S.P. Schneider, Purdue University, School of AAE, 765-494-3343, 12 July 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 Electroform: Pre-Heating Results

1. Introduction

The mandrel and electroformed throat are critical sections of the Purdue Mach-6 quiet-flow Ludwieg tube. The largest flaw in the mirror finish of the throat controls performance. NASA Langley fabricated many quiet-flow nozzles during 1972-1994, many of which suffered from problems with waviness and roughness in the throat. These problems were often large enough to make the nozzles useless. Eventually the technique of electroforming nickel onto a polished mandrel was developed. This was used successfully for the LaRC Mach-6 quiet-flow nozzle ca. 1990. The electroform is supposed to reproduce the finish of the mandrel, and it is much easier to polish on the outside of the mandrel. However, the initial performance of the LaRC Mach-6 apparently degraded after initial operation, possibly because of surface degradation in the throat associated with hot operation. Since the initial data is not conclusive, according to Steve Wilkinson, the true cause of the apparent degradation is unknown.

Low-cost and simple tests of this hot-operation degradation were desirable, in order to reduce risk. In addition, the Purdue nozzle is to introduce the use of a hard layer of electroformed nickel, approximately 1/8-inch thick, on the surface near the mandrel. Both the hard and soft nickel are nearly pure, and prepared from a sulfamate bath by GAR, the same vendor used for the LaRC Mach-6 nozzle. The hard nickel bath differs only by the addition of trace amounts of saccharin. This hard nickel, Rc33-35-38, should be much more scratch-resistant than the soft nickel used in the LaRC nozzle (Rc 21-23). However, this also introduces concerns about cracking, delamination, or other problems with the hard nickel.

Samples of the hard and soft nickel were therefore procured from GAR, and tested, as outlined in previous memos and emails. These earlier samples were plated onto glass or aluminum plate substrates that were provided by GAR (see previous memos).

However, because these tests were inconclusive, particularly regarding the surface finish, the fabrication of a test mandrel was deemed desirable. A drawing of the test mandrel is shown as Figure 1. The fabrication and electroforming are to duplicate the process used for the real mandrel, to the extent feasible, using a small scale for low cost. The mandrel was fabricated at Purdue by Lester Cox, and heat treated at Circle-City heat treat. Measurements of the finish of the test mandrel were reported in an earlier memo. The electroform was then applied to the test mandrel.

After the electroform was received at Purdue, it was machined in preparation for removal using the jig shown. However, the electroform broke free from the mandrel while the flat on the smaller end was being machined on the lathe. After cleaning the mandrel and electroform, the inside surface appeared excellent, although some scratches were apparent near one end. These isolated scratches probably occured during the break-free process, when chips entered the space between the parts while it was still turning. The sample was then cut up using a lathe and a slitting saw, per the process described in my 5/21/99 email to Larry DeMeno. The roundness of the larger half was measured before and after heating, with good results, as detailed in my 7/7/99 email. The smaller end was cut into 180,90, and two 45-deg. sections using a slitting saw, and the two 45-deg. sections were provided to Chris Tieche for measurements. This memo reports those electroform measurements of the surface finish, carried out before any heating was performed. A later memo will report comparison results carried out following heating.

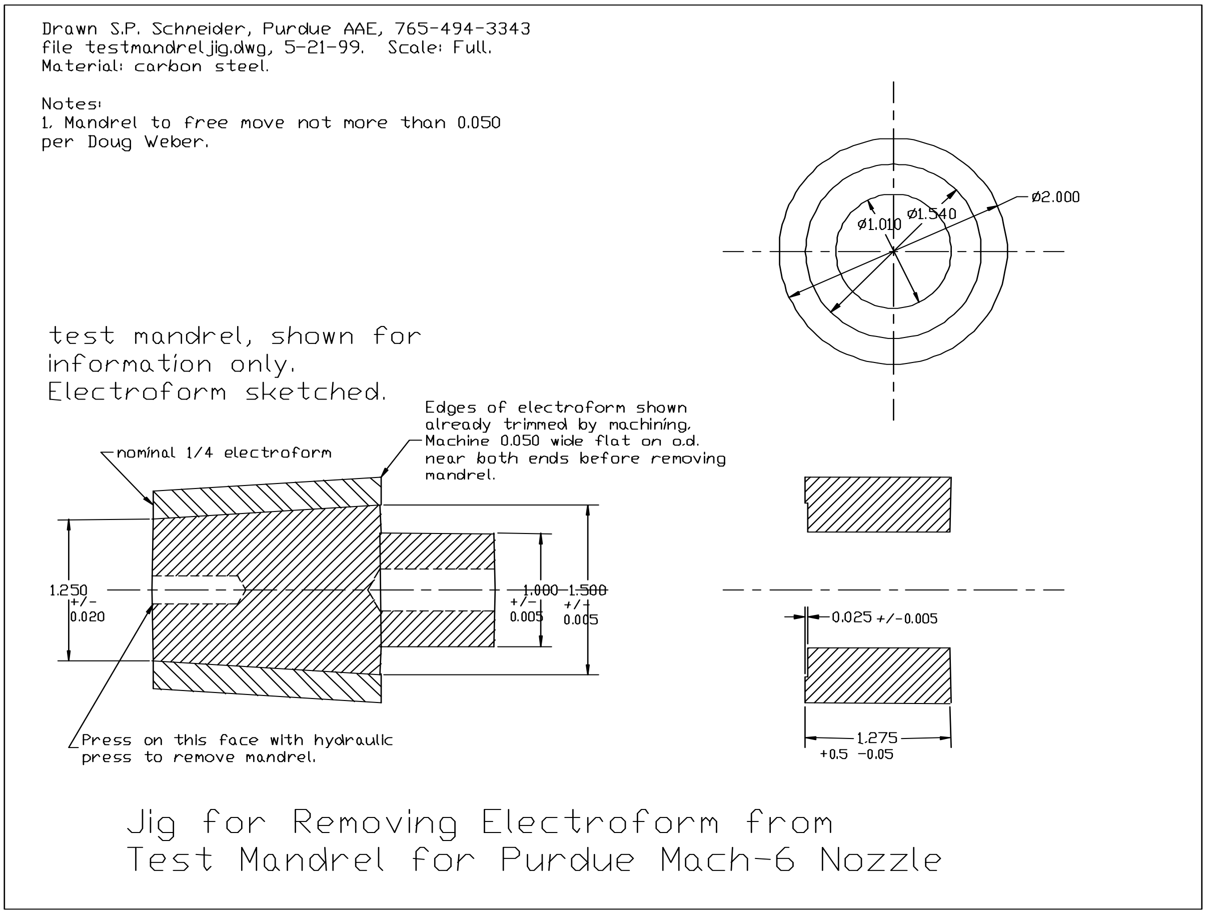

Figure 1: Drawing of Test Mandrel Electroform with Removal Jig

2. Optical Profilometer Measurements

Chris Tieche carried out measurements on the specimen using the Zygo optical profilometer at Purdue, and provided a set of .bmp files, along with an emailed summary (appended). This section presents his results. Chris is a graduate student in tribology who works under the direction of Prof. Tom Farris.

Chris took 10 measurements for the surface using the optical profilometer, for 10 sample areas. Since getting raw data out of this instrument has not been successful, he supplied some data that represents the material in the output files. These were supplied as .bmp files. Chris commented that *“The "cam" files are actual camera shots what the scope "sees." In some cases, it is easy to see the topography on the monitor than the colored images provided. In one particular case, sam1.7, the pockmarks are evident in this view. Sam1.8 shows a similar view in the "cam" bmp but with a smooth surface. If a file is not listed, it had no particular topography worth mentioning.*

The top view, contains the following info:

PV The max peak minus the max valley (P-V)
RMS
Ra
X and Y dimensions of the area sample
Maximum peak
lowest valley
H, I forgot what this was, but I don't thinks it's important here. ”

A number of defects were noted. Chris notes that “*I saw "specks" on the sample, but much of that was probably debris. I did not physically touch the specimen, but I did blow on it slightly to make sure I was looking at topography and not artifacts. The discoloration I could see physically, but other than that, I saw nothing with just my eye. I will look more carefully [at the coloration] this next time.*” Thus, the images are a random sample of defects that cannot be seen with the naked eye.

2.1. Sample 1 of 2

Figures 2 and 3 show area 1 of sample 1. The average roughness is 10nm or 0.4 microinches, with a peak-valley (PV) roughness of 201 nm or 8 microinches. The Re_k = 12 spec. calls for 30-90 microinches peak in the nozzle throat, at 150 psia, so this is an excellent finish.

