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U.S. DEPARTMENT of ENERGY

Understanding the Dark Spot on Mirrors

The End of SULI Program Summary

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Overview

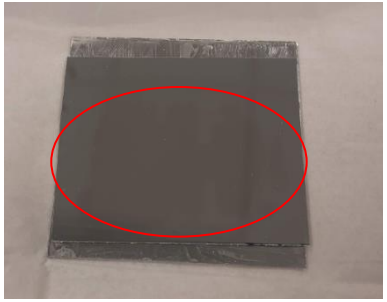
Dark Spot Issues from the past to the present

- Early Observations
- Coating 47- First attempt to resolve the dark spot issue
- Latest Results and Highlights from Coating 48 and 49 with new 800 nm scan
- System Change: 200-600 nm to 200-800 nm scan
- System Hardware Updates

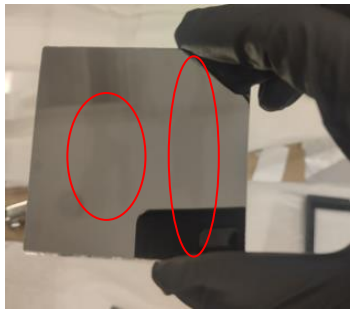
Early Observations

Initial Observations

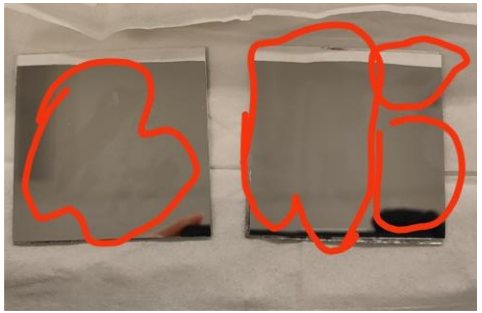
“Dark spots” first noticed at Coating 42



42 Mirror 4 DP460 dark spot



42 Mirror 5 DP460 dark spot



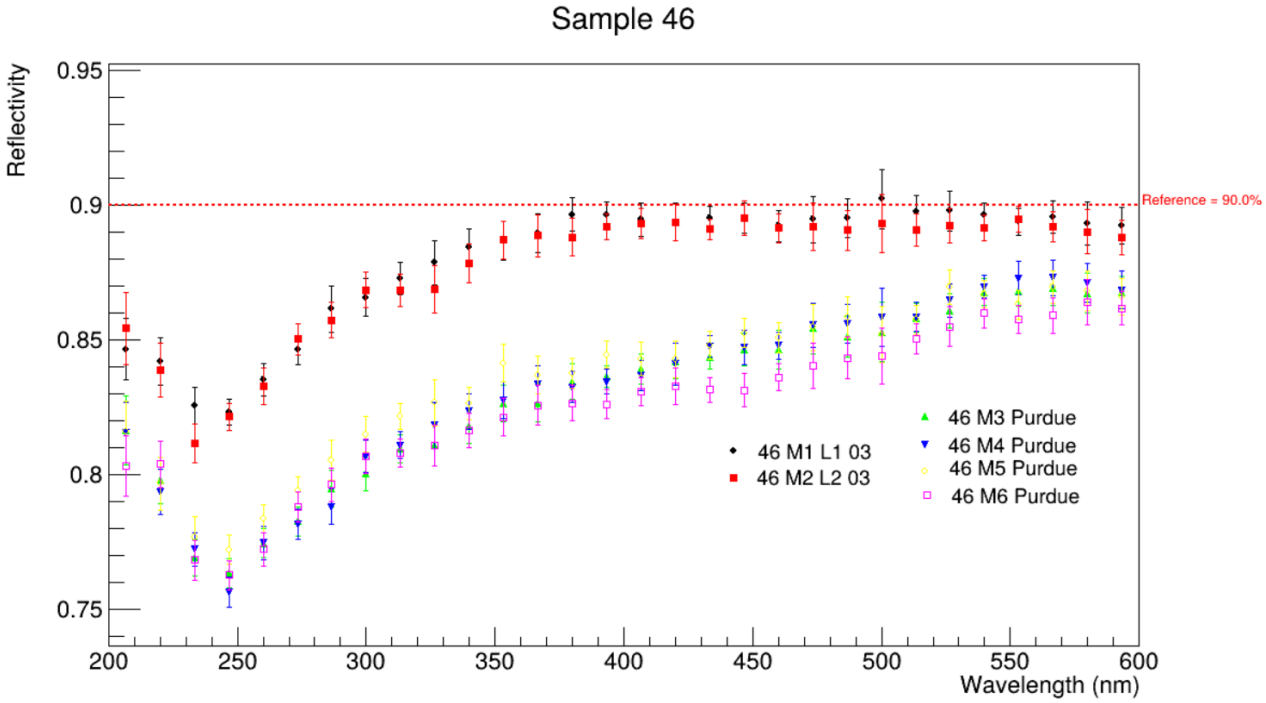
43 DP460 mirrors

- Starting from coating 36, mirrors began showing visible dark spots.
- These dark spots corresponded with reflectivity drops (~5–10%).
- Dark spots were found from coating 36 to 46(the latest batch I had at the time) except 37.

