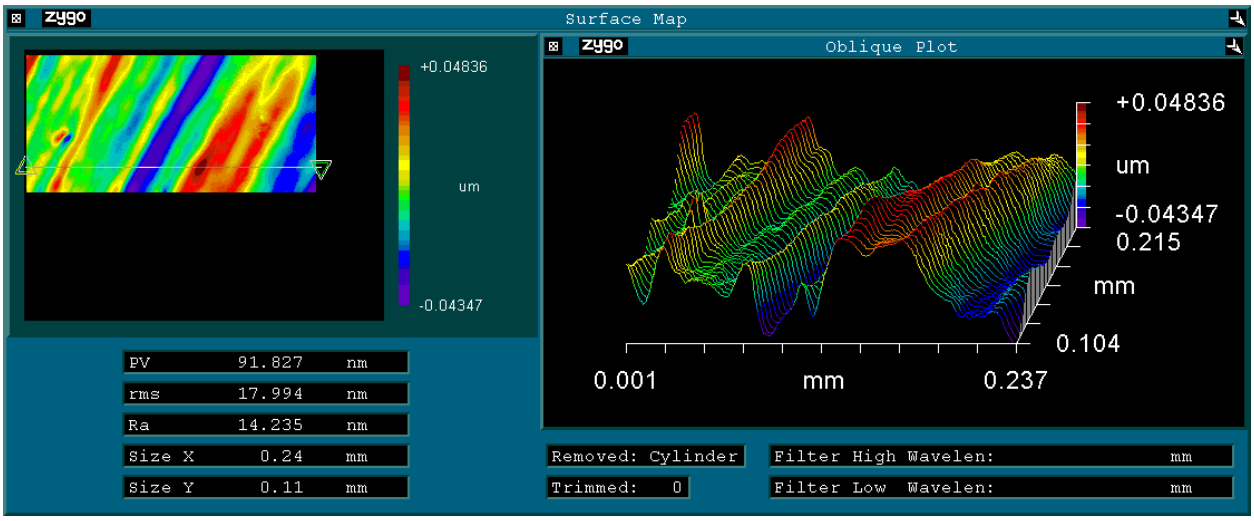

Figure 1: Sample 1 Area 1

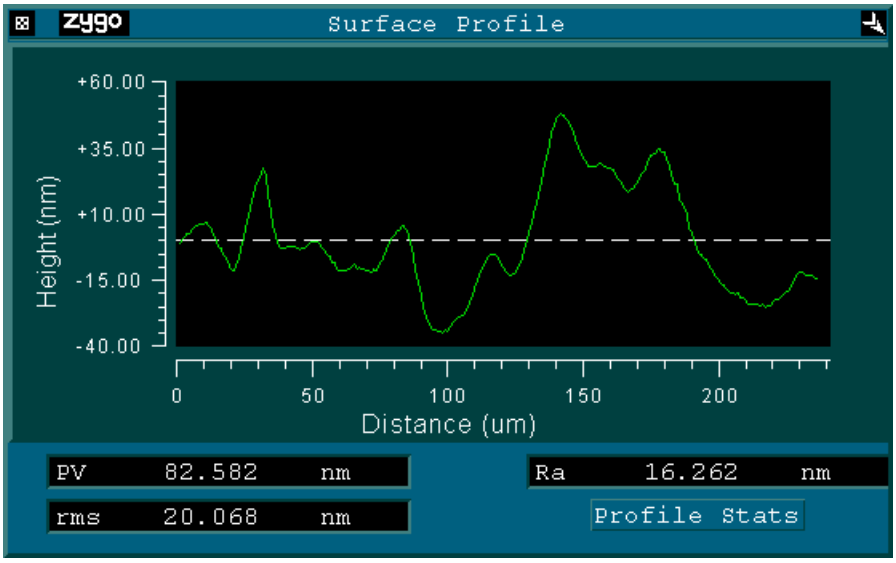

Figure 2: Selected Profile, Area 1 of Sample 1

Figures 3 and 4 show area 2 of sample 1. The results are similar, although the PV amplitude is less.

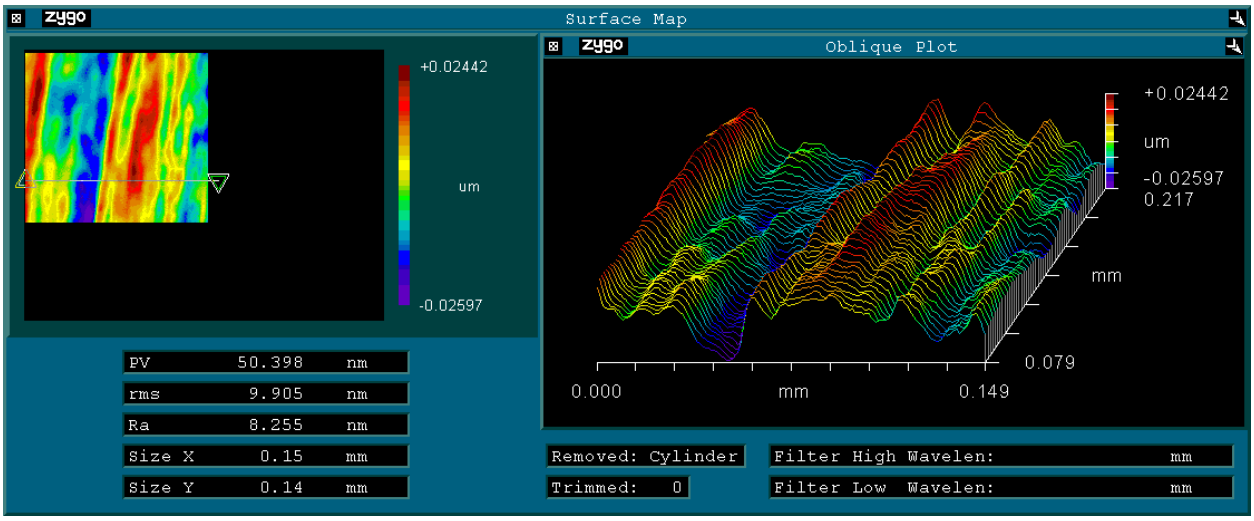

Figure 3: Area 2 of Sample 1

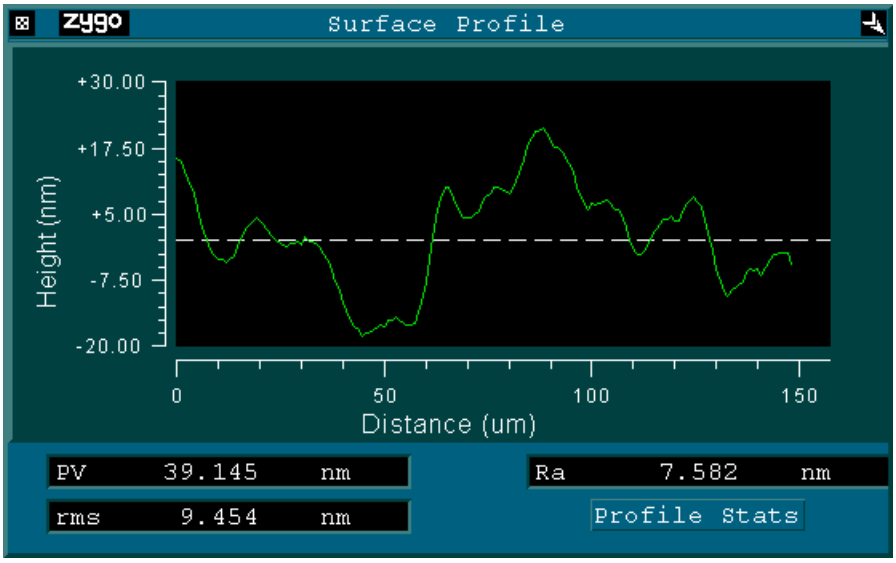

Figure 4: Selected Profile, Area 2 of Sample 1

Figures 5 and 6 show area 3 of sample 1. The results are again similar. The spanwise ridges have a spacing of roughly 50-100 microns, or 0.002-0.004 inches.