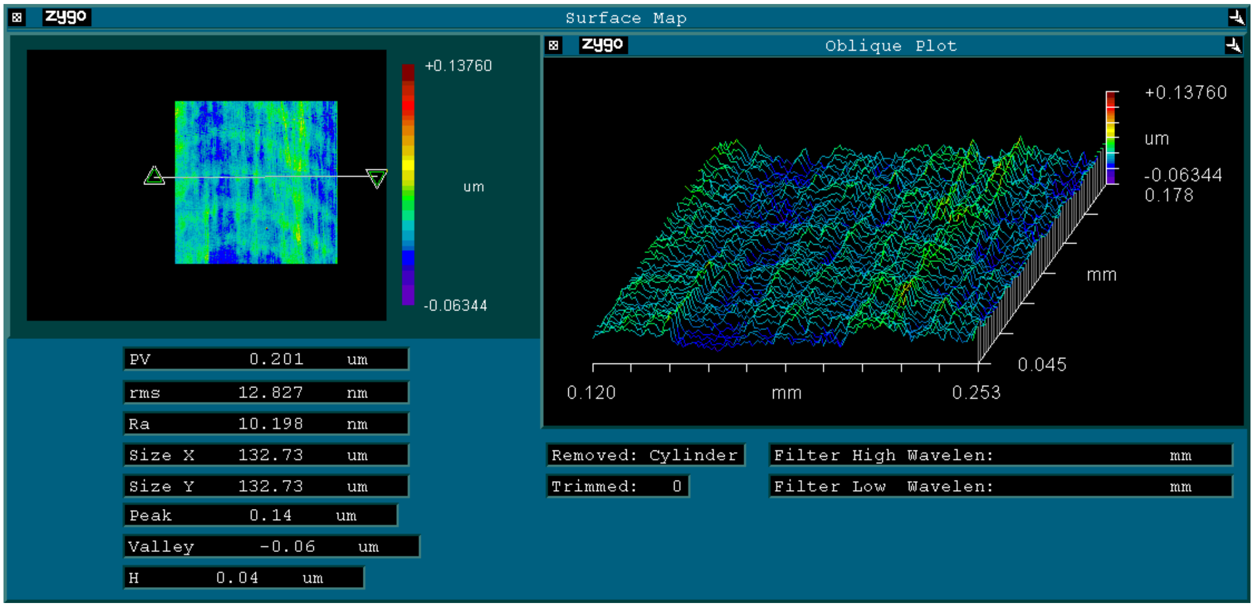

Figure 2: Area 1 of Sample 1

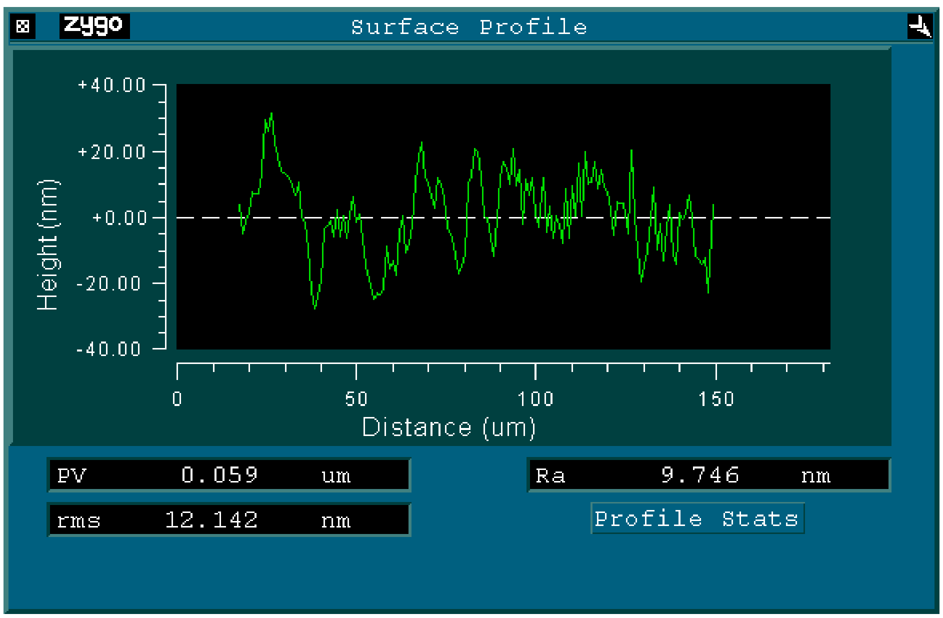

Figure 3: Area 1 of Sample 1, Selected Profile

Figures 4 and 5 show similar results for area 2 from the first sample.

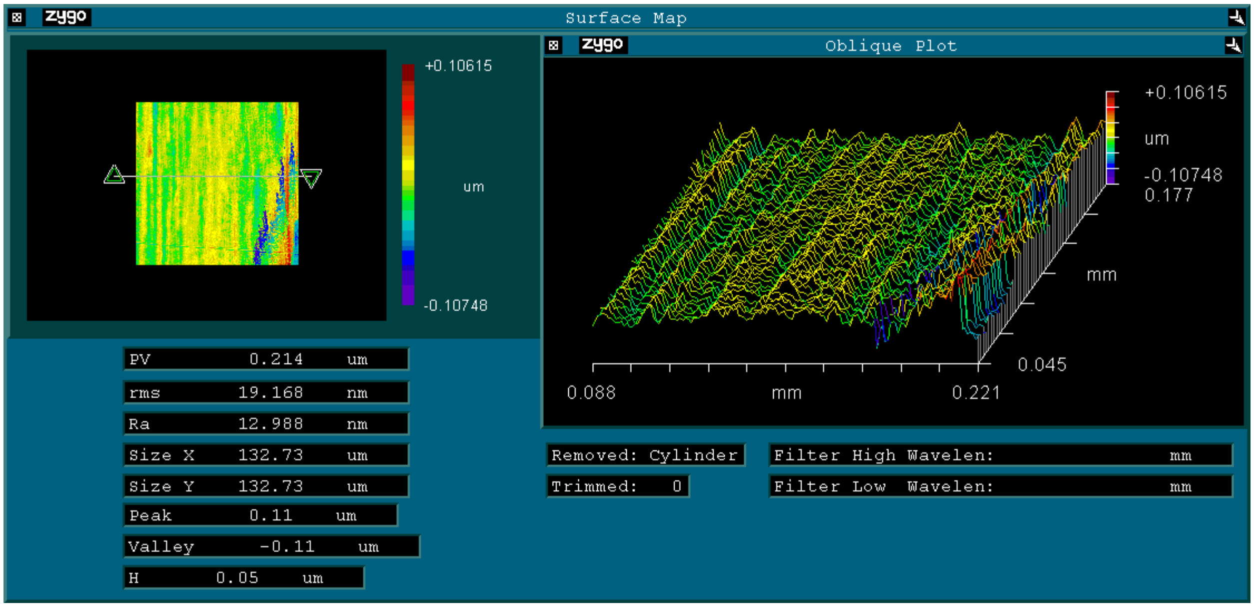

Figure 4: Area 2 of Sample 1

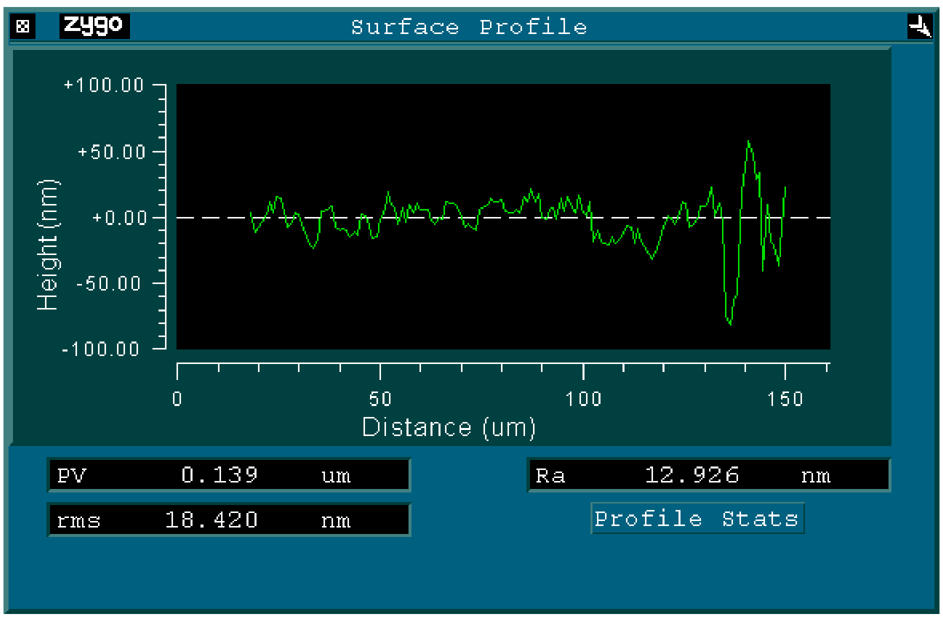

Figure 5: Area 2 of Sample 1, Profile

Figures 6 and 7 show area 3 of sample 1. According to Chris, this shows definite pits at the right hand side (RHS).

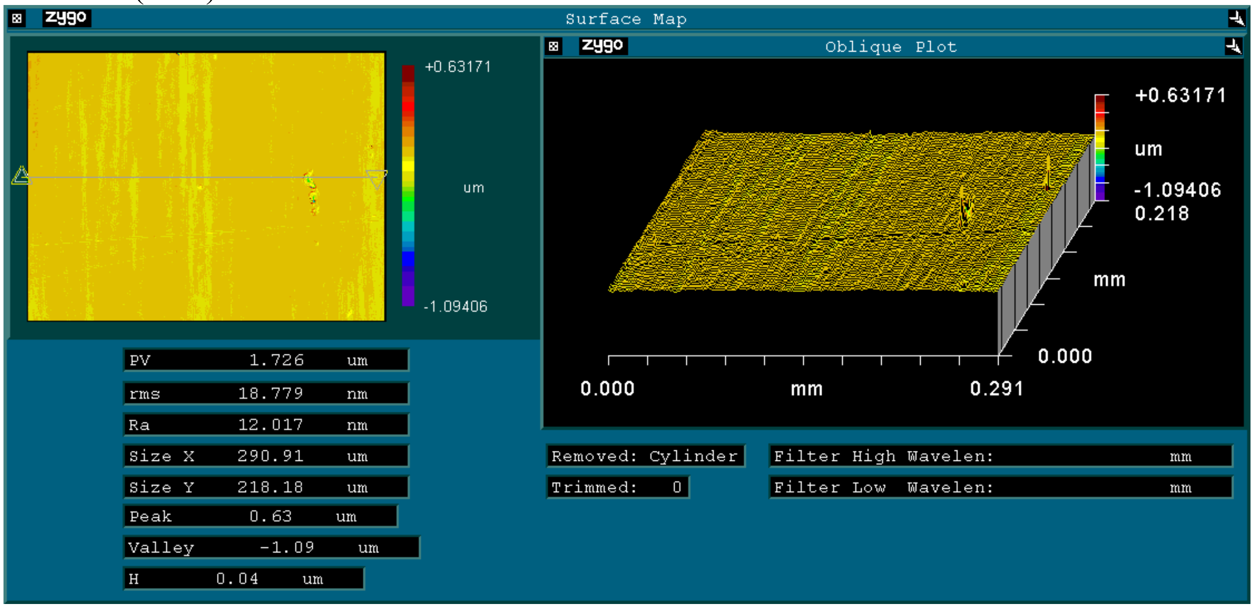

Figure 6: Area 3 of Sample 1

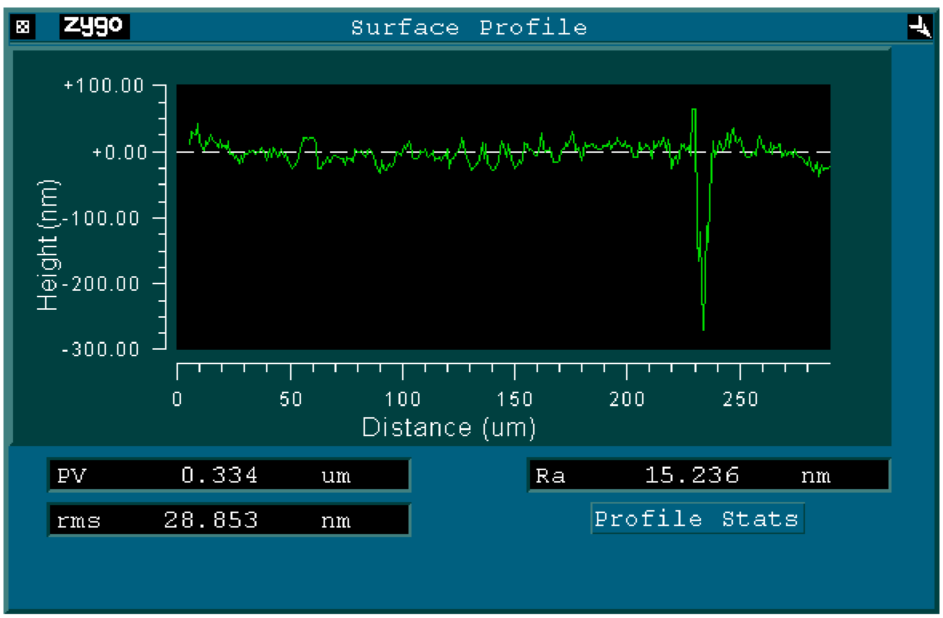

Figure 7: Area 3 of Sample 1, Profile

Thus, although the electroform has no visible pits, it does contain microscopic pits. The PV amplitude is now 1.7 microns or 67 microinches, still probably allowable. However, most of this amplitude is in the pit, which is most likely less effective in tripping the flow than a peak would be. The pit depth is about 0.3 microns.

