Experiments using *First Contact* polymer as a final cleaning step for aluminizing

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ABSTRACT

Cleaning mirrors for coating is a very exacting process and for larger mirrors it can be physically demanding. The final step of cleaning and drying the substrate is particularly problematic. Non-contact drying methods, usually with compressed air or nitrogen, can be laborious and can introduce contaminants if the compressed gas used is insufficiently pure(just a thought, recontamination is also a problem). These methods also tend to increase the static charge on the substrate surface, attracting lint. Contact methods tend to add lint or fibers to the cleaned surface. As an alternative, we are experimenting with using the *First Contact* polymer cleaning solution as the final step in mirror coating preparation. The advantage of this method is that the polymer coating, which will adhere to much of the remaining surface contaminants, may be left on the substrate until just before it is placed into the coating chamber, minimizing the time available for re-contamination. The results of our experiments on small substrates are presented.

Keywords: coating, aluminizing, mirror cleaning

1. INTRODUCTION

One large challenge in obtaining a good thin film coating is getting the substrate sufficiently clean to allow adhesion of the film with a minimum of pinhole defects. The larger the substrate, the more challenging getting the whole surface sufficiently clean becomes. Since the cleaning procedure often takes place at a location physically separated from the vacuum chamber in which the substrate will be coated, the substrate also needs to be kept clean up until it is in the coating chamber. Typically this means handling by heavy lifting equipment for large optics such as telescope primary mirrors.

While most steps involved in the cleaning introduce risks of contaminating the surface that is being cleaned, the final step, drying, provides the highest risk for re-contaminating the recently cleaned surface especially with regards to depositing dust on the surface which will cause pinholes in the coating if not removed. Hydrocarbon contaminants can also be deposited on the substrate if the gas is not sufficiently pure. During the history of coating the Canada-France-Hawaii Telescope (CFHT) primary mirror, several different approaches have been used for reducing the amount of residual dust on the substrate before coating. These have all worked to some extent, but all have some drawbacks.

One of the original methods used was to dry the surface using Kimwipe paper towels then brushing the visible lint off using an anti-static brush. This method was extremely time-consuming and only removed the dust that was visible and that was noticed on a 3.6 m diameter surface.

A second method was to dry the surface using Kimwipes then remove the dust with a CO_2 snow cleaning. This method quickly removes most of the large dust particles. The main problem is that drying with the towels tends to produce static which often causes the dust, especially the smaller dust, to adhere to the substrate with a greater force than can be exerted by the CO_2 snow. CO_2 snow has also introduced hydrocarbon contamination when the liquid is not sufficiently pure.

Our recent method has been to air dry the substrate using compressed, ultra-pure nitrogen passed through an anti-static device to reduce static charge buildup on the surface. A CO_2 snow cleaning is performed as the substrate is placed into

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the vacuum chamber. This method works well over most of the surface, but has some drawbacks. The most serious one is that the nitrogen drying is the most physically demanding step of an already demanding cleaning procedure.

Another drawback is that the surface that has not already been dried needs to be kept wet without wetting the dried part of the mirror. This requires the use of Kimwipes to keep the water within the wet area around the central hole in the mirror. These Kimwipes leave dusty patches that then need to be cleaned off, typically with alcohol.

These drawbacks could be eliminated or alleviated with the use of an air-knife. One main objection to the use of an air-knife is that using compressed nitrogen in a confined space poses a health hazard to the operators. Use of compressed air would be possible if sufficiently pure. Another objection to this is the time required to design, implement, and test such a device, especially in use on the primary mirror. This time is in short supply at CFHT. Finally, this does not solve the issue of the time between drying and having the mirror in the vacuum chamber for the mirror to gather more dust.

For this reason, the use of *First Contact* as a final step in the substrate cleaning process was put forth. *First Contact* consists of an ethanol/acetone-based polymer solution that can be sprayed or painted on an optical surface; it is manufactured by Photonic Cleaning Technologies, LLC.[1]. Upon exposure to the air, the solution dries to form an elastic film which traps any solid particles or soluble contaminants on the surface which are then removed by peeling the film. The benefits to using First Contact are that it can be easily tested on smaller substrates but the results can be applied to the primary mirror, it protects the mirror from further dust contamination until just before placing the mirror in the chamber, and it is easy to apply. The drawbacks of using *First Contact* are the expense and the static charge generated when the polymer sheet is removed from the substrate, though Photonic Cleaning is working on the latter problem. The former issue, expense, may be offset by reducing mirror cleaning time, improving chances for a successful coating, and possibly improved mirror lifetime due to fewer pinhole defects.

At CFHT, a series of experiments on small mirrors has been run to test if using *First Contact* as a cleaning step in coating mirrors produces results at least as good as our standard method (described below). This paper will describe each experiment, then give the results of the experiments, and finally give some conclusions and desired future tests.

2. EXPERIMENTAL SETUP

2.1 Experiment 1

The first experiment was an attempt to see at which point in the normal coating process *First Contact* could be introduced and still produce good results. To prepare for this experiment, thirty 50 mm square glass plates (microscope slide quality) were coated using the normal CFHT coating procedure. Twenty of the samples were subjected to four different storage conditions for a period of about 6 weeks. The other ten were stored in a closed container as references.