Initial Observations

Example Coating 46:

- Lexan-only can reach 90%
- No visible Dark spots on two Lexan-only samples.
- Dark spots on Purdue's substrate
- With ~5–10% reflectivity drop for dark spots on Purdue's substrates.



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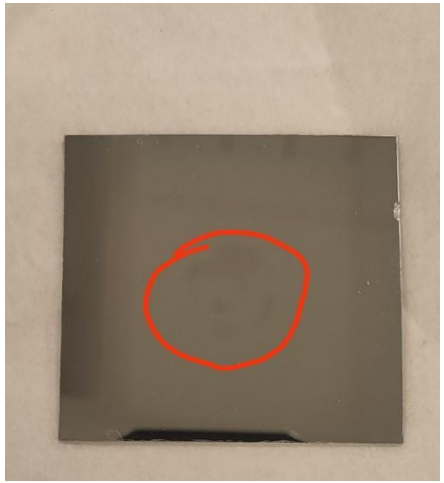
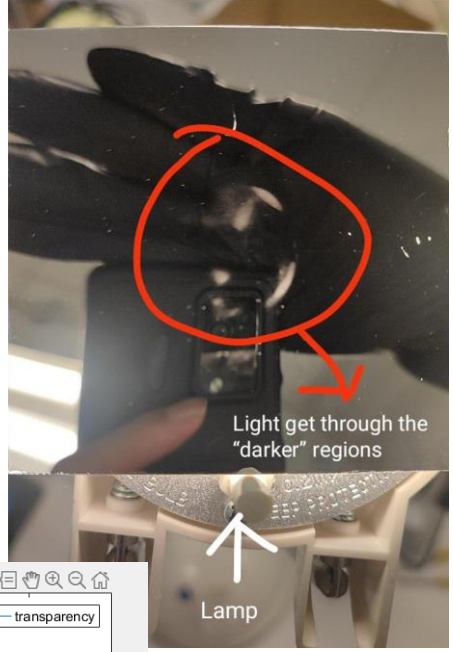
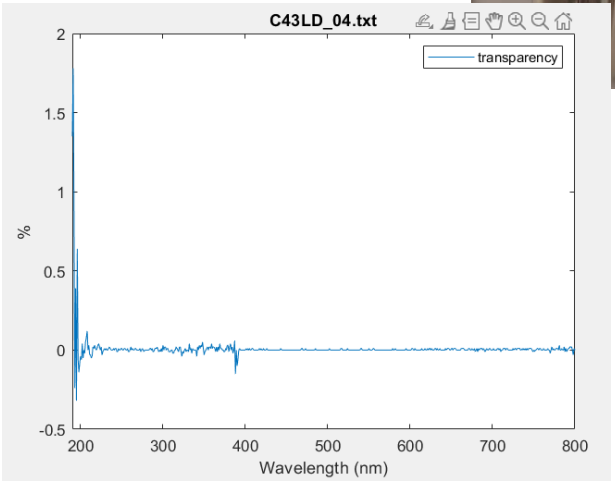
Later Observations

Testing the lexan-only(transparent substrate) mirrors from coating 43

- Coating 43 is thinner than the normal coating: 4.4kA Cr, 10kA Al. Normal is ~4kA Cr, ~16kA Al.
- Dark spots at **mechanical mount** on the frame in vacuum chamber.
- Those dark spots seems like the **thinner coating**.
- However, the Monochromator shows **0 transparency** at dark spots.







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Important findings from the observations from coating 28 to 46:

- Both SBU and Purdue's substrate have dark spots.
- Dark spots mainly appear on epoxy-used mirrors, e.g., DP460, 0989 and JB.
- Dark spots are not limited to epoxy types
- **Dark spot is due to used of epoxy?**
- Dark spots appear at **mechanical mount**.
- **0 Transparency** indicated at low light intensity, reflectivity drops may not due to light transmission.