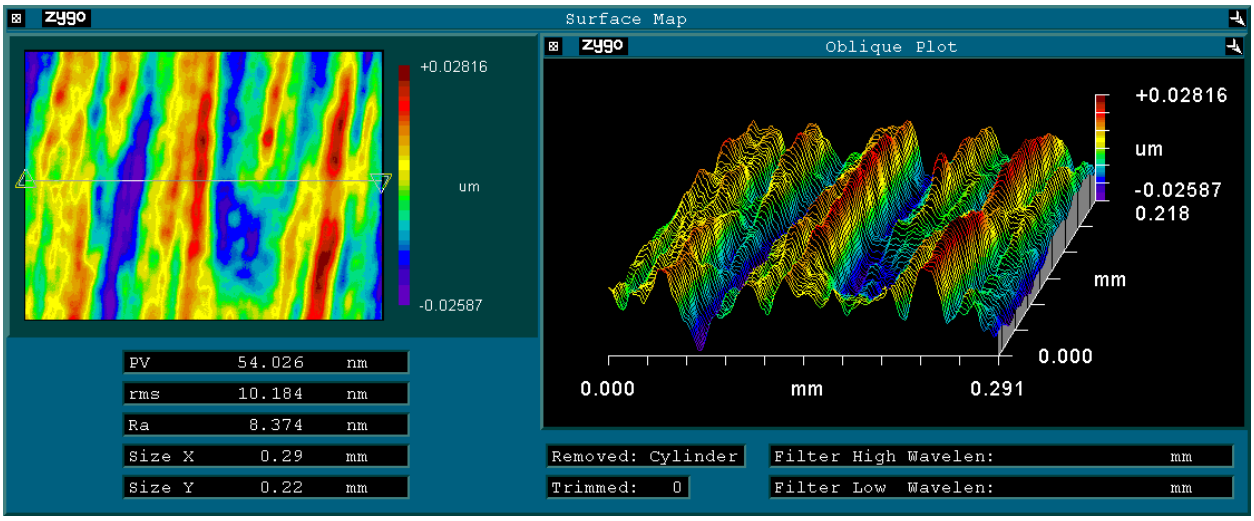

Figure 5: Area 3 of Sample 1

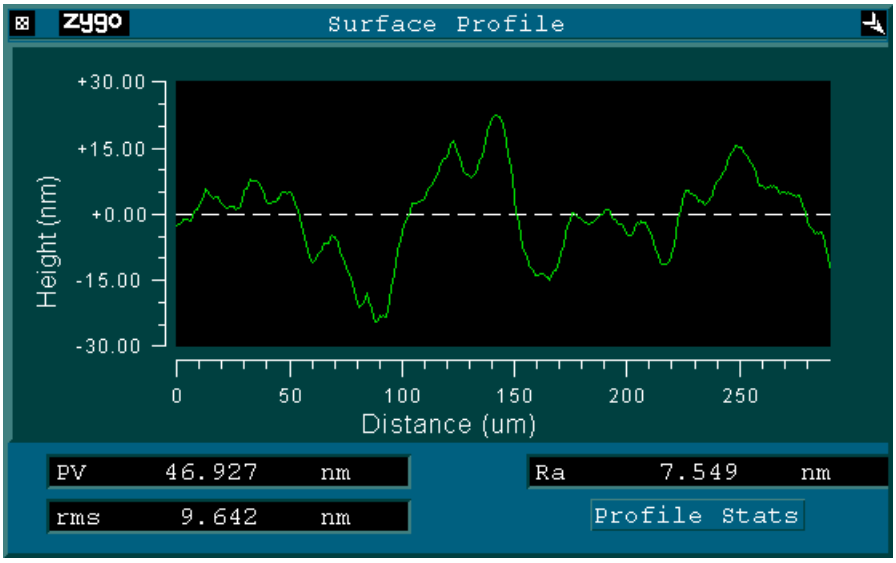

Figure 6: Selected Profile, Area 3 of Sample 1

Figures 7 and 8 show area 4 of sample 1. Chris states that *"at left center, 35micron dia hole, 350nm deep. Sides are very steep so the Zygo can get them, but the scope found the bottom."* This pit is therefore 0.0014 inches diam. by 13.8 microinches deep, which is still fairly small amplitude.

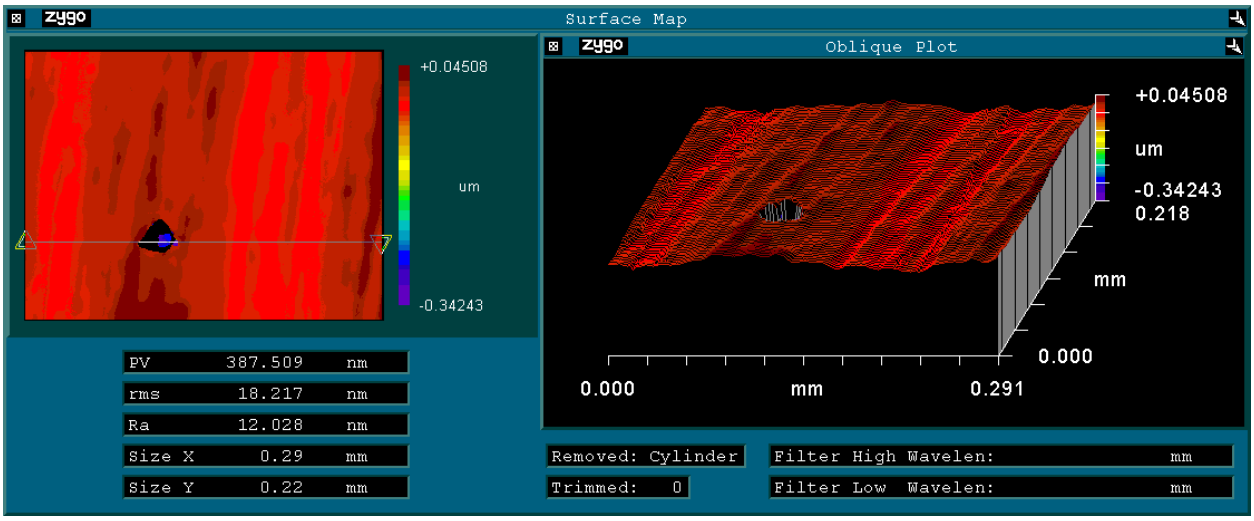

Figure 7: Area 4 of Sample 1

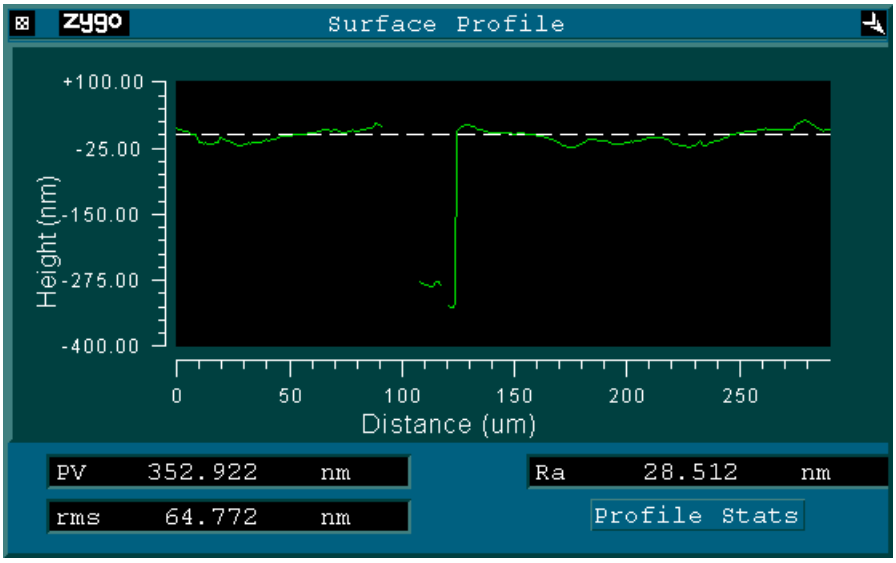

Figure 8: Selected Profile, Area 4 of Sample 1

Figures 9 and 10 show area 5 of sample 1. Similar ridges are again seen.