Before the samples were contaminated and stored, they were allowed to age for a week in a closed container to allow the aluminum oxide layer to form. At the end of this week, photographs were taken of each sample while back illuminated with a uniform source to show pinholes in the coatings. Reflectivity measurements were also taken using a TMA reflectometer which is capable of measuring reflectance and BRDF scattering at a wavelength of 670 nm. After the measurements were done, five samples (1 – 5) were contaminated with house water, five more (6 – 10) were contaminated with glycol, and a final five (11 – 15) were contaminated with hydraulic fluid (all common contaminants for our mirror). All fifteen were dusted with crushed cinder from outside the CFHT dome while still wet. These samples were then left exposed in the CFHT dome for 6 weeks. Five more (15 – 20) were stored in a closed container with no contaminants applied. The final 10 were unused in this experiment.

At the end of the 6 weeks, the samples were stripped, cleaned and re-coated. The stripping and cleaning procedure was as follows: rinse with house water; rinse with a sodium lauryl sulfate based soap (Orvus) mixed with de-ionized (DI) water; rinse with house water; drag wipe surface with cotton soaked in an Orvus/DI water solution; rinse with house water; then with DI water; apply Green River[2] to the mirror by putting Kimwipes on the surface and pouring the Green River onto the Kimwipe; leave this in place until most of the aluminum is gone; rinse with house water; scrub the surface with cotton soaked in Green River. This process was followed for all twenty samples. At this point, the processing diverged for the samples.

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[2] "Green River" is a solution of HCl and $CuSO_4$ (copper sulfate) in the following proportions: 272 g of 37% HCl to 22.7 g of $CuSO_4$ diluted in 1 liter of de-ionized water.

Four of the samples, one from each contaminant group, had *First Contact*, applied at this point. The rest of the samples were now rinsed with house water and DI water. At this stage, four more samples were coated with *First Contact*. The remaining twelve samples underwent two scrubs using cotton and a slurry of DI water and calcium carbonate ($CaCo_3$) powder with a rinse of house water between the scrubs. Four more samples were coated with *First Contact* after the second scrub but before rinsing. The final eight samples were rinsed and dried carefully using Kimwipes. Four of the final eight were then coated with *First Contact* and the last four were coated, as is. Table 1 summarizes this process and indicates which samples were used at each step.

At this point, it is worthwhile noting that, in an attempt to make the *First Contact* easier to remove, a Kimwipe was placed on each sample while the *First Contact* was wet. This actually made it more difficult to remove the *First Contact* and left behind a lot of "fluff". This was removed using a second coating of *First Contact* before coating. It is important to note that this mistake was due to CFHT inexperience with using *First Contact* and not due to any suggestions made by Photonic Cleaning Technologies. The consequences of this mistake and what was learned from it are discussed in the results section of this paper.

The samples were now coated using a 30 second plasma cleaning stage instead of the normal 10 minute cleaning. The procedure shown, taken all the way through to the drying stage, is the same as is used on the CFHT primary mirror. The main difference is that drying is normally done with compressed air instead of Kimwipes. Plasma cleaning is also available in the larger vacuum chamber used to coat the primary mirror. A coating of about 600 Angstroms thickness was achieved on the samples.

Table 1: Processing applied to the 20 samples in experiment 1. Numbers refer to the glass plate sample numbers. FC indicates *First Contact* was applied.

Contaminant	FC on Green River	FC after Rinsing Off Green River	FC after Two $CaCO_3$ Scrubs, no Rinse	FC after $CaCO_3$ Rinse, Kimwipe Dry	$CaCO_3$ Rinse, Kimwipe Dry, No FC
House Water + Cinder Dust	1	2	3	4	5
Glycol + Cinder Dust	6	7	8	9	10
Hydraulic Fluid + Cinder Dust	11	12	13	14	15
No Contaminant	16	17	18	19	20

After allowing the aluminum oxide layer to form, for six weeks in this case, the samples were back illuminated and photographed, tape tests were performed over the entire surface, and the reflectance and roughness of the samples were measured using the TMA reflectometer.

2.2 Experiment 2

This experiment was done to validate the results of the previous experiment and to ensure that the plasma cleaning, as short as it was during experiment 1, did not hide some issue with the cleaning. Plasma cleaning will often allow a less than perfect cleaning to result in an acceptable coating.

For this experiment, twenty-four of the previous samples were stripped, cleaned, and re-coated using the standard CFHT coating procedure. They were allowed to age for ten days and were then split into four groups: six samples (1 – 6) had no contamination placed on them, six (7 – 12) had pump oil placed on them, six (13 – 18) had machine oil placed on them, and six (19 – 24) had vacuum grease placed on them. Shortly after contamination, the samples were processed.

All twenty-four samples were washed and rinsed using Orvus soap and were then stripped of aluminum using Green River. The samples were cleaned using one of the following three procedures:

- One $CaCO_3$ scrub followed by rinsing with house water then DI water. Dried with dry nitrogen.
- Two $CaCO_3$ scrubs followed by rinsing with house water then DI water. Dried with dry nitrogen.
- Two $CaCO_3$ scrubs followed by rinsing with house water then DI water. Dried with Kimwipes.