Strategies:

To understand what these dark spots are and what is causing this is critical,

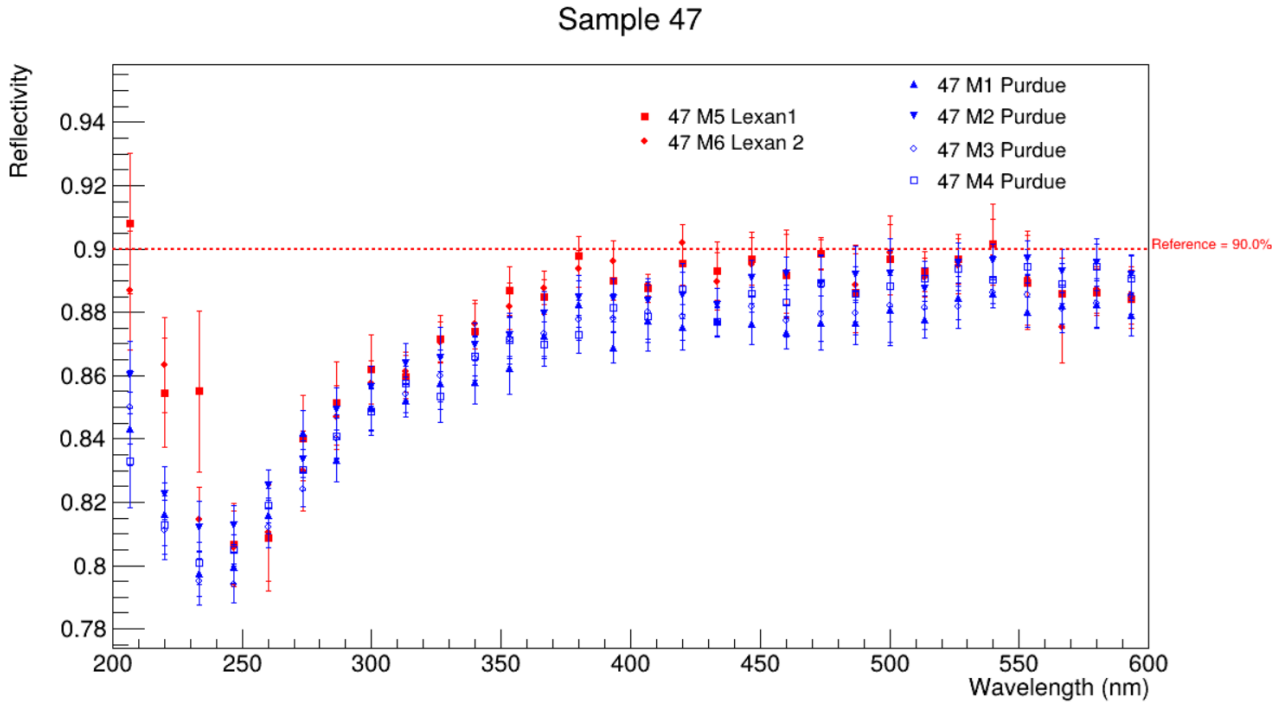
- **Potential solution**: thicken the coating if coating is thinner at dark spots.
- Quantitatively verify “used of epoxy” dependency.
- Further verify “transparency” impacts.

Coating 47 - First attempt to resolve the dark spot issue

Coating 47 → testing potential solution by thickening the coating

5kA Cr and 20kA Al

- Lexan-only, no dark spots near 90%
- Purdue, no dark spots, with some contaminations, near 89%
- May be a good news that with thicker coating: Purdue's substrates(blue) have great improvement and almost catch up Lexan-only mirrors(red) with no visible dark spots and reflectivity split.



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Latest Results and Highlights from Coating 49 and 48

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Coating 48 to test “used of epoxy dependence”

Half coating thickness: 2 kA Cr, 8 kA Al. Hopefully some transparency can be measured.

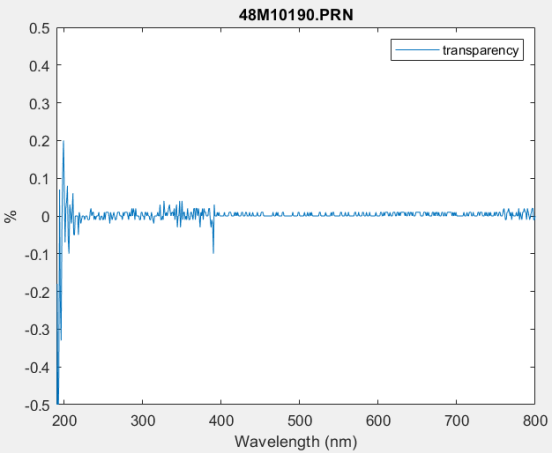
Transparency test on coating 48(2kA Cr, 8kA Al)