Figures 8 and 9 show area 4. Chris says that this is *"same sample shot as above, but area sampled excludes pits. Notice changes in Ra, RMS -- this is due to the exclusion of the spikes."* PV improves by a factor 5 without the pits, although Ra only decreases by 20%.

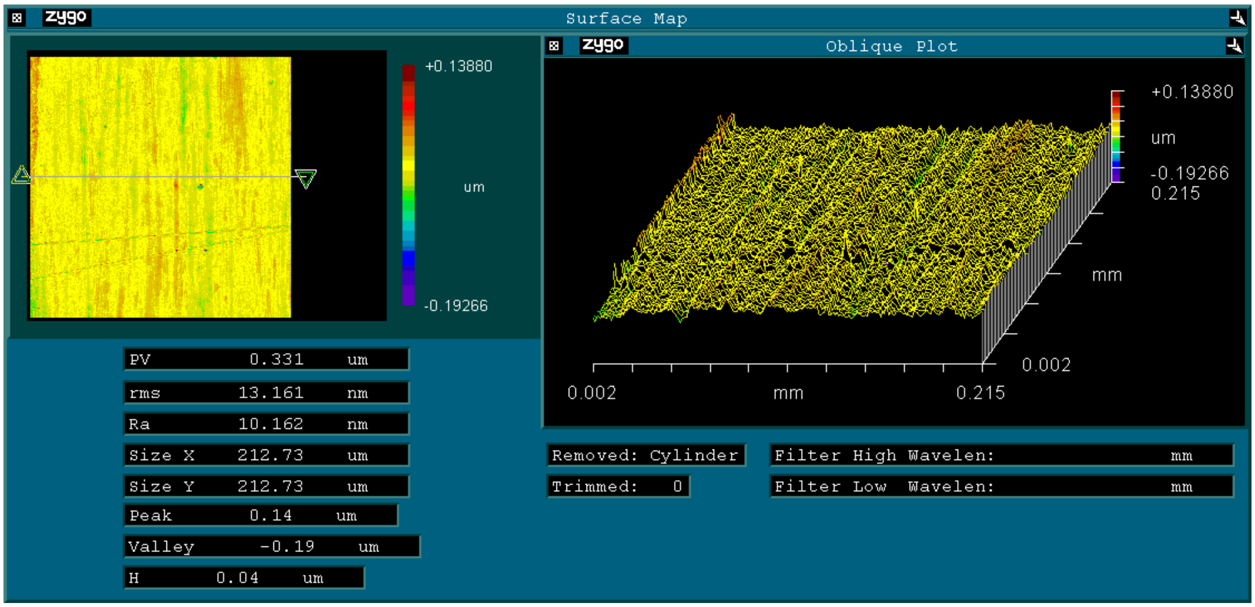

Figure 8: Area 4 of Sample 1

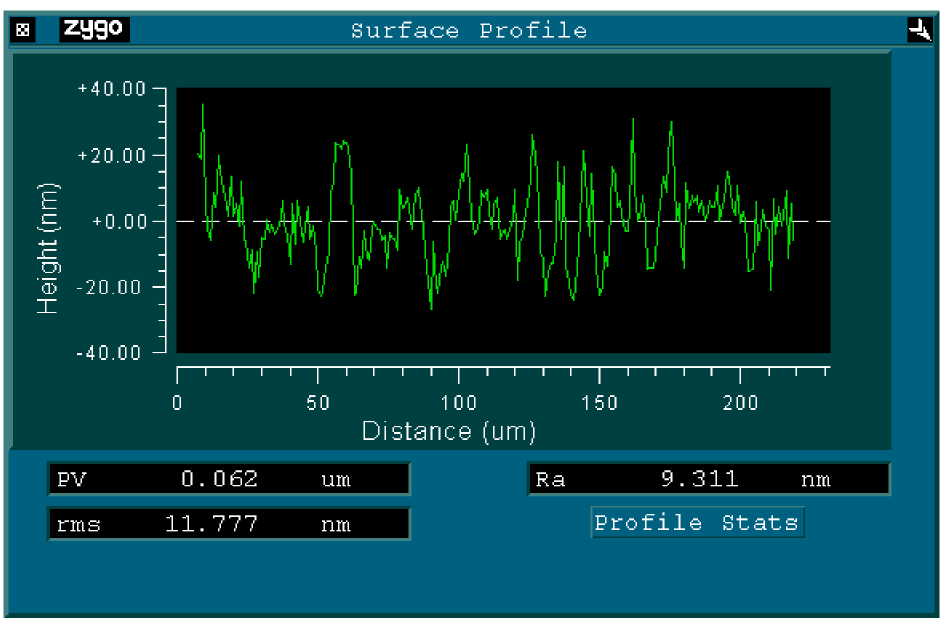

Figure 9: Area 4 of Sample 1, Profile

Figures 10 and 11 show area 5. Chris says to note the pits top LHS and bottom RHS. The amplitudes are similar.

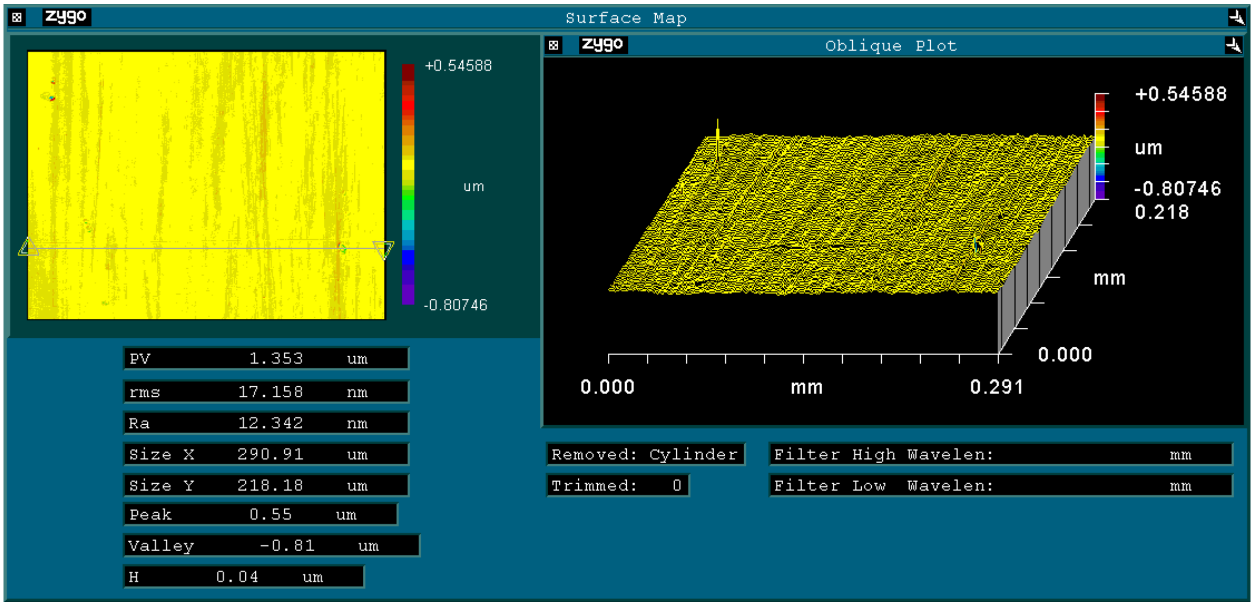

Figure 10: Area 5 of Sample 1

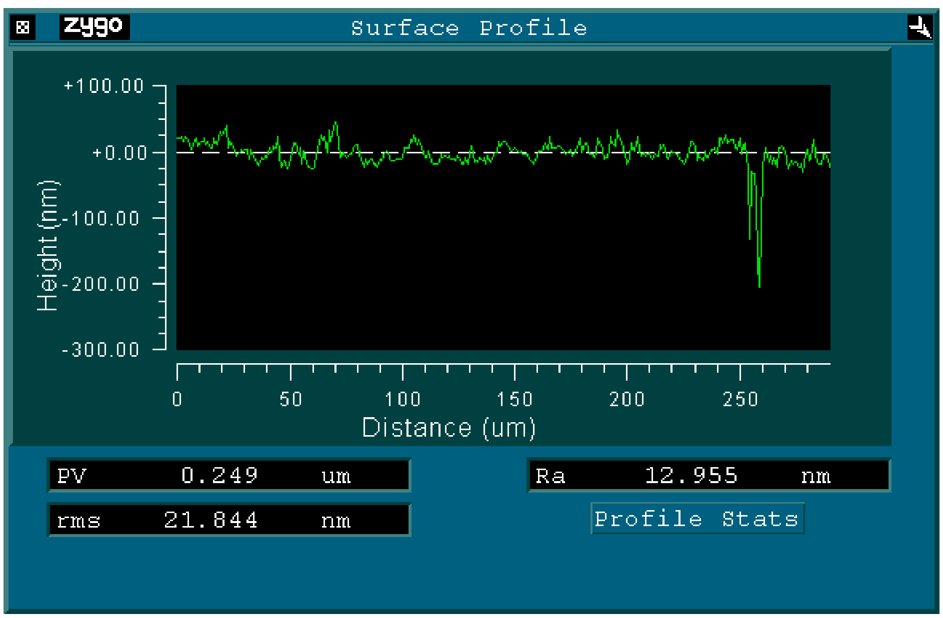

Figure 11: Area 5 of Sample 1, Profile

Figures 12 and 13 show area 6. Chris notes that "*again, pits above excluded with this smaller sample area. Note smaller pit toward right center.*"