In this case, the Kimwipe drying was done until the surface was completely dry, as was formerly done with the primary mirror, instead of only mostly dry, as was done in Experiment 1. Finally, one of each pair of samples with the same contaminant and the same cleaning procedure was coated with *First Contact* to allow a one-to-one comparison of the methods. Table 2 shows how all the samples were processed.

The mirrors were then coated in two batches, 1- 16 first, then 17 – 24. A thickness of about 600 Angstroms was achieved. No plasma cleaning was done.

After several weeks, the samples were measured for reflectivity and BRDF scatter at a single wavelength, measured for reflectivity versus wavelength in the CFHT spectrophotometer, back illuminated photographs were taken, and full sample tape tests were performed.

Contaminant	Single $CaCO_3$ scrub then rinse and air dry		Two $CaCO_3$ scrubs then rinse and air dry		Two $CaCO_3$ scrubs then rinse and Kimwipe dry	
	FC	No FC	FC	No FC	FC	No FC
None	1	2	3	4	5	6
Pump Oil	7	8	9	10	11	12
Machine Oil	13	14	15	16	17	18
Vacuum Grease	19	20	21	22	23	24

Table 2: Processing applied to the 24 samples in Experiment 2.

2.3 Experiment 3

The goal of this experiment was to determine what kind of contaminants, on a cleaned surface, we can expect *First Contact* to remove and still provide a successful coating. For this experiment, sixteen samples were stripped, cleaned with two $CaCO_3$ scrubs, rinsed with house water, then DI water, and dried with dry nitrogen. The samples were then immediately contaminated with a visible level of the substances shown in Table 3. All the samples were then coated with *First Contact* except the last two which were used for controls.

Contaminant	Sample #
None	1, 2
Finger Oil	3, 4
Machine Oil	5, 6
CO_2 Clean	7, 8
Kimwipes	9, 10
House water	11, 12
Pump Oil	13, 14
None; No FC	15, 16

Table 3: Contamination added to samples in Experiment 3 prior to application of *First Contact*.

All sixteen samples were coated in a single set with no plasma cleaning done prior to evaporation. After several weeks, the samples were measured for reflectance and scatter at a single wavelength, measured for reflectivity versus wavelength in the CFHT spectrophotometer, back illuminated photographs were taken, and a tape test was done across the full sample.

3. EXPERIMENTAL RESULTS

3.1 Notes on Tests and Measurements

The photograph setup for the back illuminated images of the samples was, unfortunately, not consistent over the three sets of samples photographed (initial aluminization before any tests, results from Experiment 1, and results from Experiments 2 and 3 which were performed at the same time). The masking of the back illumination, camera orientation, and even the camera changed from setup to setup. In addition, the last set was transported to our headquarters before the photographs were taken and some sustained scratches in transit. For these reasons, a pinhole area counter was not possible as originally intended. Instead, the images were ranked by eye as to number of pinholes with a rank of 1 indicating numerous pinholes, 2 indicating a moderate number of pinholes, and a rank of 3 indicating few pinholes. Some very subjective non-integer ranking was also applied. Figure 1 shows examples of images with rankings of 1, 2, and 3.

While this system is somewhat subjective, it is very capable of differentiating between samples with many pinholes and those with few pinholes. To keep the ranking somewhat consistent, three images were used as references for a 1, 2, or 3 ranking and these images were referred to frequently during ranking of the other images.

In addition, the reflectance measurements from the TMA reflectometer were done at different temperatures and different pressures for the different experiments. The reflectometer is sensitive to these things, so these reflectance measurements are only good for relative comparisons within a group and are not valid in an absolute sense. The roughness measurements should be more valid in an absolute sense.

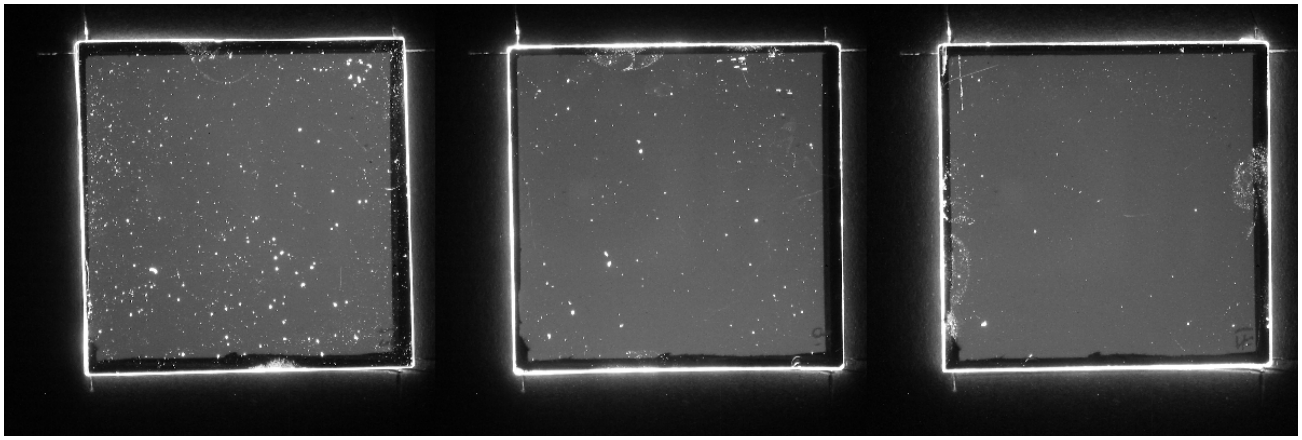

Figure 1: Image showing three examples of images with pinholes. The rankings of these images is 1, 2, and 3 from left to right. Edge smudges are thought to be from glove contamination and affect all samples at some level.