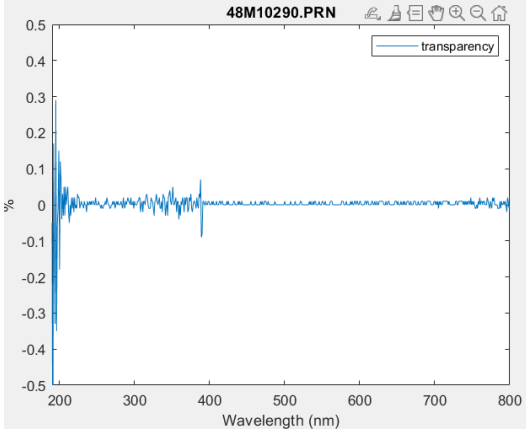
I did both 45 degree and 90 degree incident angle on the mirror samples.
Simple conclusion: From all the results I have, they are all **0 transmission,** ignoring signal noises.
However, I used my phone's flashlight which can easily see light transmission from the back of coating even environment is bright.
My guess is that with a lower intensity spectrometer light source relative to our cell phone flashlight, most of the light is absorbed or reflected, failing to produce a detectable signal for the photodiode.

Transparency test on coating 48(2kA Cr, 8kA Al)

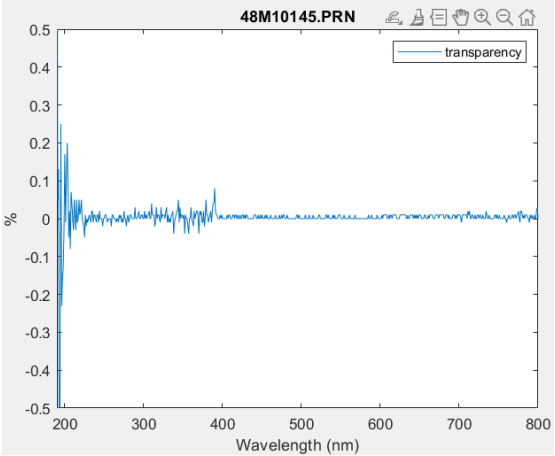
90 degree:

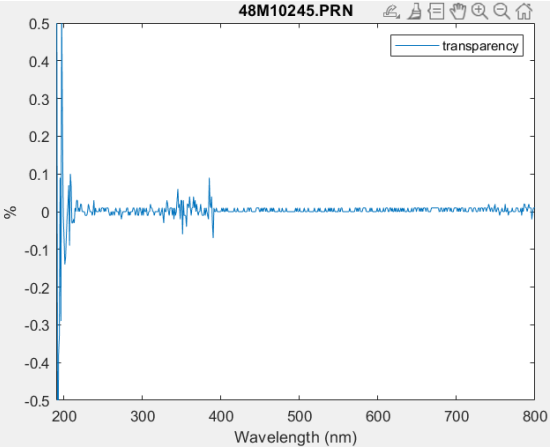
Lexan-only cleaned mirror





45 degree:





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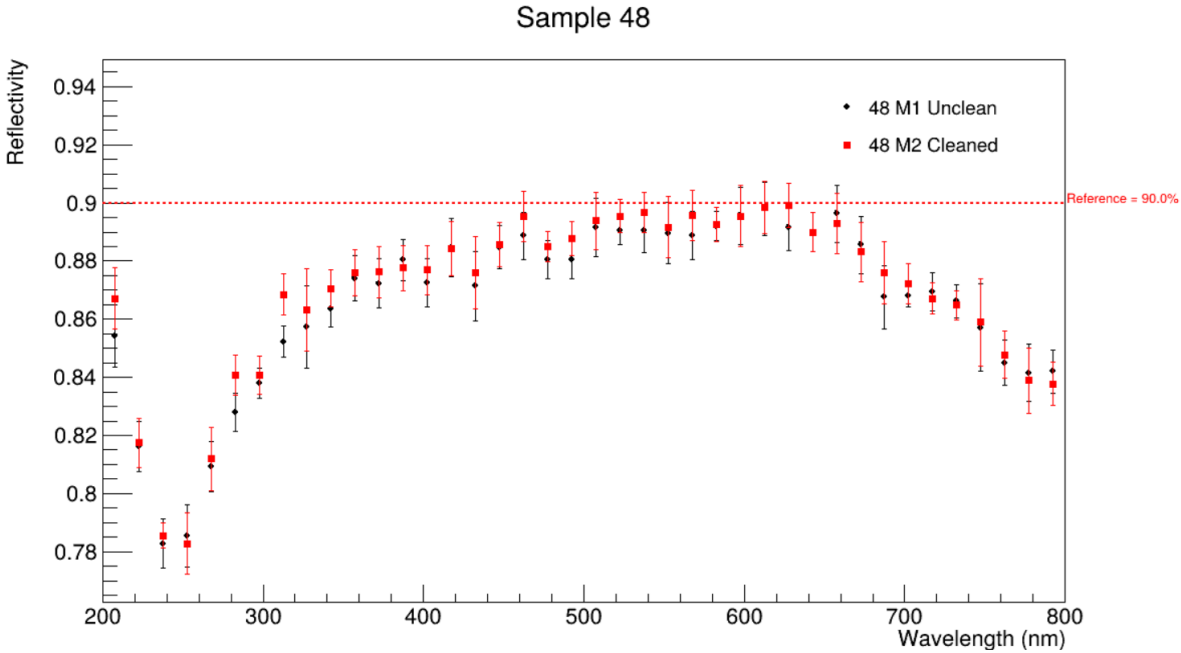
Coating 48(2kA Cr, 8kA Al): Good Lexan-only mirrors as reference