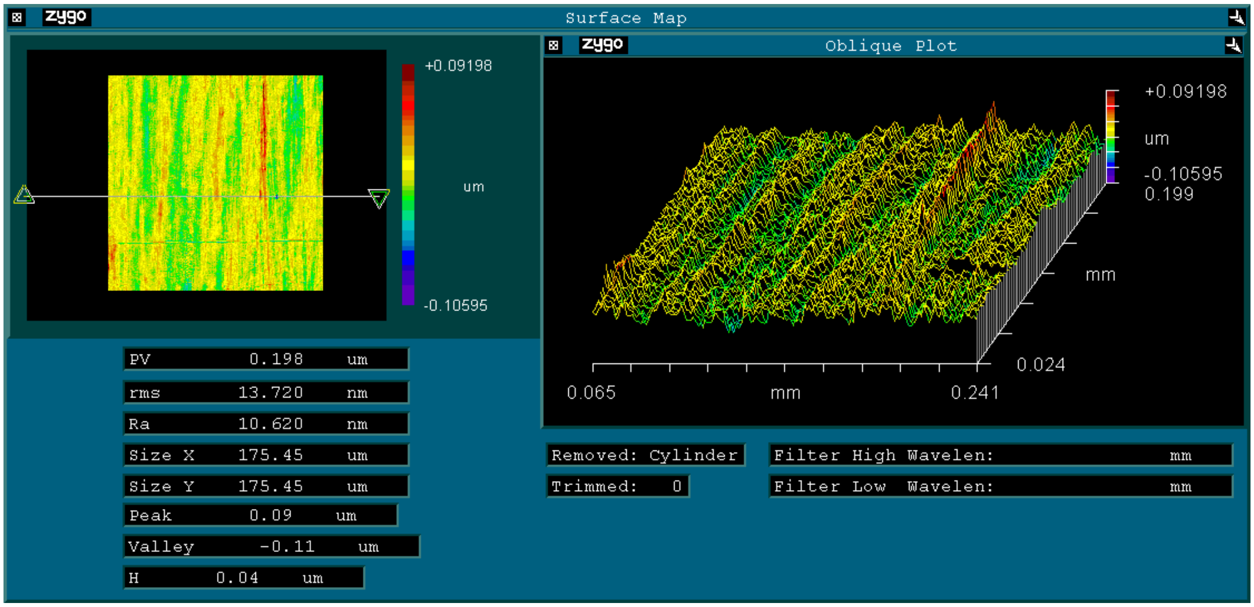

Figure 12: Area 6 of Sample 1

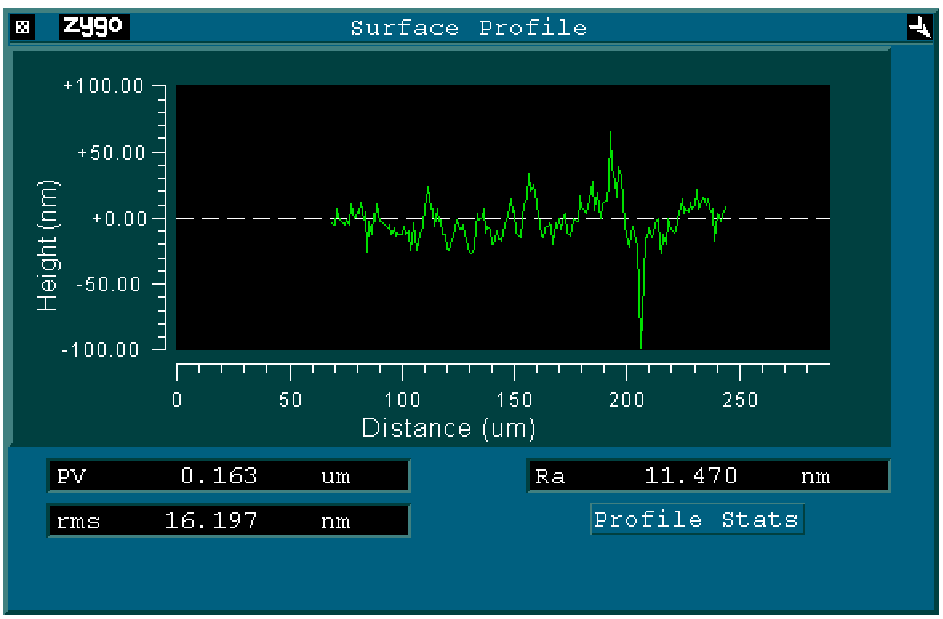

Figure 13: Area 6 of Sample 1, Profile

The ridge in Fig. 13 near 200 microns is 180 nm or 7 microinches P-P, which is substantial but still well within spec.

Figures 14 and 15 show area 7 of sample 1. Chris notes that "*This scan was toward the center of the specimen. cam view shows the pockmarks.*" Figure 16 shows the cam(era) view.

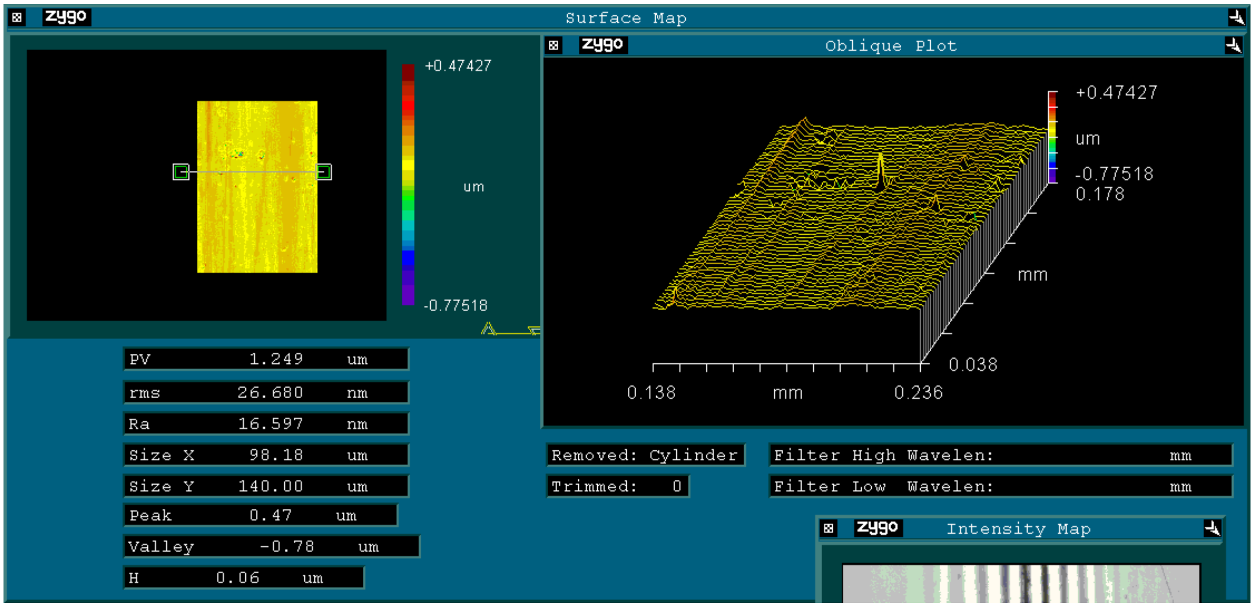

Figure 14: Area 7, Sample 1

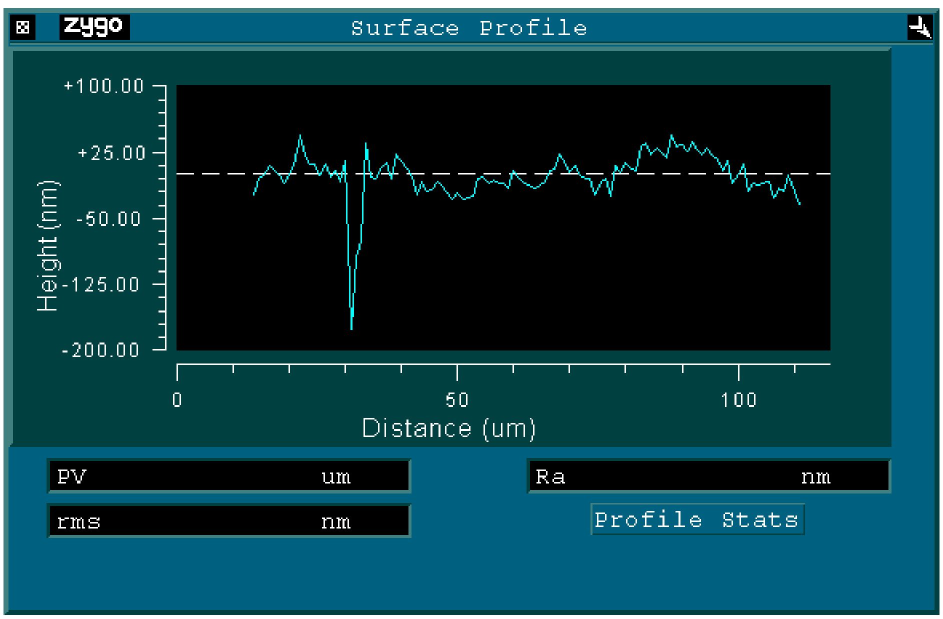

Figure 15: Area 7, Sample 1, Profile

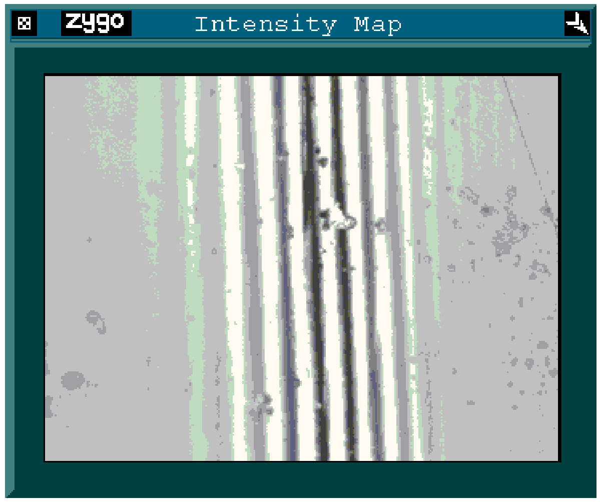

Figure 16: Area 7, Sample 1, Camera View

Figures 17-19 show the results for area 8. Chris notes "*Very smooth. Cam view shows what a good surface looks like.*" Here, PV is 0.25 microns, 1/5 of the value for area 7, which has the pits.