In Experiment 1, the roughness measurements were done after the tape tests were performed, so the results of the roughness measurements are somewhat suspect. However, the conclusions drawn in this paper do not rely on these data. For Experiments 2 and 3, the tape tests were performed after the roughness measurements were taken.

Finally, it should be noted that the removal of the *First Contact* film from the edges of these substrates proved to be a bit challenging. The substrates were cut from 4 mm thick commercial grade plate glass and had sharp corners and edges that were minimally ground. The sharp edges tended to separate the *First Contact* on the surface from the *First Contact* on the edge so that it did not all come off together. The front surface layer came off easily, but the thin edges made detaching[3] the residual *First Contact* more difficult, so the substrates that used *First Contact* typically needed to be handled more. It is felt that on a large substrate with beveled corners and fine ground edges, this would be less of an issue.

3.2 Experiment 1 Results

The errors that happened while performing this experiment mean that these results will not be examined in too much depth. However, the results were sufficient to draw some basic conclusions, at least qualitatively.

The main issue with the results from this experiment was that the pinhole counts were worse for the samples where *First Contact* was used. This, in itself, is not enough to invalidate the results, of course. However, the results of Experiment 2, which was done more carefully, contradict this result. The hypothesis for the increase in pinholes is that the second coat of *First Contact* removed the bulk of the "fluff", but did not have the capacity to completely remove the "fluff" thus increasing the pinhole count.

The results of this experiment are tabulated in Table 4. This table has the same entries as Table 1 except the results are given in place of the sample number. Three results are given in each cell: the pinhole number ranking, the result of the

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[3] The *First Contact* film was detached by applying Photonic Cleaning Technologies' adhesive strips to the film and pulling.

tape test (normally either good or bad), and the average roughness measurement over 5 locations. The reflectance is not reported since all samples were the same to within a few tenths of a percent.

Although the experiment was not fully controlled, some conclusions can be drawn from it. First, the tape test only failed on one sample. This sample was processed with $CaCO_3$ scrubs, but no rinsing and it was noted that visible $CaCO_3$ remained after the *First Contact* was removed from these samples. It is known that *First Contact* will only lift a certain quantity of contaminant before saturating, so this failure is not unexpected.

The samples on which *First Contact* was applied after rinsing, while having more pinholes than hoped for, average pinhole ranking of 1.8 ± 0.6 excluding the failed coating, are in line with the pinhole rankings of all of the substrates when initially coated (rankings not given here). The average ranking over all the samples after the initial coating, cleaned in the standard way with no *First Contact*, and prior to contamination, was 1.5 ± 0.6 with some much better and some much worse. During the processing above, extra care was given to the four samples with no *First Contact* applied. So, even with a flawed application of *First Contact*, the coatings were still useable in most cases.

Contaminant	FC on Green River	FC after Rinsing Off Green River	FC after Two $CaCO_3$ Scrubs, no Rinse	FC after $CaCO_3$ Rinse, Kimwipe Dry	$CaCO_3$ Rinse, Kimwipe Dry, No FC
House Water + Cinder Dust	0.9, Good, 16.2	1.9, Good, 24.3	2.8, Good, 12.6	2.0, Good, 19.3	3.2, Good, 10.6
Glycol + Cinder Dust	1.0, Good, 16.1	2.0, Good, 16.0	1.4, Good, 22.3	2.8, Good, 15.4	3.2, Good, 15.0
Hydraulic Fluid + Cinder Dust	1.1, Good, 18.5	2.0, Good, 19.2	1.5, Good, 28.1	1.5, Good, 18.2	3.1, Good, 19.6
No Contaminant	1.0, Good, 26.2	2.0, Good, 13.5	2.8, Bad, 38.5	2.8, Good, 20.2	3.2, Good, 13.1

Table 4: Tabulated results for Experiment 1. Data in each cell are pinhole ranking (1 – bad, 3 – good), tape test results, and roughness at 670 nm in Angstroms.

A final conclusion one can draw is that *First Contact* should not be used without a thorough rinsing of the substrate, though thorough drying is not necessarily mandatory.

3.3 Experiment 2 Results

This experiment gave very clear results and indicates that using *First Contact* after a rinse and dry provides very good results, typically much better than without using *First Contact*. In this case, all of the samples were processed in the same way at the same time. For every combination of surface contaminant and cleaning procedure there were two samples, one with *First Contact* and one without to allow for an easy comparison. Table 5 gives the results for this experiment laid out like Table 2 except now the cells contain the pinhole ranking (1 – bad, 3 – good), the tape test results, and the surface roughness averaged over six measurements in Angstroms.