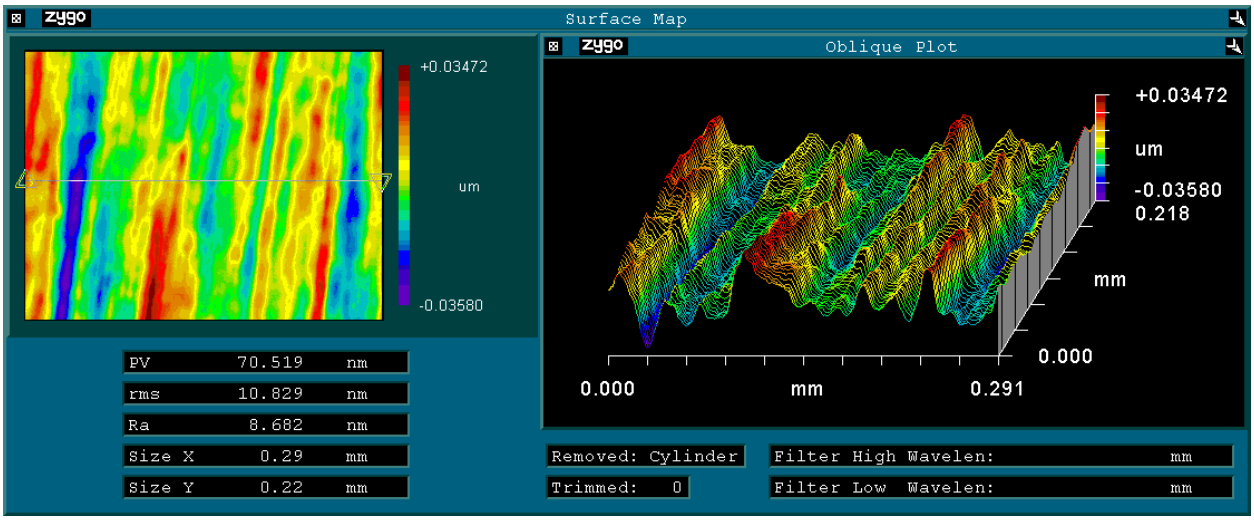

Figure 9: Area 5 of Sample 1

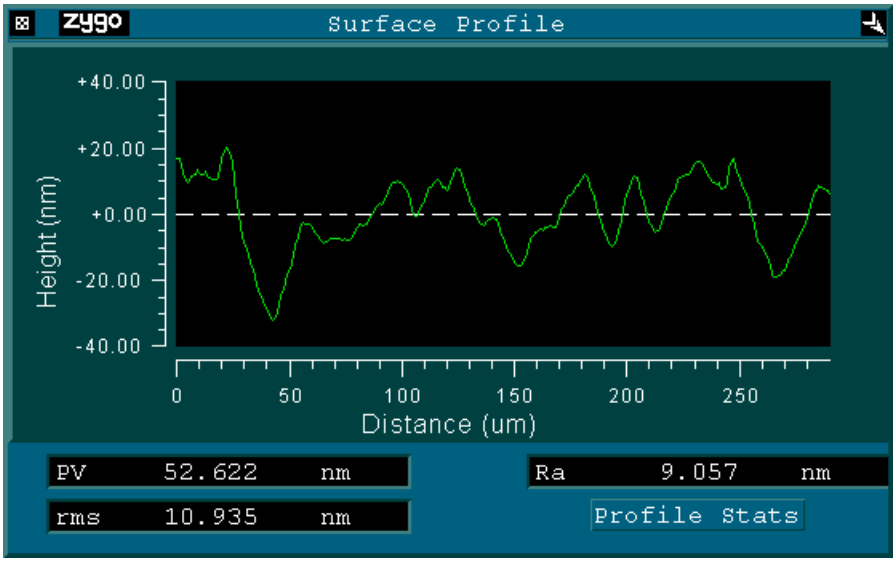

Figure 10: Selected Profile, Area 5 of Sample 1

Figures 11-14 show areas 6 and 7 of sample 1. These look similar.