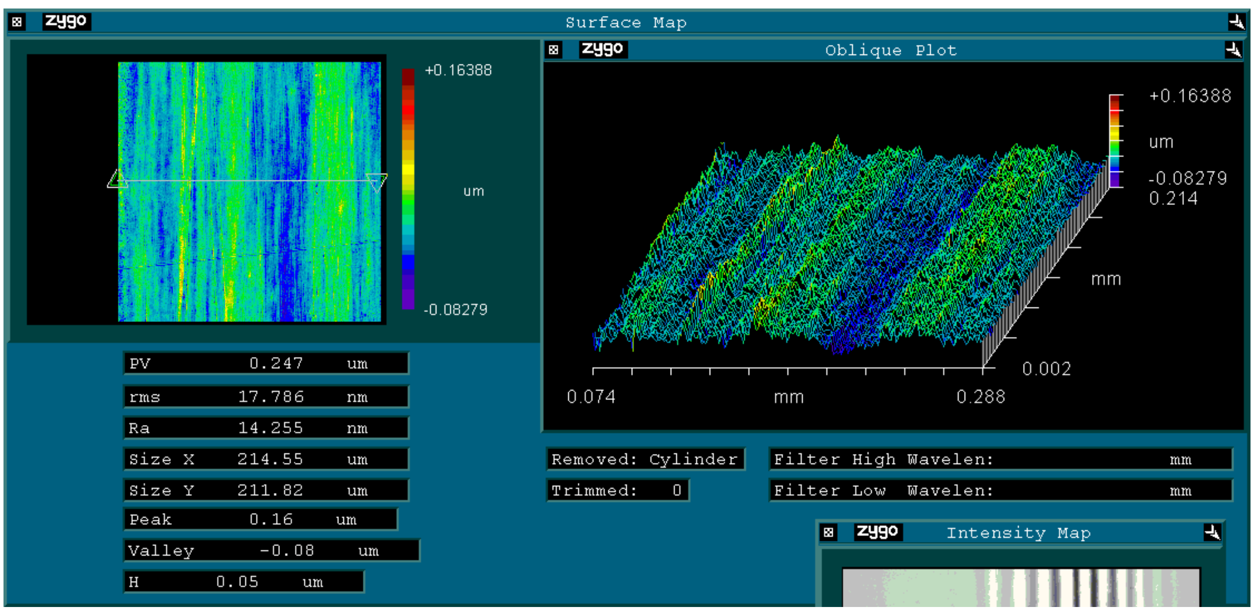

Figure 17: Area 8 from Sample 1

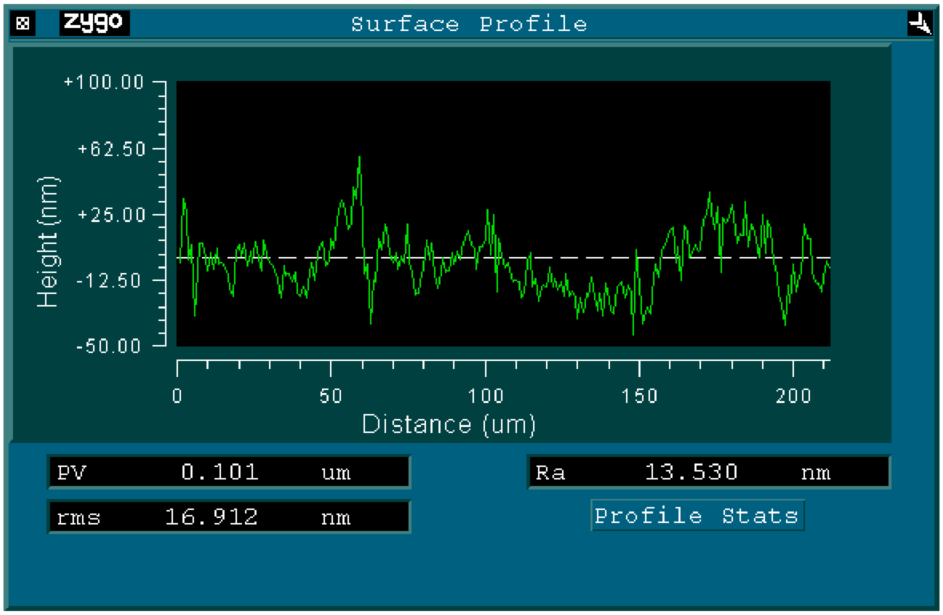

Figure 18: Area 8 of Sample 1, Profile

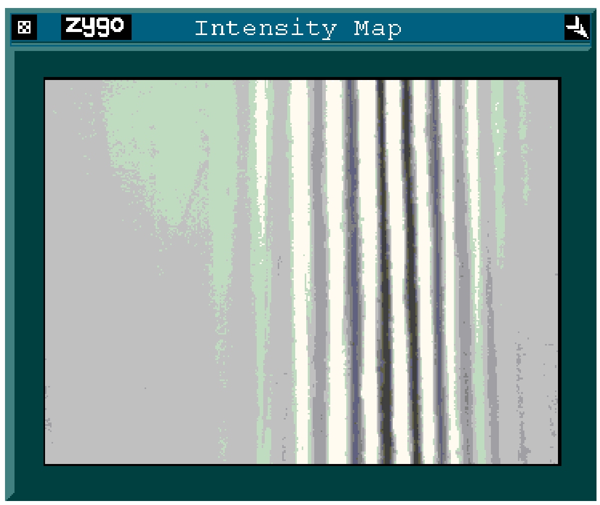

Figure 19: Area 8 of Sample 1, Camera View

2.2. Sample 2 of 2

Figures 20 and 21 show area 1 of the second sample. PV is very low.

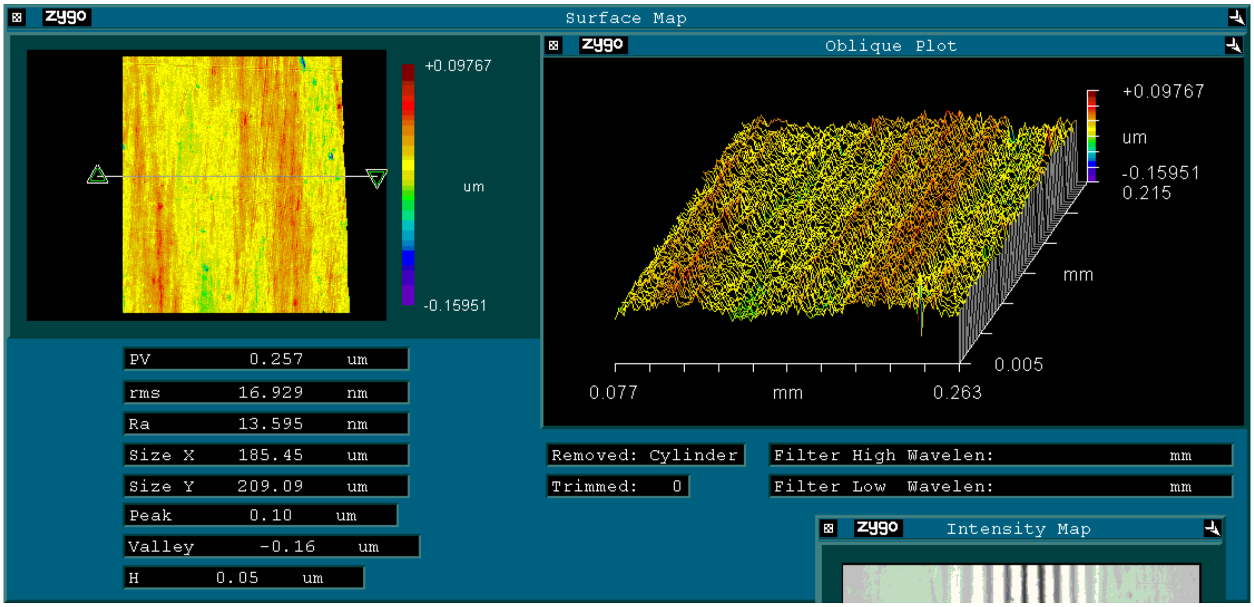

Figure 20: Area 1 of Sample 2

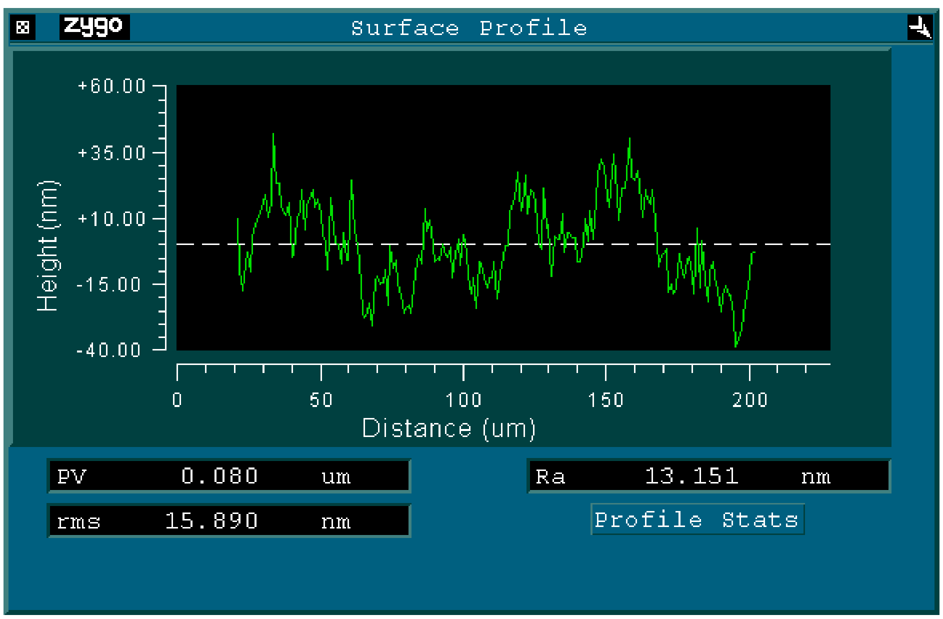

Figure 21: Area 1 of Sample 2, Profile

Figures 22 and 23 show area 2 of sample 2. Chris says to note the very large peak (1300nm = 51 microinches) at the center. This is the first real peak identified in the data, an isolated flaw. It is possible that this is associated with the pits in the mandrel. It's hard to see how such a peak could have survived the process of the electroform breaking free from the spinning mandrel, though. PV is similar to the pitted areas.