Contaminant	Single $CaCO_3$ scrub then rinse and air dry		Two $CaCO_3$ scrubs then rinse and air dry		Two $CaCO_3$ scrubs then rinse and Kimwipe dry	
	FC	No FC	FC	No FC	FC	No FC
None	2.5, Good, 12.5	0.7, Good, 21.0	2.0, Good, 11.6	1.0, Good, 12.0	3.0, Good, 11.8	0.7, Good, 15.9
Pump Oil	2.8, Good, 11.4	0.9, Poor, 22.5	2.0, Good, 14.2	1.1, Poor, 12.0	2.7, Good, 13.2	1.0, Good, 12.6
Machine Oil	2.9, Good, 10.6	1.0, Good, 12.1	2.5, Good, 12.1	1.1, Good, 9.7	3.0, Good, 14.4	0.9, Good, 23.2
Vacuum Grease	3.0, Good, 9.2	1.1, Good, 12.1	2.2, Good, 13.2	0.8, Good, 12.0	2.9, Good, 8.3	1.0, Good, 9.9

Table5: Tabulated results for Experiment 2. Data in each cell are pinhole ranking (1 – bad, 3 – good), tape test results, and roughness at 670 nm in Angstroms.

The results in the table indicate several things. First, the samples treated with *First Contact* consistently have fewer pinholes than those without. The only samples with less than good tape tests are the ones where *First Contact* wasn't used. The two that did not pass the tape test both had been exposed to pump oil. It is possible that this oil does not come off well at the time the coating is stripped and it does not clean off well using $CaCO_3$. Finally, the roughness may be better in samples using *First Contact* than those without, but this is not consistent in all combinations. More will be said on this later.

Oddly, one scrub and air dry and two scrubs and Kimwipe dry produced better pinhole results, in conjunction with *First Contact*, than two scrubs and air drying. At this point, we have no good hypothesis to explain this result.

Given that there is a sample with and without *First Contact* for each combination, it is reasonable to look at the twelve samples with *First Contact* as a set and the twelve without as a second set. If this is done, then an average and standard deviation over the sets can be done for the pinhole rankings and the surface roughness. The results of these calculations are: with *First Contact*: Pinhole ranking = 2.6 ± 0.4, Roughness = 11.9 ± 4.4 Angstroms; without *First Contact*: Pinhole ranking = 0.9 ± 0.1, Roughness = 15.1 ± 7.0 Angstroms. The improvement in pinhole ranking with *First Contact* is clear. There is also an apparent improvement in roughness of about 3 Angstroms on average. More significant is the size of the error bars which are based on the standard deviation over all the measurements for each mirror (six measurements on each mirror) in each group. In addition to giving better roughness measurements, the samples using *First Contact* gave more consistent roughness results than samples not prepared using *First Contact*.

For this data set, the samples were also scanned using the absolute reflectance attachment to our Shimadzu spectrophotometer. Again, all the curves were averaged depending on whether *First Contact* had been used. The curves are shown in Figure 2. The standard deviation of the curves over the wavelength range plotted is 0.13 ± 0.03% for the curve with *First Contact* and is 0.16 ± 0.03% for the curve without *First Contact*. Surprisingly, there is a small increase, on average, in the reflectivity when using *First Contact*.