Cleaned(ethanol soaked) and Uncleaned(ethanol unsoaked) lexan-only mirror:

- They are highly consistent
- Can’t conclude alcohol bath is having any impact
- ~89% maximum reflectivity
- Provide reference for subsequent testing, named M1 & M2



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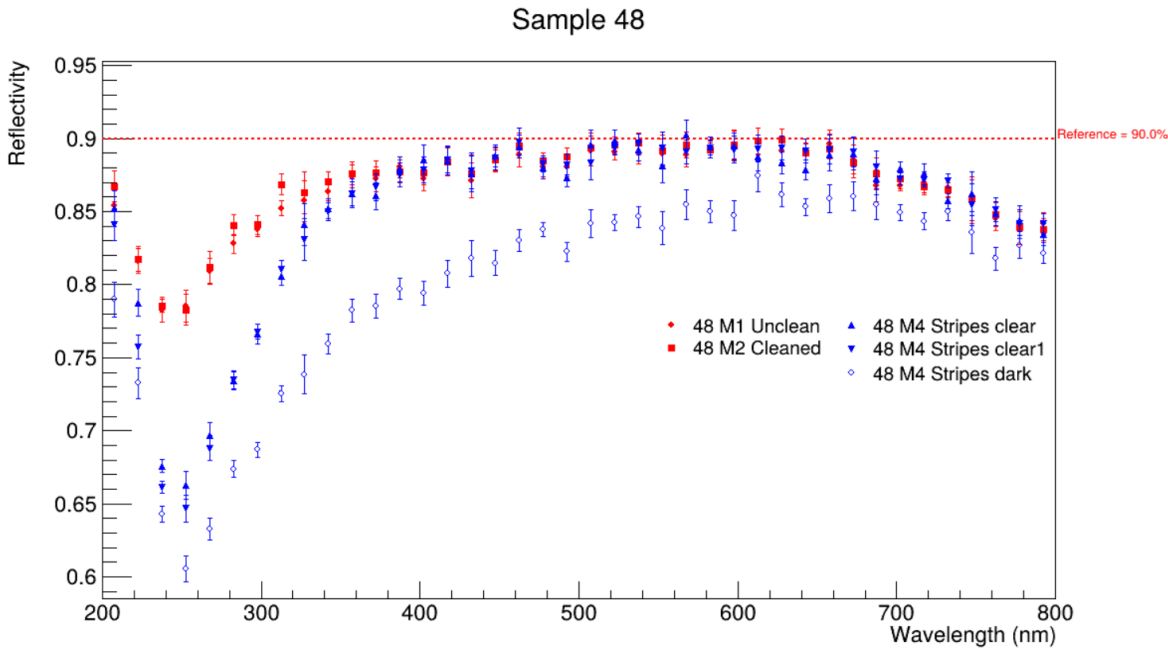
Coating 48(2kA Cr, 8kA Al): Dark spots on epoxy area

M4 “Stripes” mirror(blue) vs M1 & M2 reference (red)

With Lexan substrate but two stripes of DP460 epoxy on one side.

- Dark spots on epoxy stripes area only.
- Clear spots consistent with M1 & M2.
- ~5% reflectivity drop on dark spots. Also, dropping effect is weaker at higher wavelength



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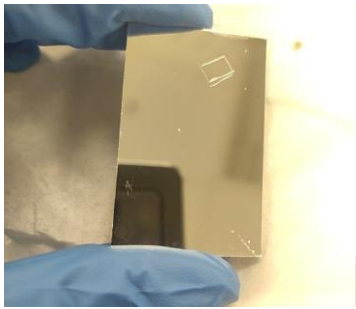
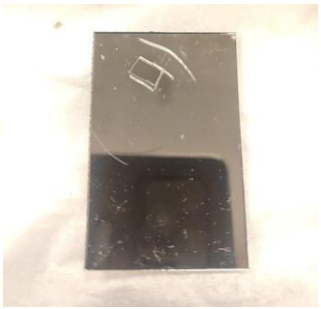
Coating 48(2kA Cr, 8kA Al): Dark spots on mechanical mount