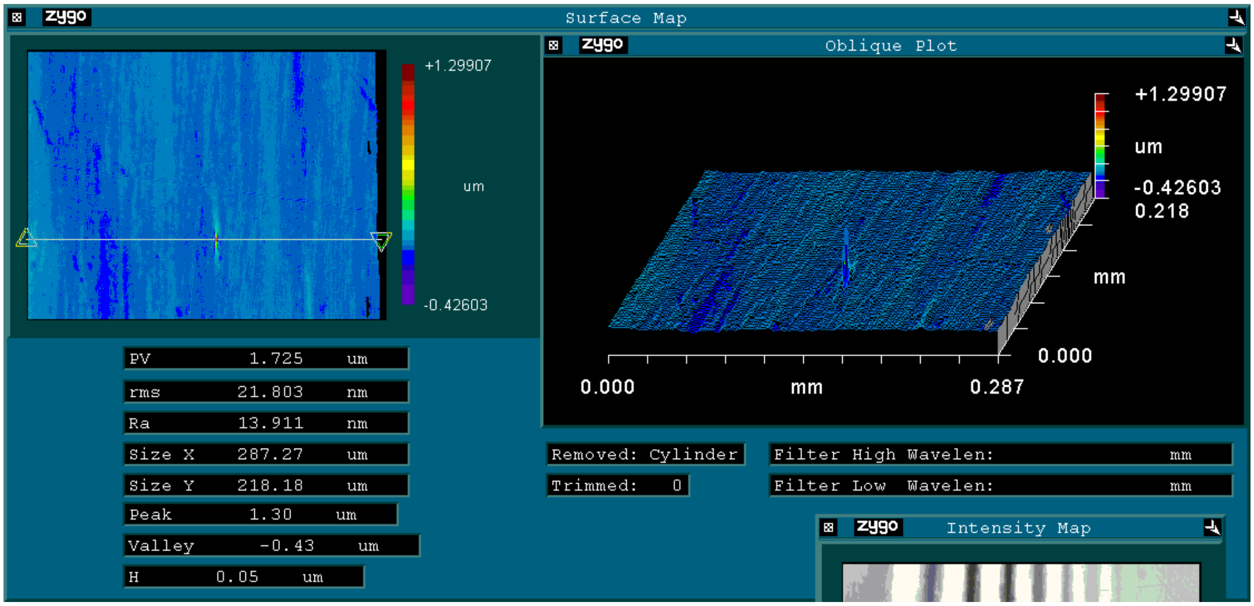

Figure 22: Area 2 of Sample 2

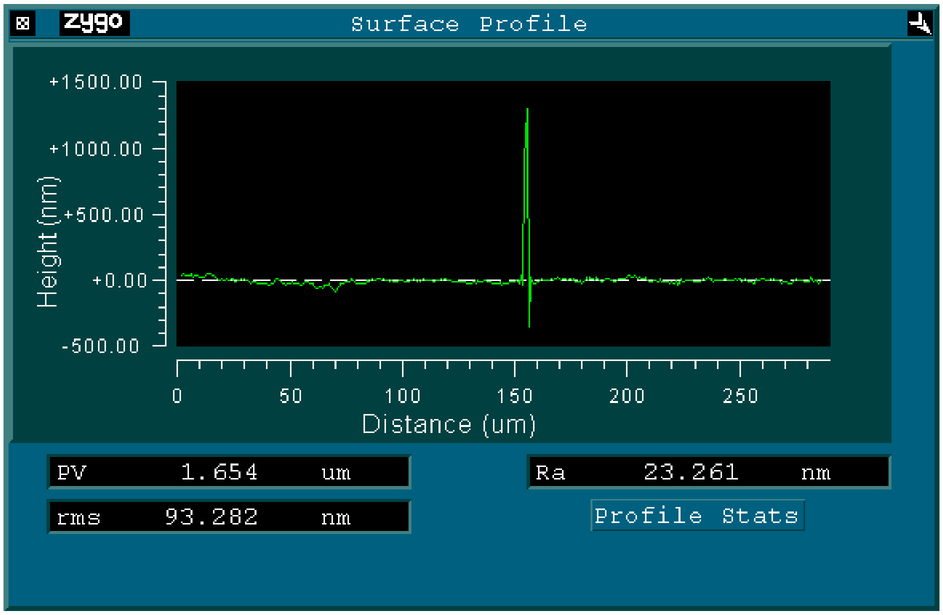

Figure 23: Area 2 of Sample 2, Profile

Figures 24 and 25 show area 3 of sample 2. This is "*the upper left region of area 2*". Here, the PV values are much smaller, without the peak.

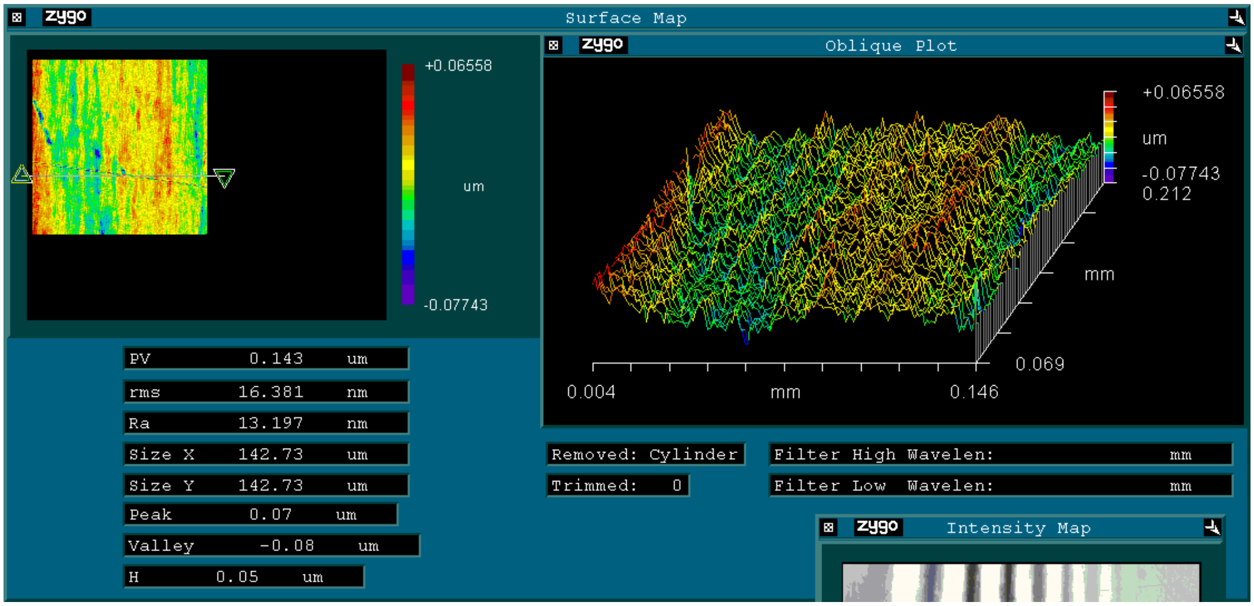

Figure 24: Area 3 of Sample 2

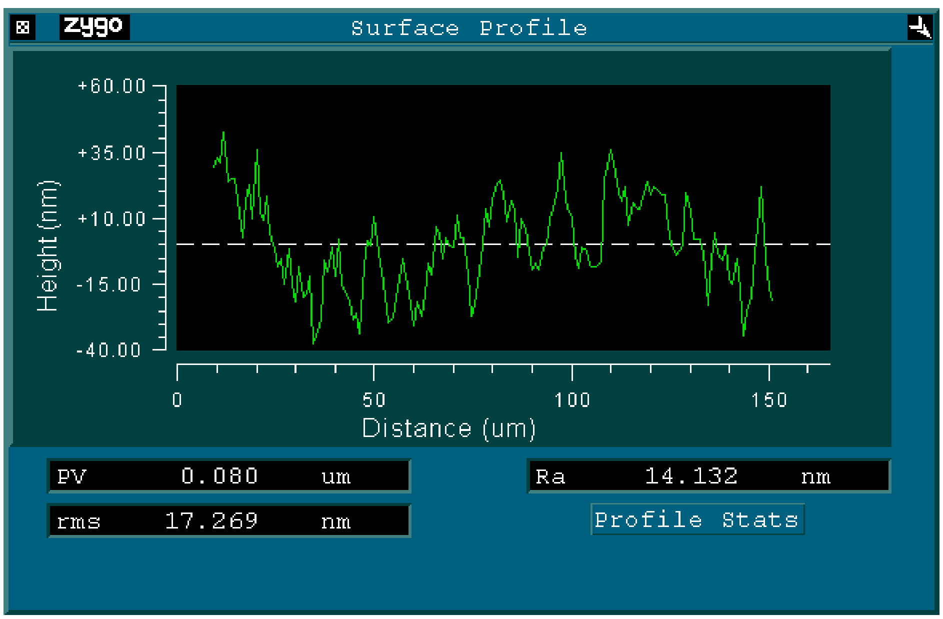

Figure 25: Area 3 of Sample 2

Figures 26 and 27 show area 4 of sample 2. Chris says to *"note peak at upper RHS. Smaller one at LHS."* The peak is about 500 nm or 20 microinches.