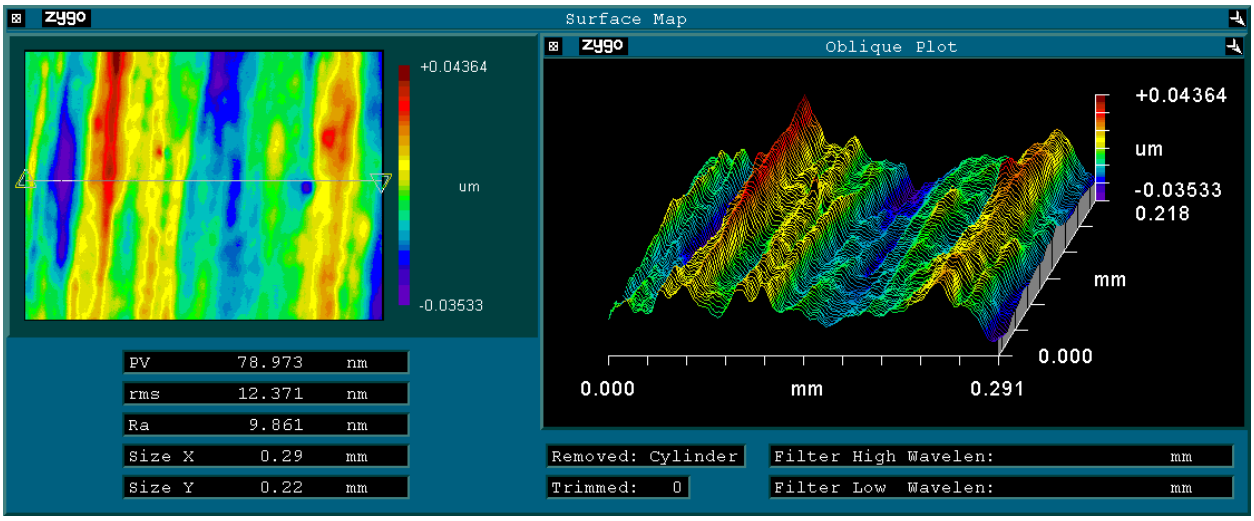

Figure 11: Area 6 of Sample 1

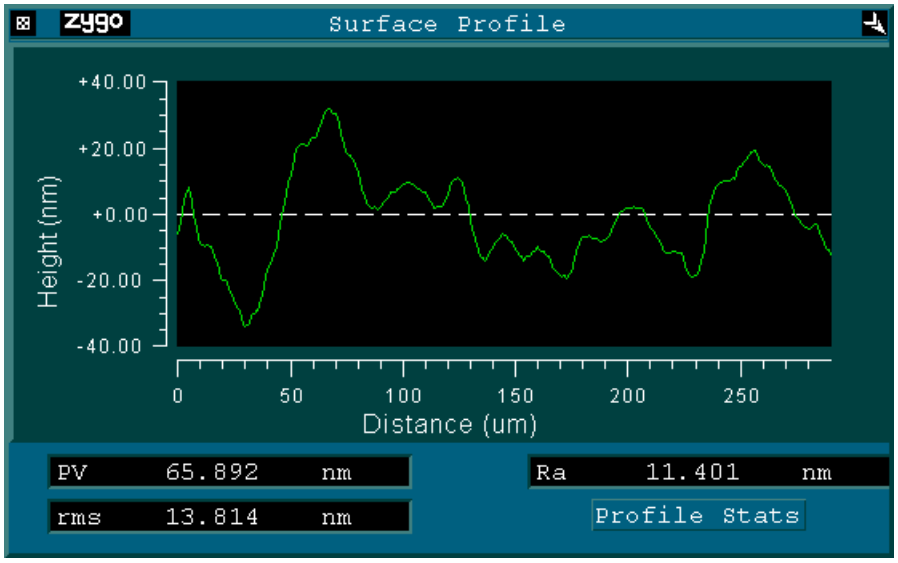

Figure 12: Selected Profile, Area 6 of Sample 1

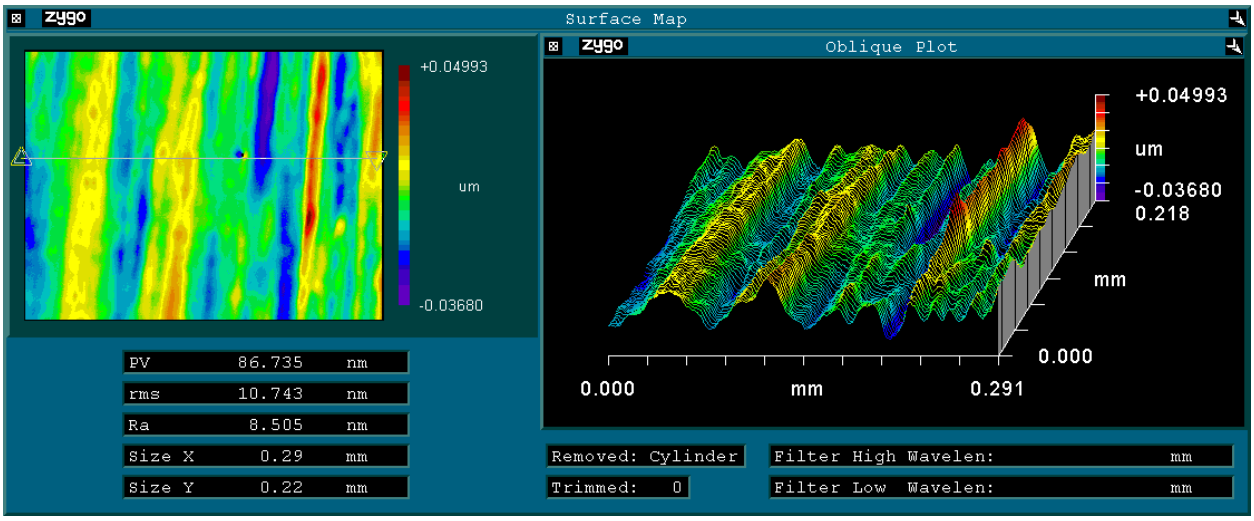

Figure 13: Area 7 of Sample 1

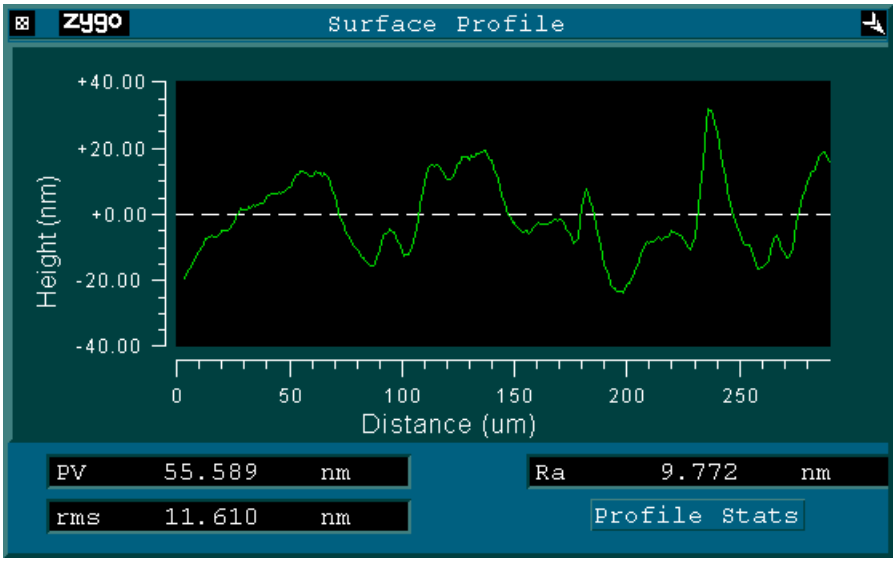

Figure 14: Selected Profile, Area 7 of Sample 1

Figures 15 and 16 show area 8 of sample 1. Chris noted that *"50nm deep hole at upper right. Deep valley at LHS. Peak-to-valley max (PV) is about 85nm here. The scope couldn't get all the way to the bottom of the hole so PV is lower in .bmp than what it should be."* 60 nm depth would be 2.4 microinches, still not a critical problem.

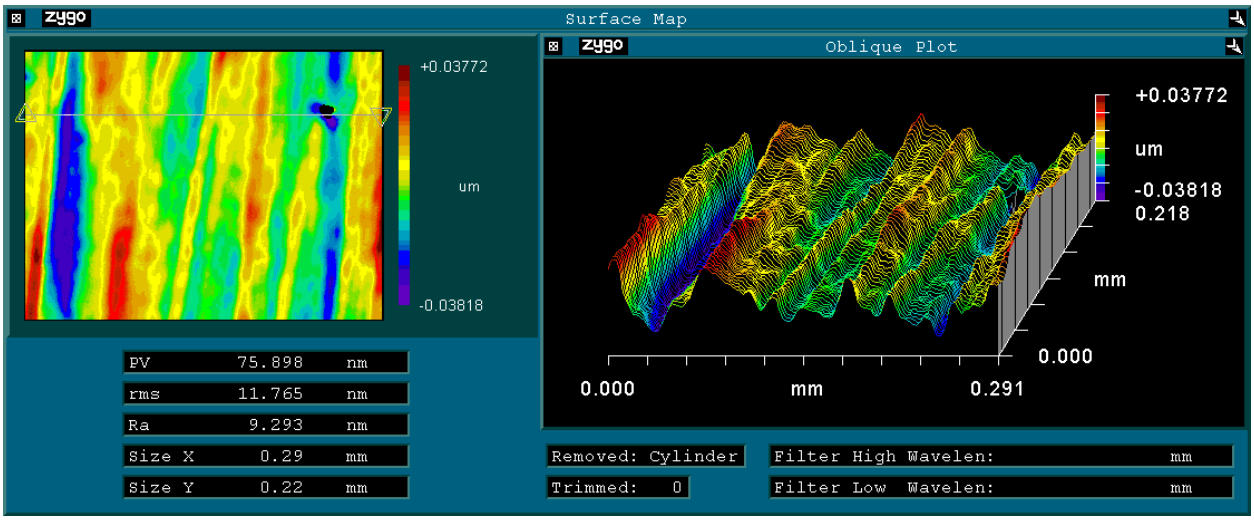

Figure 15: Area 8 of Sample 1

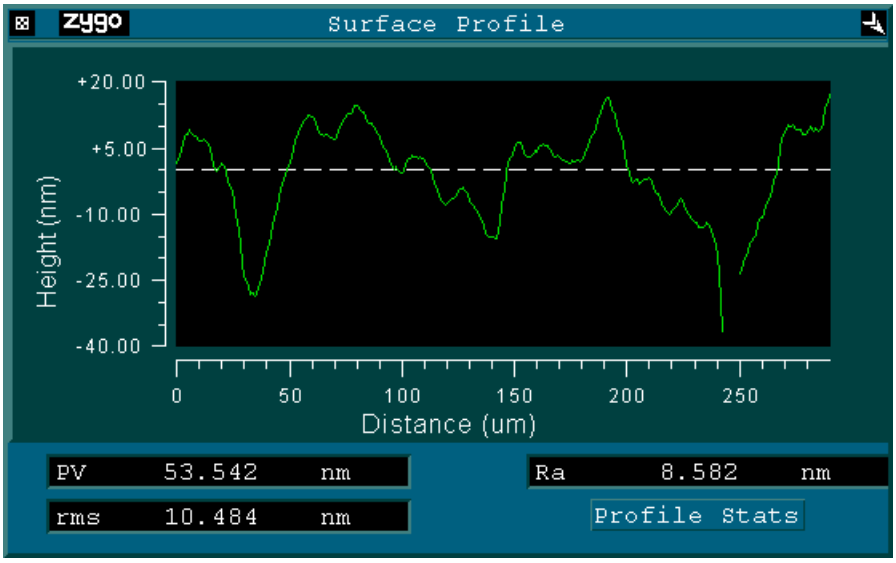

Figure 16: Selected Profile, Area 8 of Sample 1

3. Measurements on Sample 2

Figures 17 and 18 show area 1 of sample 2. Chris noted that *"most of view is a discolored surface. the clean surface is at upper right. PV is around 300nm. The discoloredsurface appears to be rougher, but only at the junction with the clean surface."* The depression is again substantial but not excessive (11.8 microinches P-V).