“Cleaned lexan-only” vs M1 & M2:

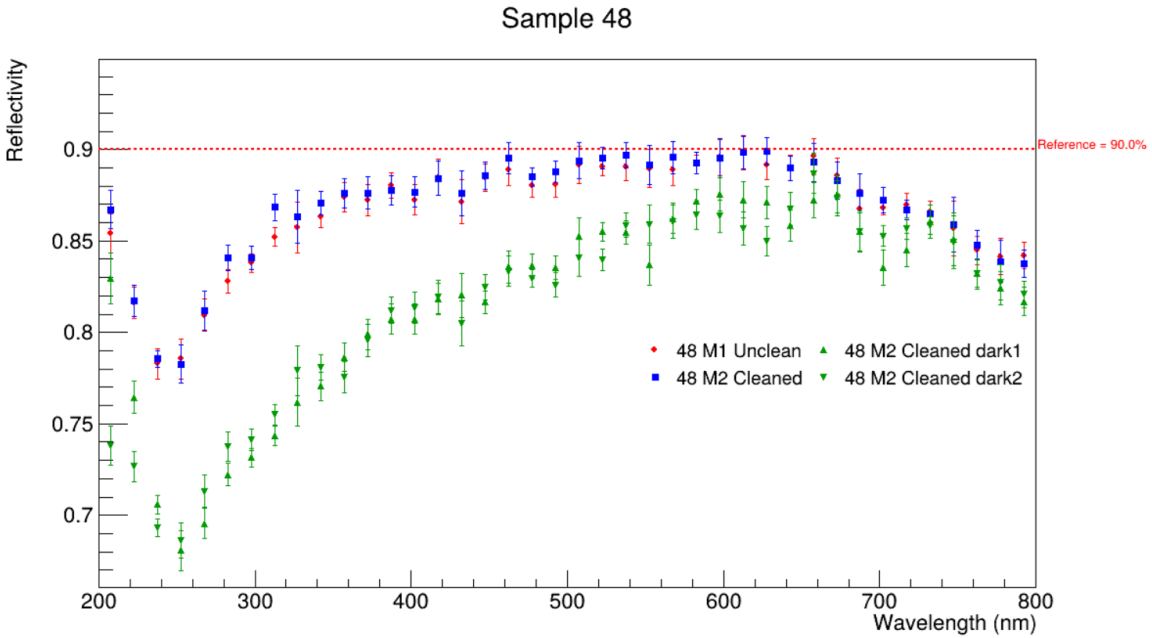
- Same dark spots at **mechanical mount**
- Maximum ~10% reflectivity drop.



Front



Back



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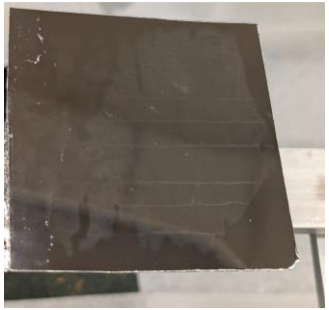
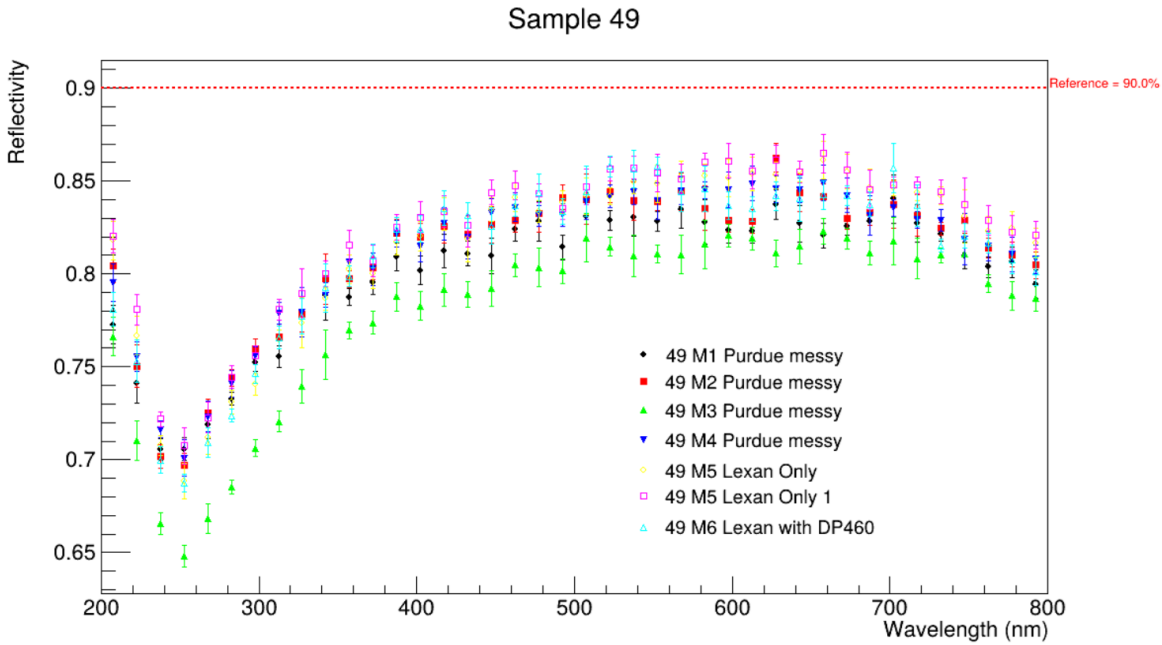
Coating 48 Conclusion:

- Confirmed: “Used of Epoxy” → visible dark spots → lower reflectivity
- Confirmed: Mechanical Mount → visible dark spots → lower reflectivity
- 0 transparency. Dark spots may be visible under higher light intensity, not contradicted with condition of low light intensity from monochromator.

Coating 49(6kA Cr, 24kA Al, the thickest coating)

- Thickest coating
- No dark spot → similar in coating 47
- The contamination spots are no much different than Lexan-only but create some spread from 500 to 700 nm range.
- The M3(in green) is noticeably lower with worst contaminations.





Expected: Thick coating reduces reflectivity

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Coating 49(6kA Cr, 24kA Al, the thickest coating)

Same dark spots at mechanical mount.

Coating 49 Conclusion:

- No dark spot at such thick coating in front side. Reflectivity with high consistency among all mirrors in this batch beside mirror 3 which has the most contaminations .
- Lots of contaminations→ Substrate quality control.
- However, the maximum reflectivity is only 85%, which indicates that we have exceeded the range where the maximum reflectivity can occur.

Plans for Future:

- Balanced coating thickness: eliminates dark spots while maximizing reflectivity
- Stable and good quality control of mirror substrates
- Mechanical mount/stress adjustment

Current established on dark spots:

- Dark spots are thinner coating.
- Dark spots not dependent on epoxy types.
- Dark spots correlate strongly with epoxy-backed regions.
- Dark spots correlate strongly with mechanical interaction interface.
- Thicker aluminum coatings reduce very much but do not entirely eliminate the reflectivity gap between epoxy(dark spots) and non-epoxy areas.
- Transmission = 0, is not a factor in reflectivity drop under low light intensity.
- Substrate quality control

Current theory:
glue/epoxy/stress/substrate quality → unknown interactions with lexan(likely some thermal property) → dark spots → low reflectivity