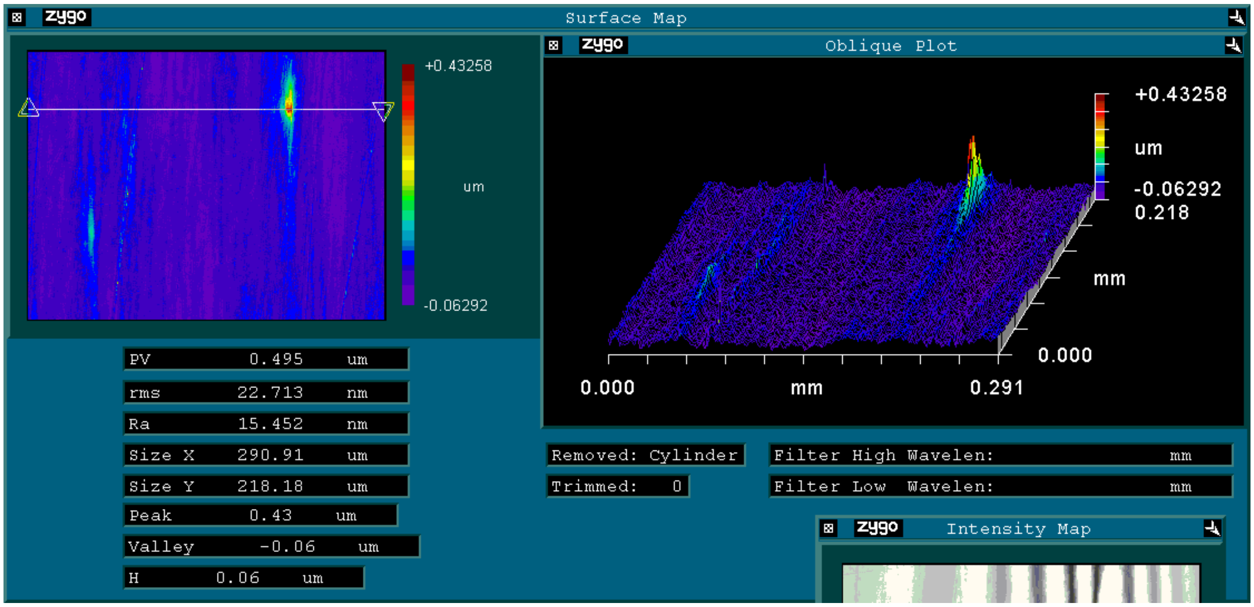

Figure 26: Area 4 of Sample 2

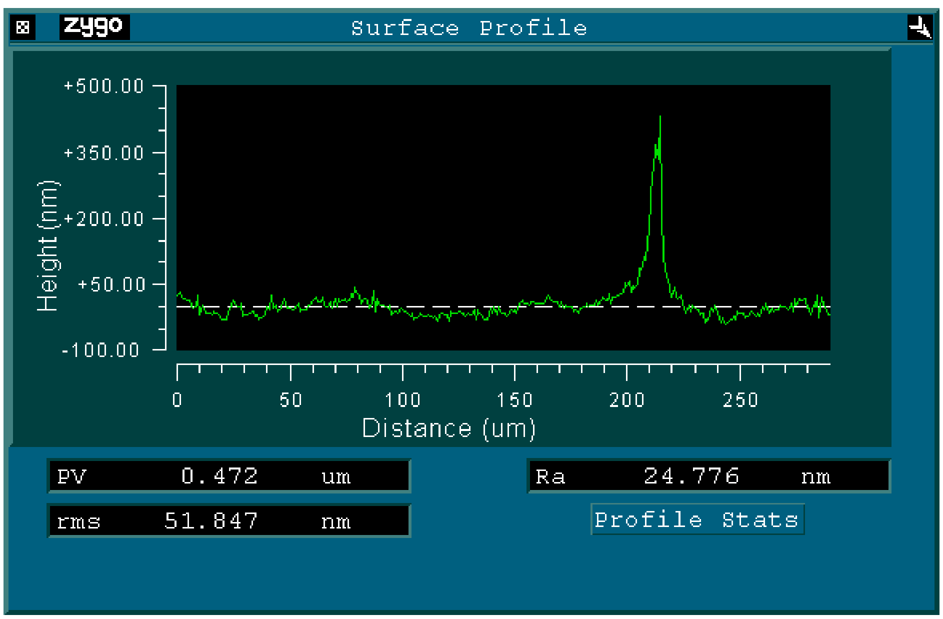

Figure 27: Area 4 of Sample 2, Profile

Figures 28 and 29 show area 5 of sample 2. Chris says this is the "*region between the peaks in the above scan.*" Here, again, the PV is small with the defects left out of the image.

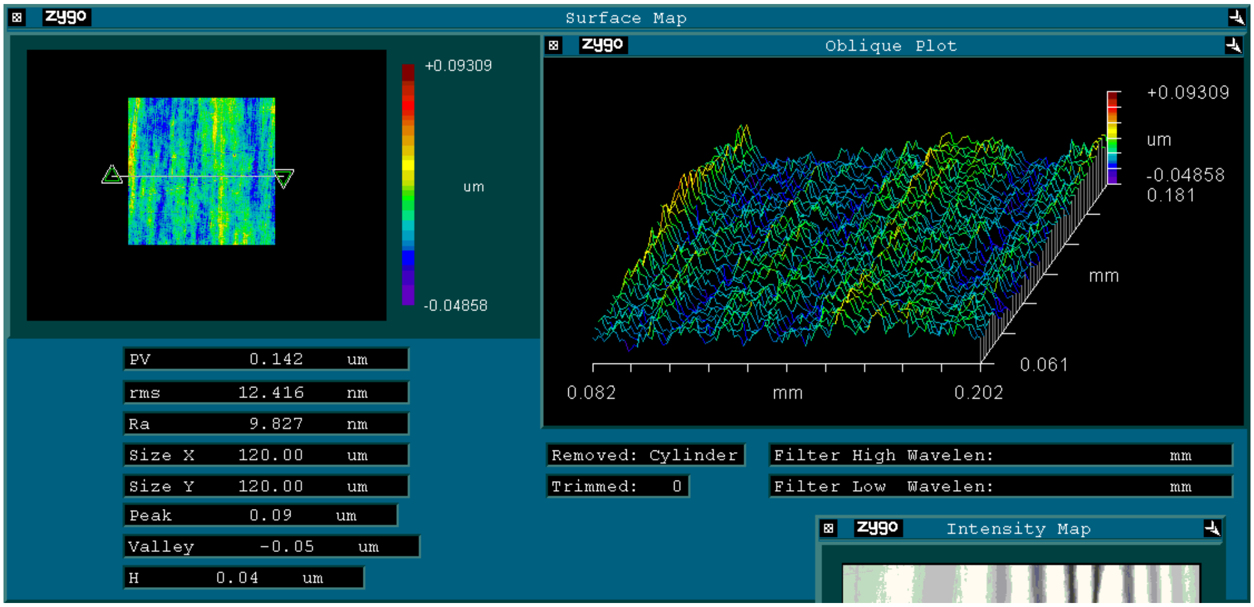

Figure 28: Area 5, Sample 2

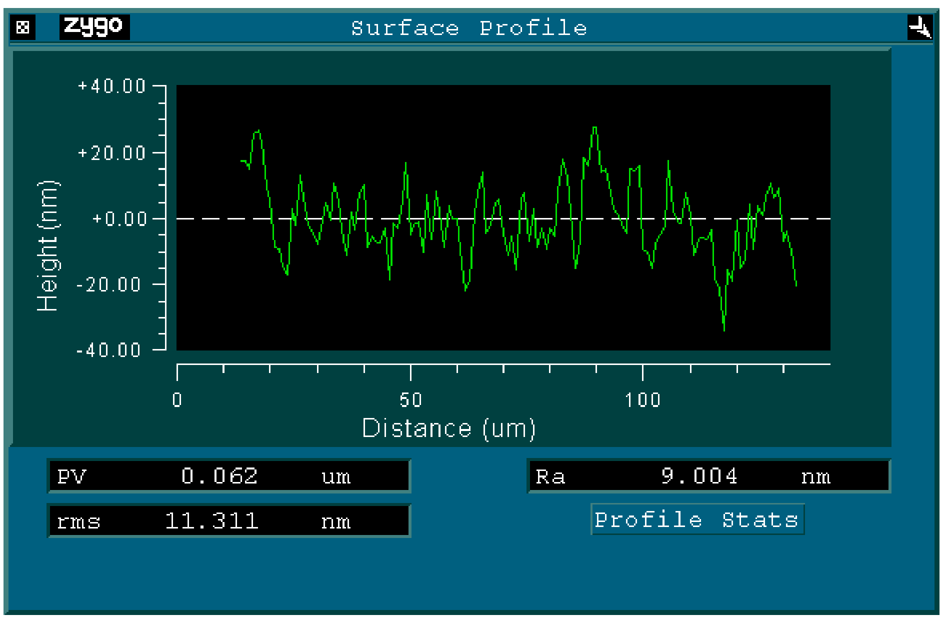

Figure 29: Area 5, Sample 2, Profile

Figures 30 and 31 show area 6 of sample 2. Chris notes a "*peak (730nm = 29 microinches) at top center.*" PV is 0.86 microns, or 34 microinches, within spec.

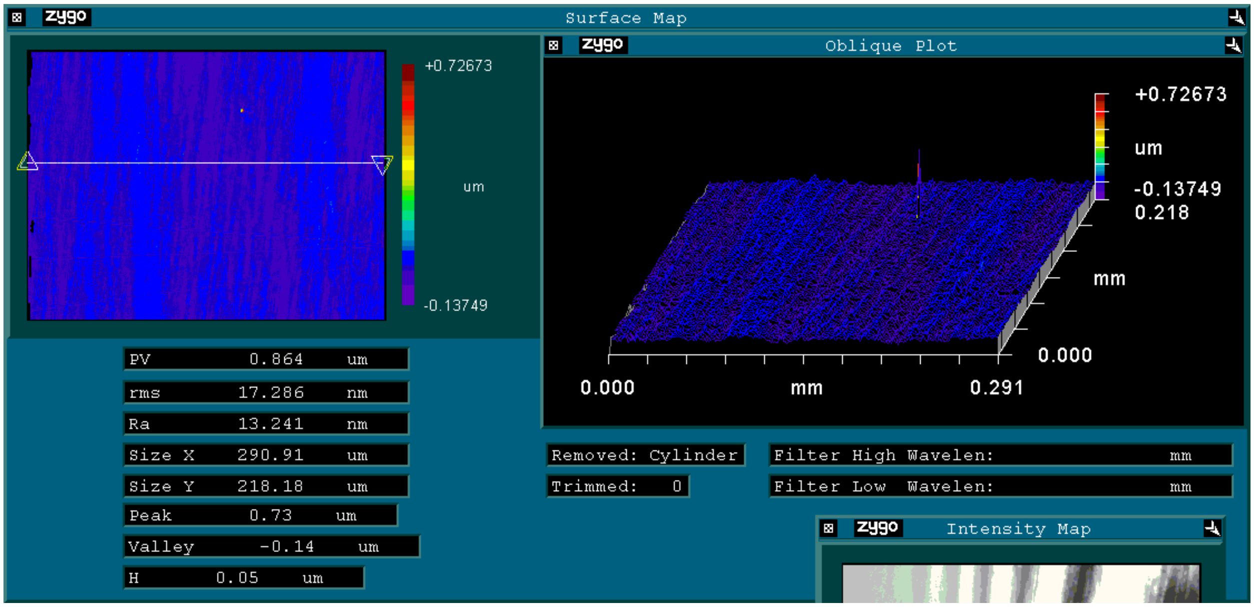

Figure 30: Area 6, Sample 2

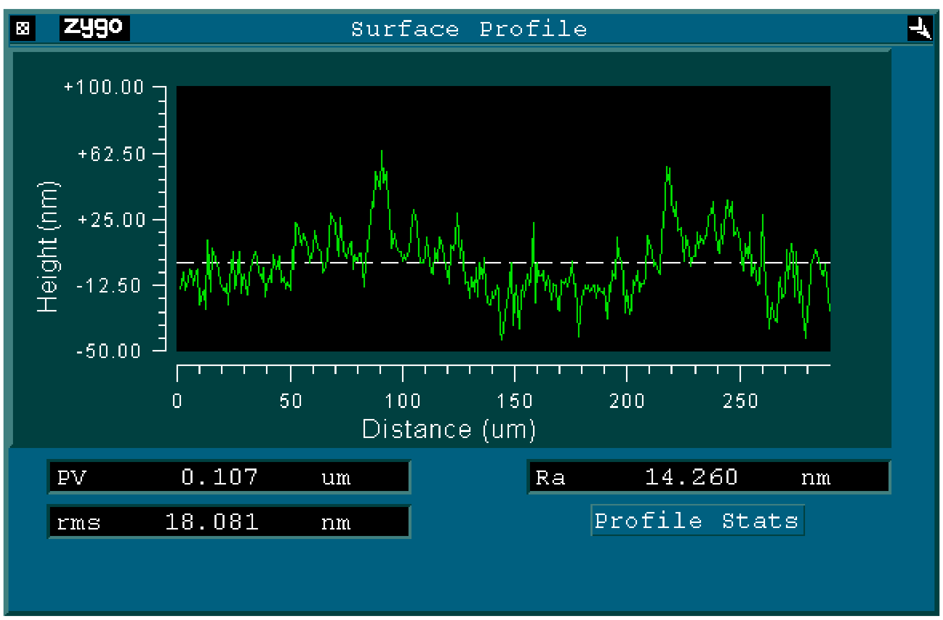

Figure 31: Profile, Area 6, Sample 2

Figures 32-35 show areas 7 and 8 of sample 2. Area 7 shows streaky roughness as from polishing, with no visible pits or peaks. Area 8 appears to have some pits and peaks in a line along with lower part. PV is 4 times higher.