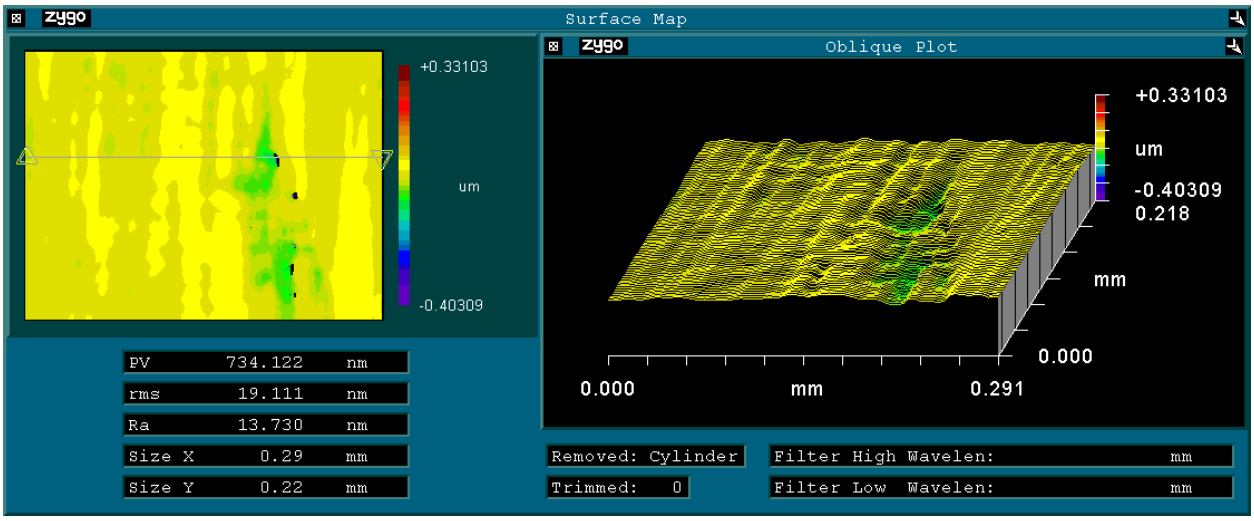

Figure 17: Area 1 of Sample 2

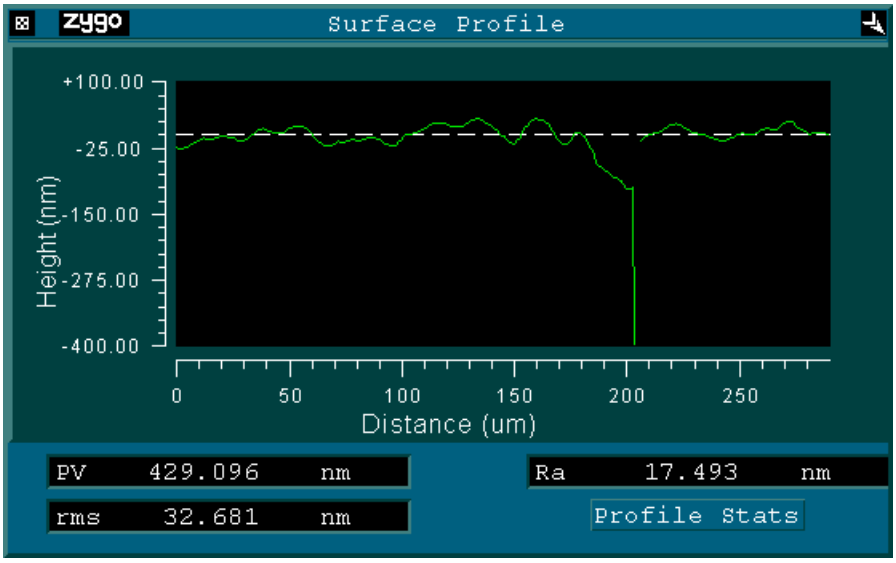

Figure 18: Selected Profile, Area 1 of Sample 2

Figures 19-20 show area 2 of sample 2. Chris notes that *"500nm extrusion left center. This is not dust, as seen in oblique view. Surface profile view indicates that this is not a spike either. PV is around 500nm."* This is 19.7 microinches. This is a significant flaw of a type we did not expect to find in the electroform. It indicates that the electroforming process is not perfect, and that we will probably have to polish the electroform after receipt in order to get best performance.

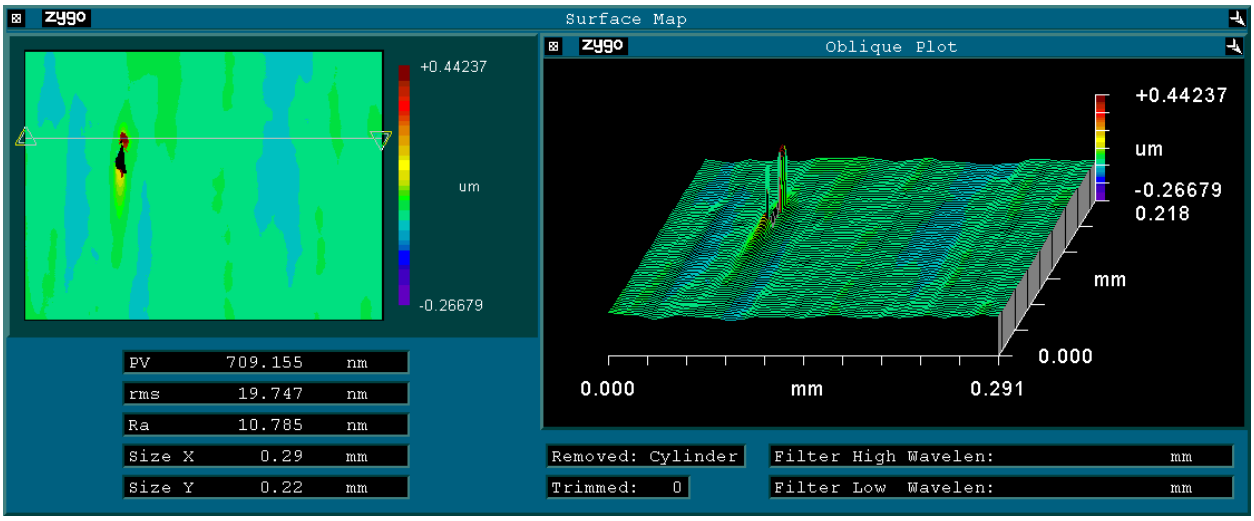

Figure 19: Area 2 of Sample 2

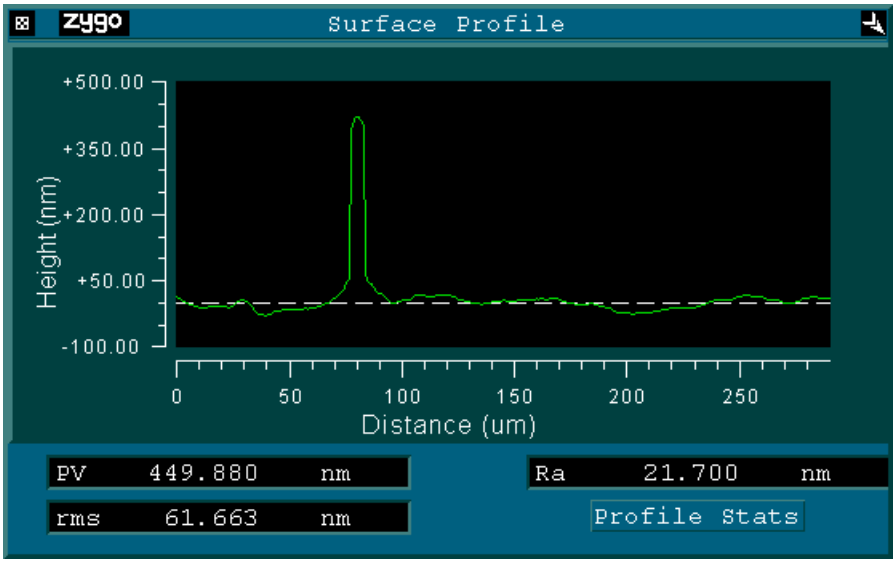

Figure 20: Selected Profile, Area 2 of Sample 2

Figures 21 and 22 show area 3 of sample 2. This shows the spanwise ridges characteristic of sample 1. Chris noted that “pronounced ridges apparent”.