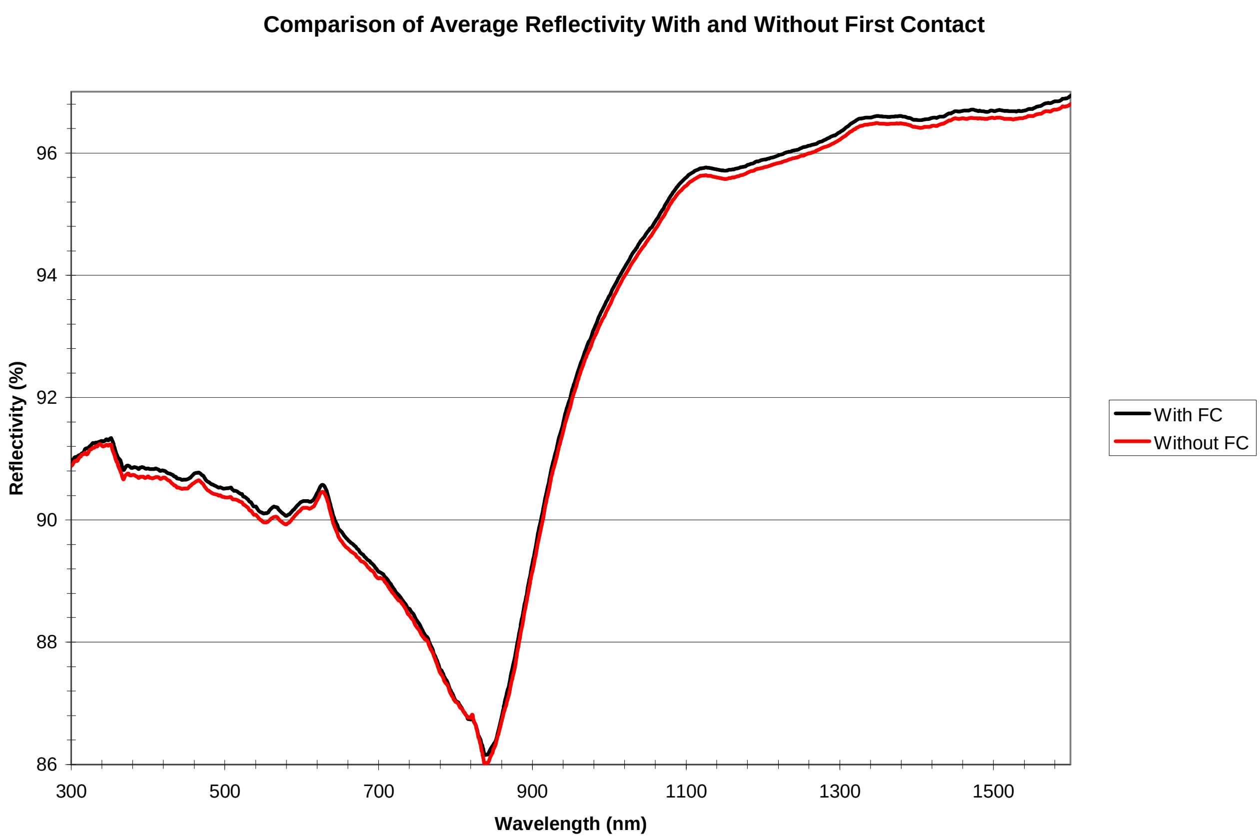

Figure 2: A comparison of average reflectivity of the samples with and without using *First Contact*. The data stops at 1600 nm since the scans become unreliable with this spectrophotometer configuration beyond this range.

A plot of the difference between the two curves, Figure 3, shows this gain in reflectivity even more distinctly. The dip at around 830 nm is likely caused by a known calibration issue with the Shimadzu in this configuration at around 832 nm.

If the difference is averaged over the plotted wavelength range, the reflectivity increase when using *First Contact* is 0.12 ± 0.03%, including the dip at around 800 nm. While the difference between the two curves lies within the error bars for the curves, taken to be the standard deviation of the curves over the wavelength range, the fact that the difference is near the edge of the error bars indicates that some level of increase is real.

Note that, in Figure 2, each curve is an average over twelve separate samples. The samples were cleaned and coated at the same time and scanned alternating between one with *First Contact* and then one without since they were scanned by sample number. In fact, all measurements on these samples were done in sample number order at the same time without reference to which procedure was performed on them. There is little chance that this increase in reflectivity or improvement in the pinhole count or roughness is due to instrument drift or some other systematic caused by unequal treatment of the samples.