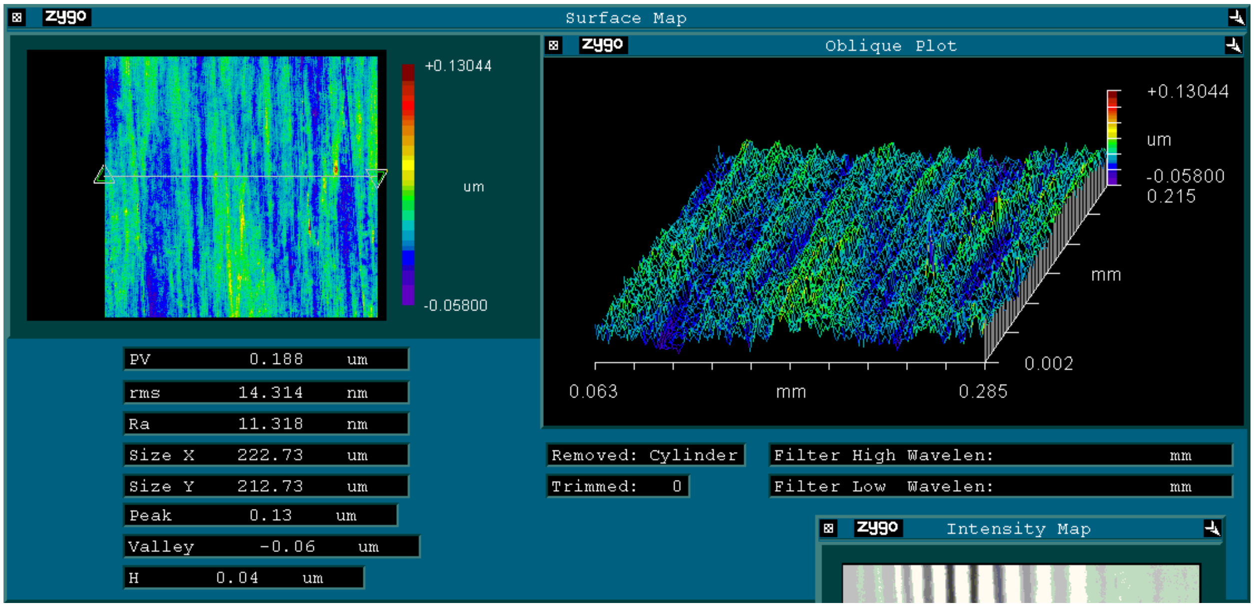

Figure 32: Area 7, Sample 2

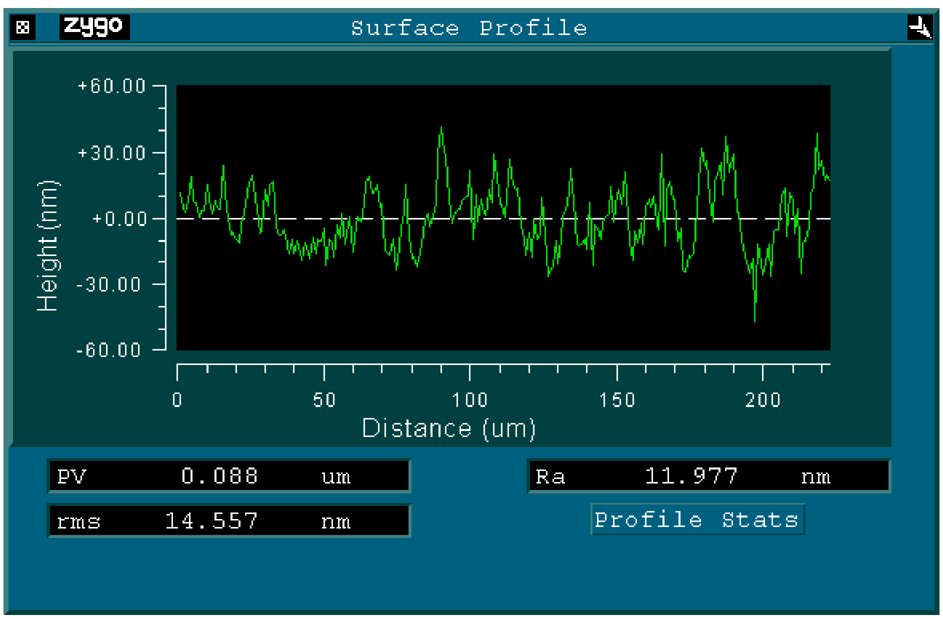

Figure 33: Area 7, Sample 2, Profile

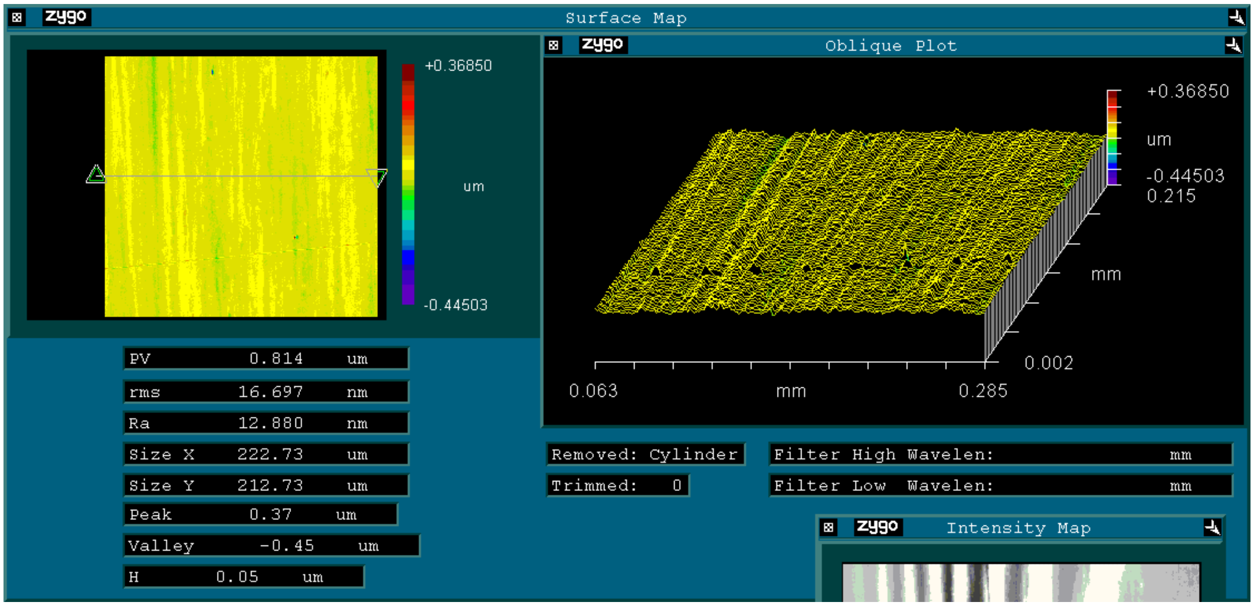

Figure 34: Area 8, Sample 2

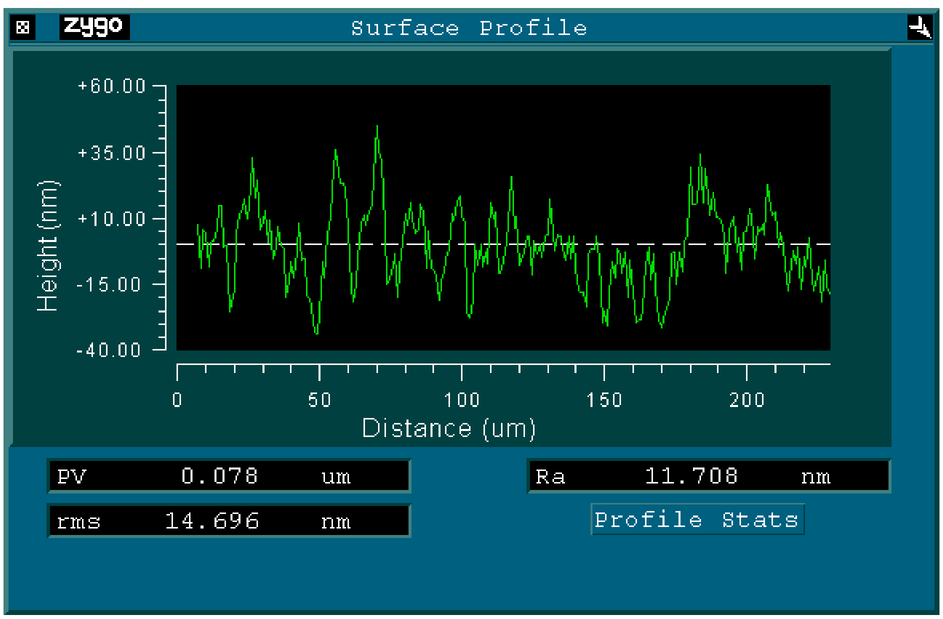

Figure 35: Area 8, Sample 2, Profile

3. Conclusions

The electroform has defects of up to about 50 microinches rms, which is within spec but only marginally so. The defects in the electroform are substantially higher than the defects in the mandrel, apparently. Random defects occur which are not visible to the naked eye but which can be detected (in these near-flat semi-destructive tests) using the Zygo. The defects are still OK, but the quality of the mandrel must be maintained to maintain sufficient quality on the electroform. It is not clear how these results relate to Langley's, which were obtained with substantially different instrumentation (profilometers, mostly). The specs derive from the earlier Langley results.