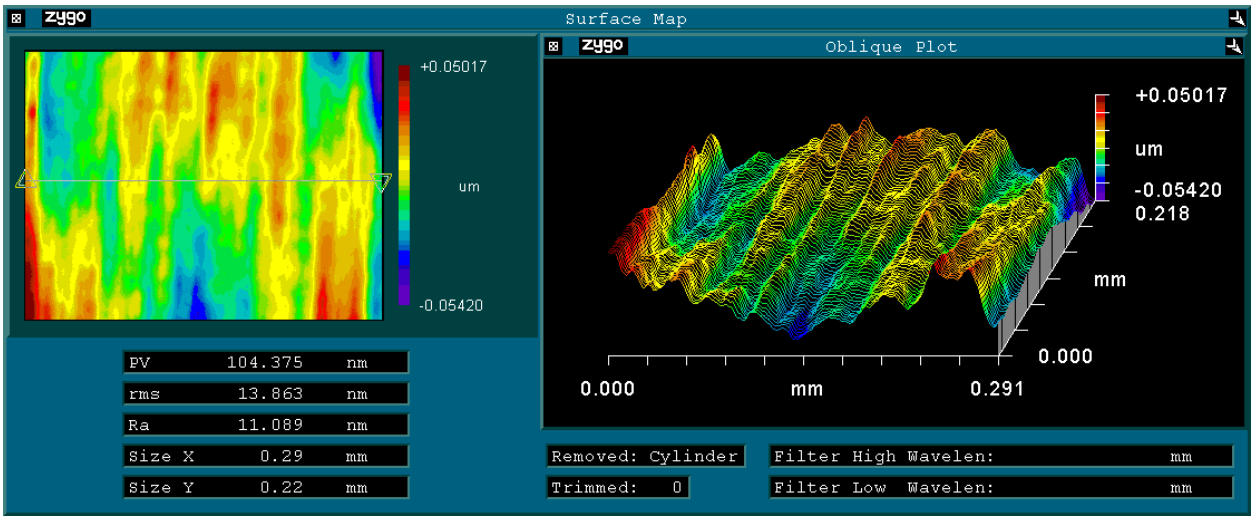

Figure 21: Area 3 of Sample 2

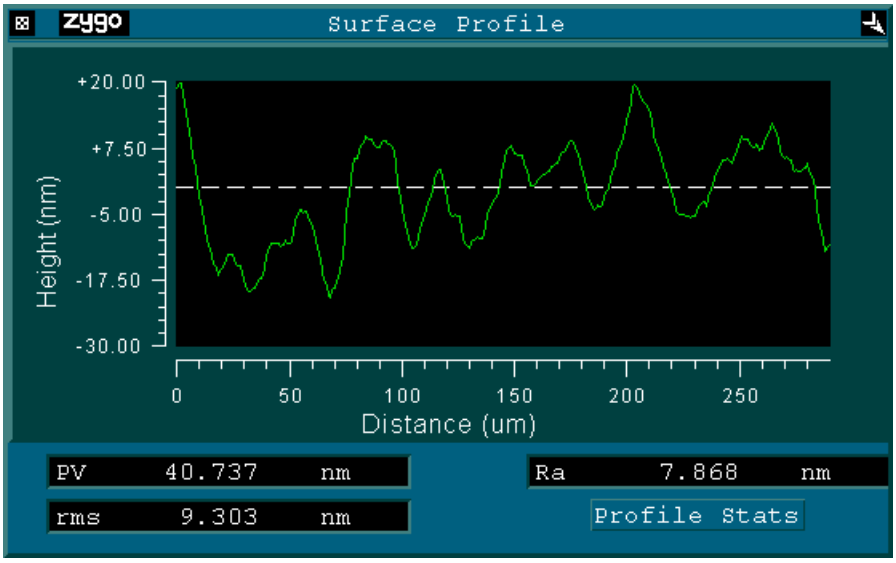

Figure 22: Selected Profile, Area 3 of Sample 2

Figures 23-32 show areas 4-8 of sample 2. These again show the characteristic spanwise corrugations of low amplitude.

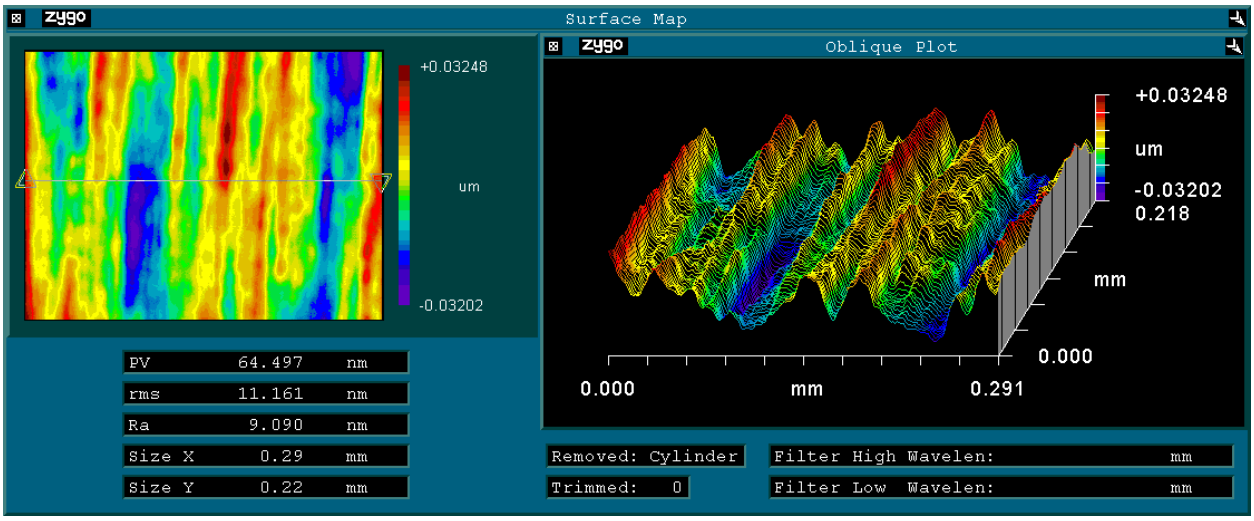

Figure 23: Area 4 of Sample 2

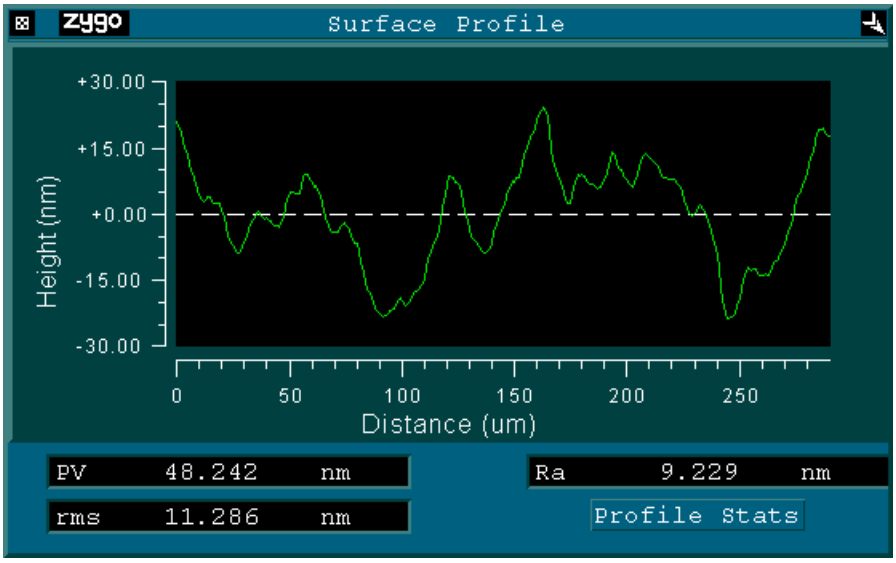

Figure 24: Selected Profile, Area 4 of Sample 2

Figures 25 and 26 show area 5 of sample 2.