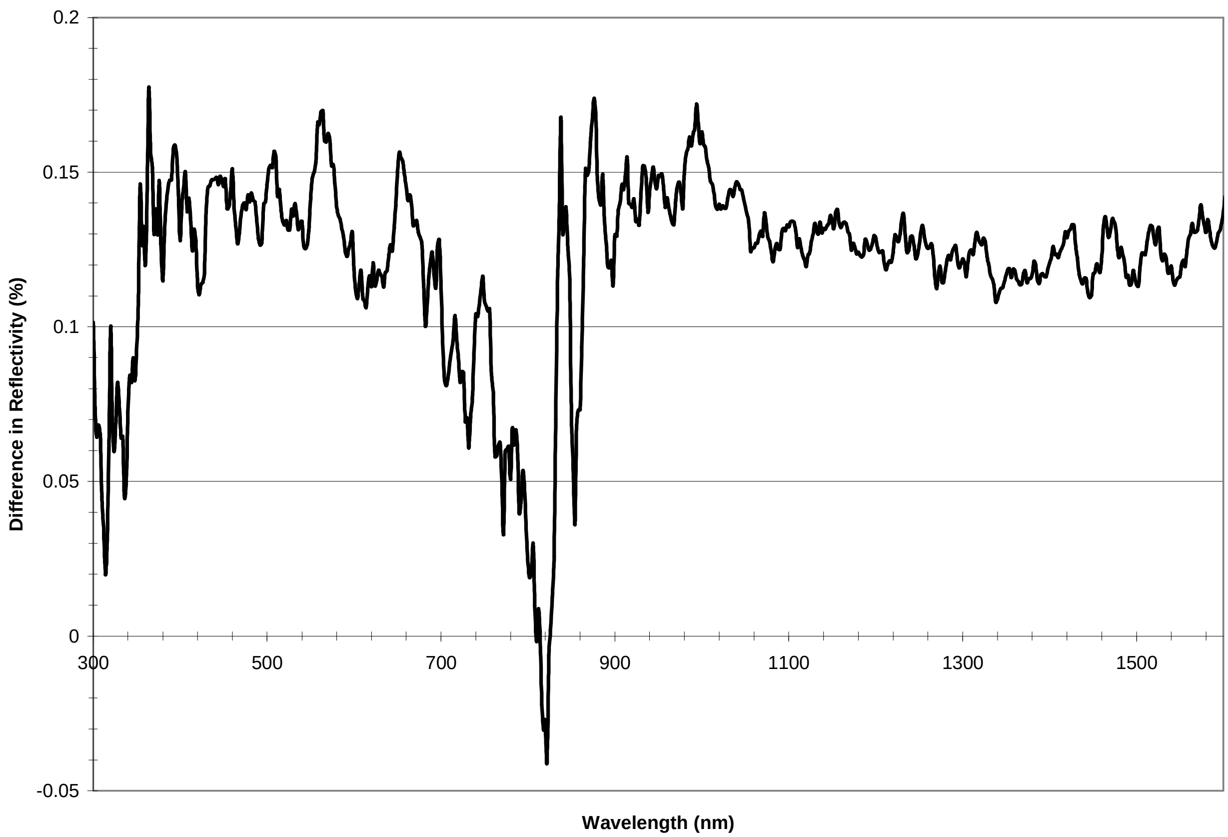

Figure 3: Difference in reflectivity curve with and without using *First Contact* as a final cleaning step.

3.4 Experiment 3 Results

Experiment 3 was done in an attempt to see how well *First Contact* could contend with substrate contamination after cleaning. The results, which are compiled in Table 6, show that *First Contact* is able to remove many common sources of contamination without further cleaning of the substrate. The only coating failure was due to fingerprint contamination which *First Contact* seems to be unable to lift off sufficiently to allow a good coating, at least with only one application.

It is interesting to note that the pinhole ranking and roughness measurements for most of the samples are consistent with the measurements in Experiment 2 using two $CaCO_3$ scrubs and air drying, which is how these samples were all cleaned. Contaminating with Kimwipes, house water, and pump oil, however, show improvements in pinhole ranking and in roughness. There is no good explanation for why these contaminants allow for better coating after removal by *First Contact*.

The two samples where *First Contact* was not used were somewhat better than what was achieved in Experiment 2 for any samples without *First Contact*. These samples were prepared and coated on the same day as the samples in Experiment 2.

Contaminant	Sample 1	Sample 2
None	1.5, Good, 10.8	2.0, Good, 9.8
Finger Oil	1.5, Bad, 39.5	2.0, Bad, 12.8
Machine Oil	2.0, Good, 15.6	1.9, Good, 12.6
CO_2 Clean	2.0, Good, 13.8	2.2, Good, 16.5
Kimwipes	2.8, Good, 15.2	2.2, Good, 11.6
House water	2.9, Good, 9.0	3.0, Good, 8.8
Pump Oil	2.7, Good, 11.0	3.0, Good, 8.4
None; No FC	1.3, Good, 13.5	2.0, Good, 9.5

Table6: Tabulated results for Experiment 3. Data in each cell are pinhole ranking (1 – bad, 3 – good), tape test results, and roughness at 670 nm in Angstroms.