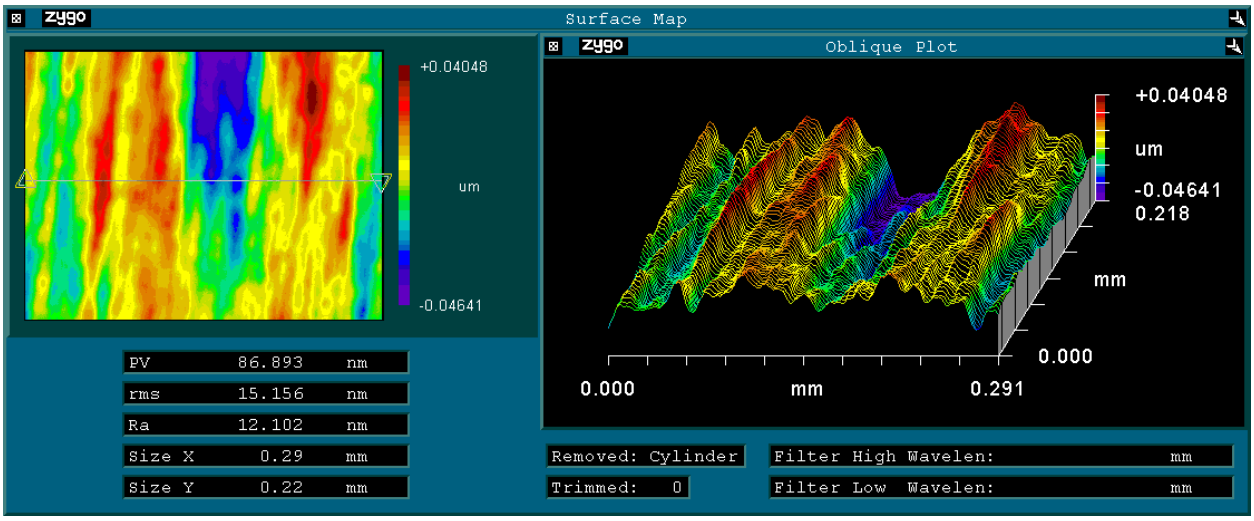

Figure 25: Area 5 of Sample 2

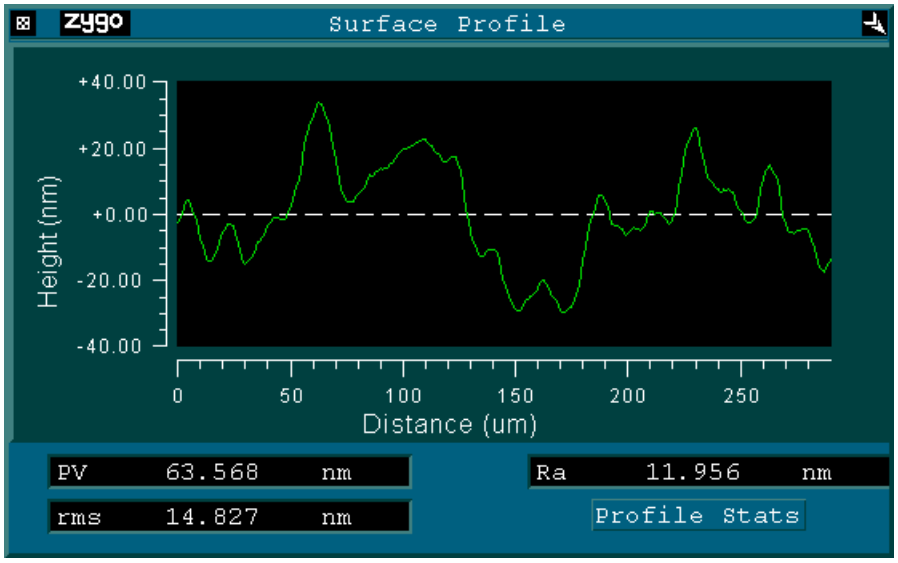

Figure 26: Selected Profile, Area 5 of Sample 2

For area 6 of sample 2, Figures 27-28, Chris noted that "2 holes at left hand side appear black in top view. Pronounced ridging". The amplitude is up to 50 nm or so, about 2 microinches.

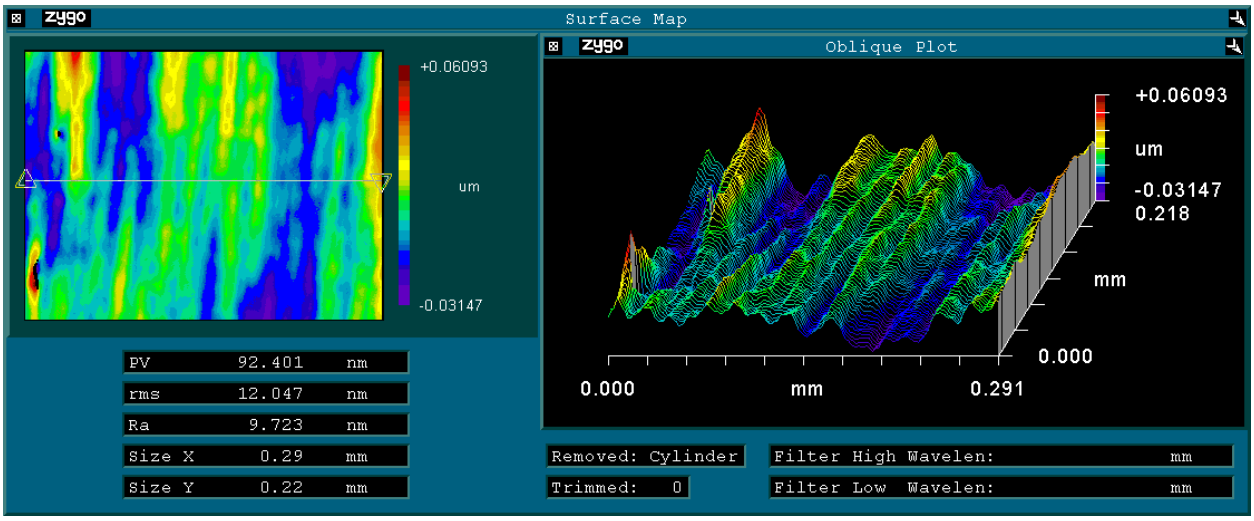

Figure 27: Area 6 of Sample 2

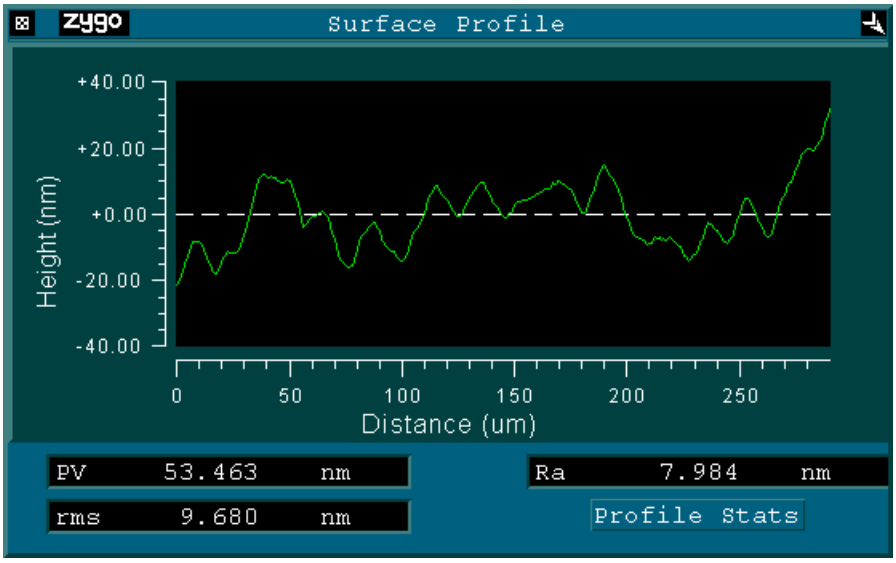

Figure 28: Selected Profile, Area 6 of Sample 2

For figures 29-30, area 7 of sample 2, Chris noted that *"discoloration through center of view. It appears at the same locale as the broad valley through center of oblique view."*

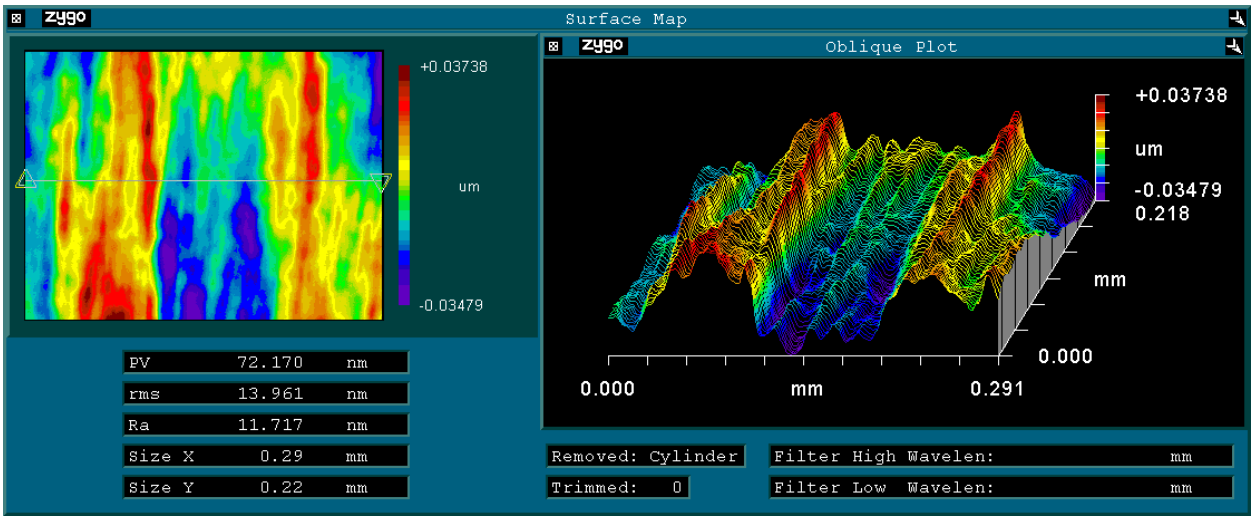

Figure 29: Area 7 of Sample 2

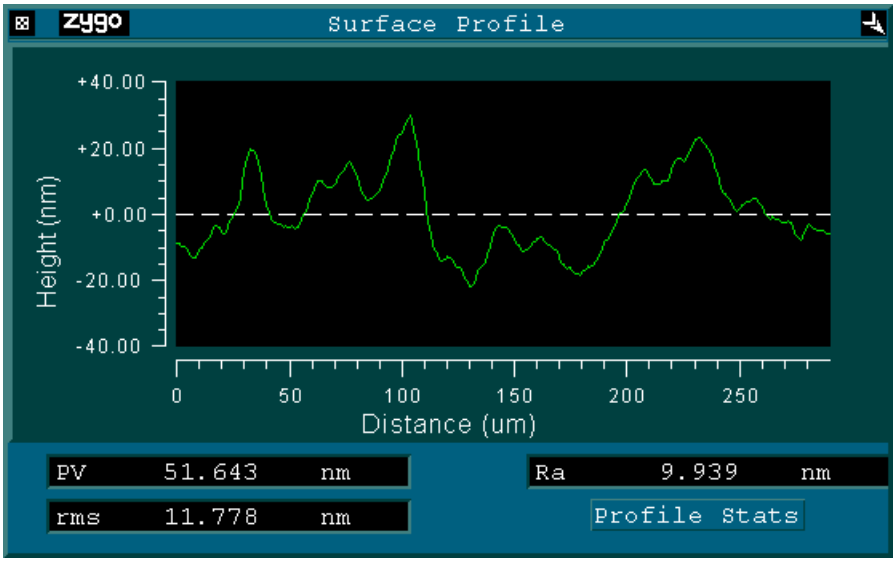

Figure 30: Selected Profile, Area 7 of Sample 2

For Figures 31-32, area 8 of sample 2, Chris noted that *"same band of discoloration, but further along the specimen. No apparent impact on topography here."*

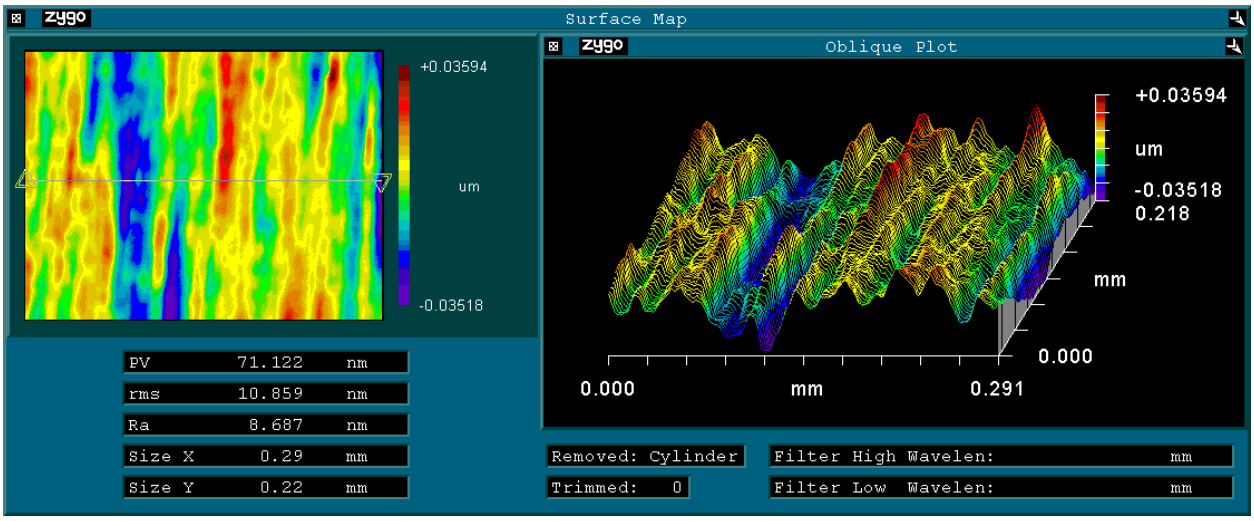

Figure 31: Area 8 of Sample 2

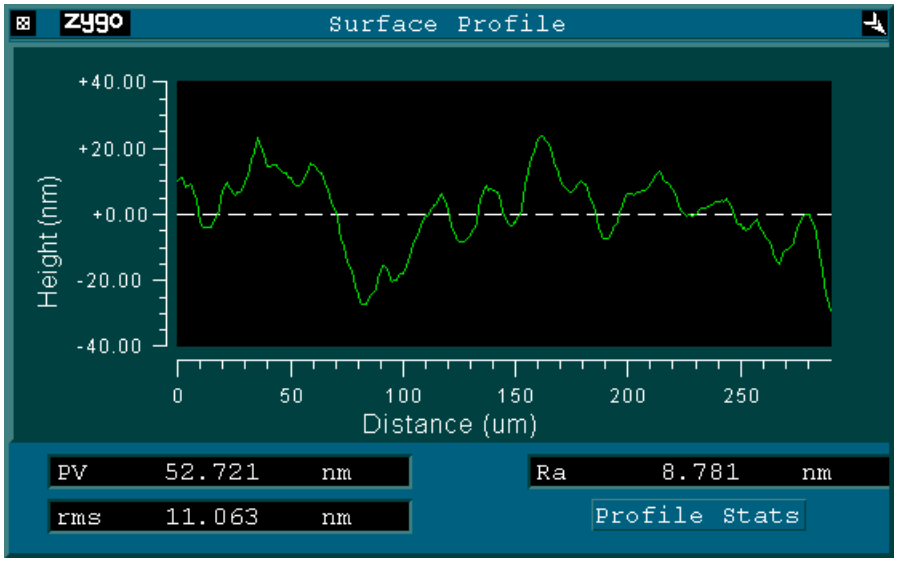

Figure 32: Selected Profile, Area 8 of Sample 2