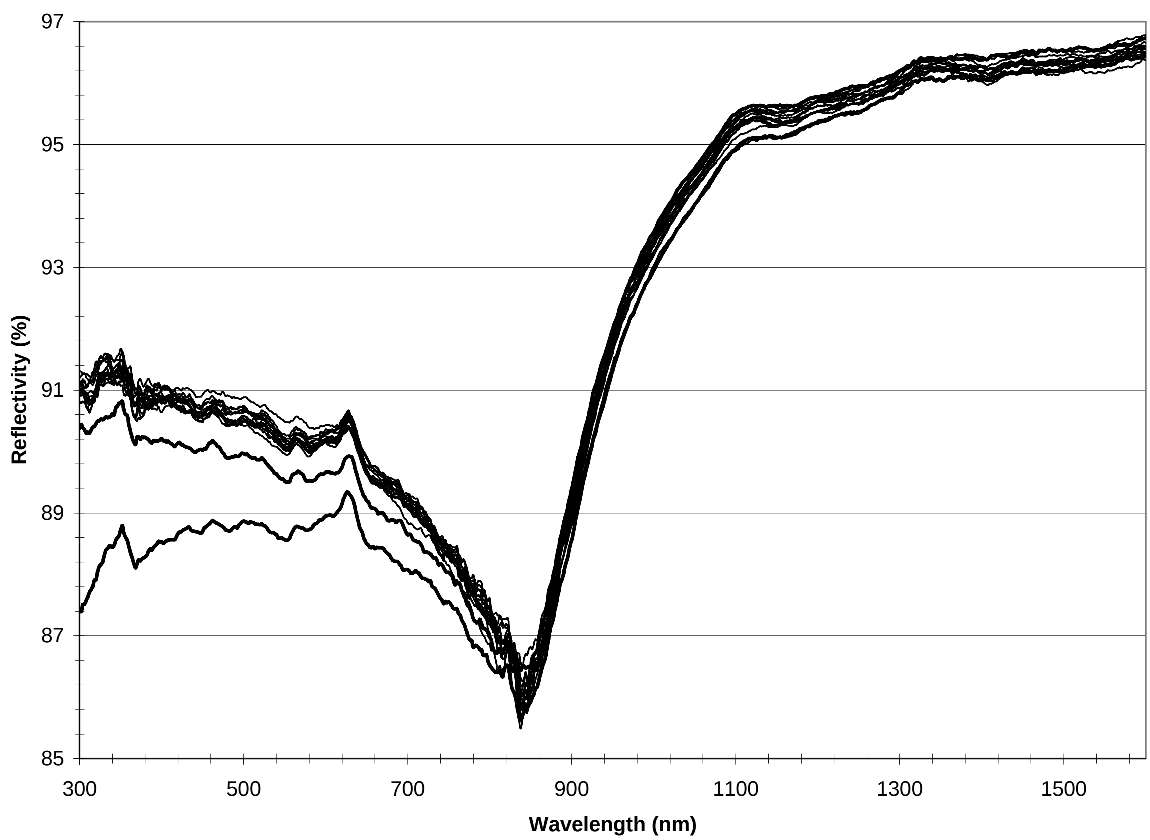

Figure 4: Reflectivity of samples contaminated in a variety of ways prior to final cleaning with *First Contact*. The finger oil samples are presented with a thicker line to emphasize the difference of these from the rest.

These samples were also scanned with the Shimadzu spectrophotometer prior to the tape tests. All of the scans are shown in Figure 4. The grouping of curves is similar to the grouping found in Experiment 2 with the exception of the two curves with finger oil contamination. Both of these show significant reflectivity degradations in the blue, but only the first sample shows degradation in the red. The level of contamination was worse in sample 1 with finger oil.

Figure 5 shows the back illuminated photographs of the samples contaminated with finger oil. The area touched is clear although by eye, these samples did not show strong signs of problems. One result to take away from this experiment is that, in the words of one of the authors of this paper, "Fingerprints are evil", at least where coating is concerned. This indicates that if a surface is contaminated with fingerprints, a thorough re-cleaning is necessary to achieve good results.

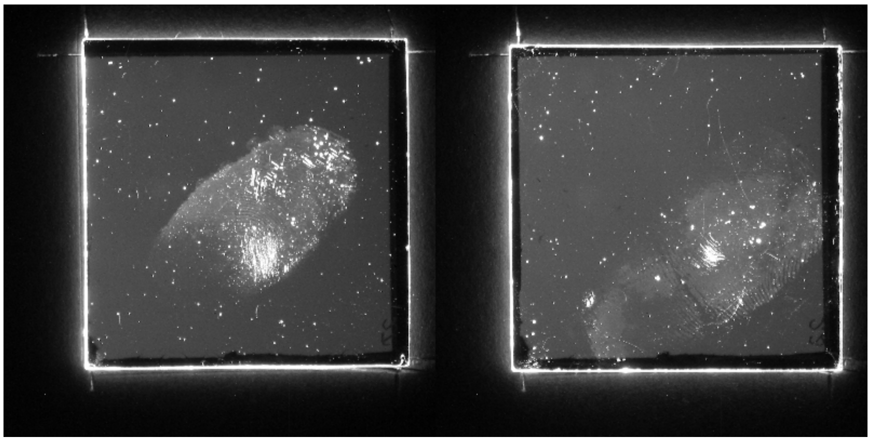

Figure 5: Back illuminated image of samples contaminated with finger oils. The area contaminated is obvious.

Another significant result is that *First Contact* allowed a good coating to take place even when the samples had been contaminated with substances that would normally completely inhibit adhesion of the aluminum, such as machine oil. Recall that these samples were not plasma cleaned prior to coating which also helps to remove many oily contaminants.

In this experiment, no silicon-based oils, such as diffusion pump oil, were used as contaminants. As this is another common source of contamination, it would be very interesting to see if *First Contact* were able to remove it as well.

4. CONCLUSIONS AND FUTURE WORK

These experiments have shown clearly that use of *First Contact* as a final step in cleaning prior to coating works as well as standard cleaning procedures. In fact, the experiments indicated that a typical coating using *First Contact* as a final cleaning step is much more likely to give better results in terms of pinhole count than only using the standard cleaning procedure. Even when used poorly, as in Experiment 1, use of *First Contact* still allows for an acceptable coating to happen, and when used properly, can give excellent results. In addition, many common contaminants that may creep back onto the surface of a mirror after cleaning but prior to coating are removed with the use of *First Contact*.

Excellent results can be obtained using the standard procedure if great care is taken, as in Experiment 1. The succeeding experiments, however, show that good to excellent results can be obtained more regularly if *First Contact* is used. There was no sign that the surface roughness was increased with *First Contact*, in fact the surface roughness seemed to improve. Finally, there were indications that a slight, though probably not significant, increase in reflectivity is possible when using *First Contact*.

The issues found with removing the *First Contact* from the edges of the substrate will be investigated in the near future. We feel confident that this is mainly due to the form factor of our substrates and would be a non-issue on actual mirror substrates. This work will be done in consultation with Photonic Cleaning Technologies to make sure that errors, like those in Experiment 1, are not repeated.

It is hoped that the next step will be to use *First Contact* in preparing our f/8 secondary prior to coating. This would help prove the concept on a larger mirror, about 1.5 m diameter. The mirror also has centering fiducials inscribed in the glass. This would show how *First Contact* works on a substrate with surface defects.