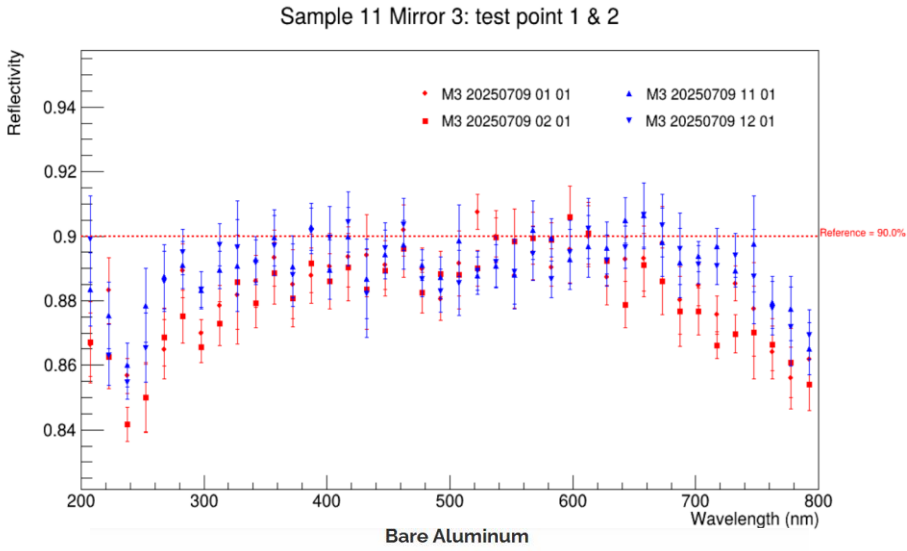
System Change: 200-800 nm scan

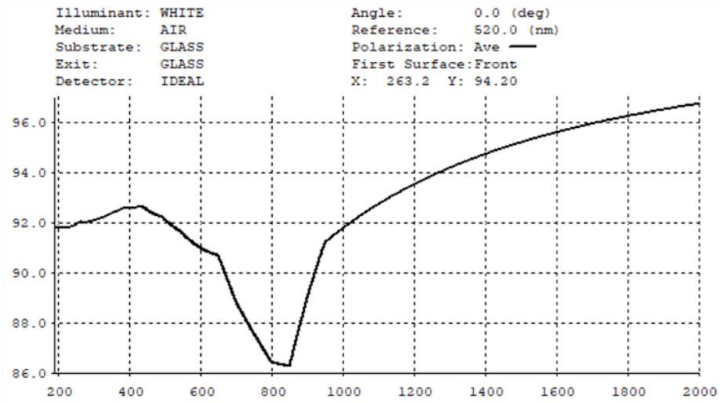
After coating 46, we interested in the reflective performance in the infrared region, so I upgraded the scanning range from 200-600 nm to 200-800 nm.

New references for 800 nm tested with Sample 11 mirror 3

- Two test points; Each test points was measured twice.
- Generally speaking, the reflectivity starts to drop at around 600 nm. The dropping phenomenon is consistent with professionally manufactured mirrors.

Due to interband transitions, where photon energy is being absorbed by electrons to jump to a higher energy level instead of being reflected.
https://www.osti.gov/servlets/purl/15005391





Professional Al coated mirror reflectivity vs wavelength curve(200 m to 2000 nm):
https://www.advancedoptics.com/optical-coating-data-unprotected-bare.html

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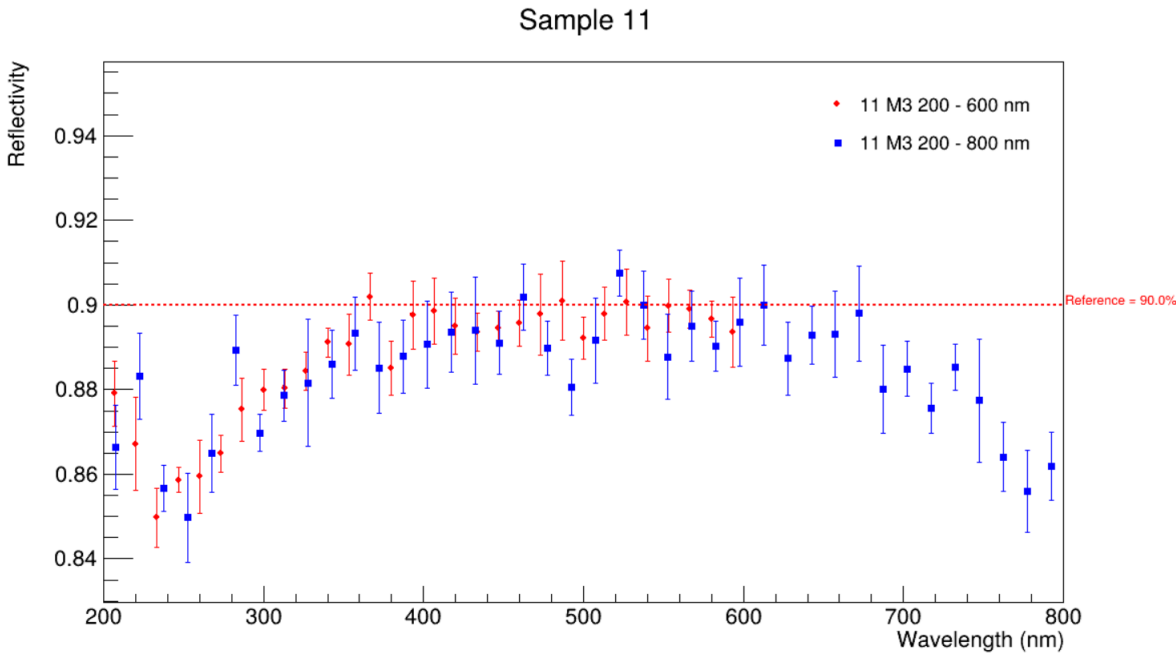
System updated to scan 200 to 800 nm

- New references for 800 nm
- Verified by mirror 3 of coating 11



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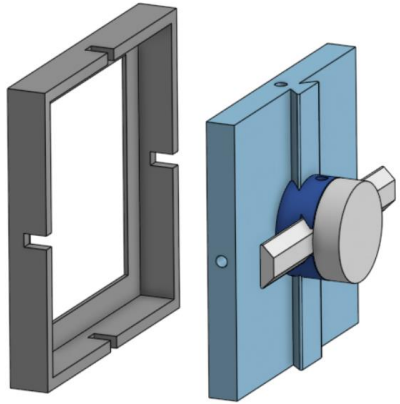
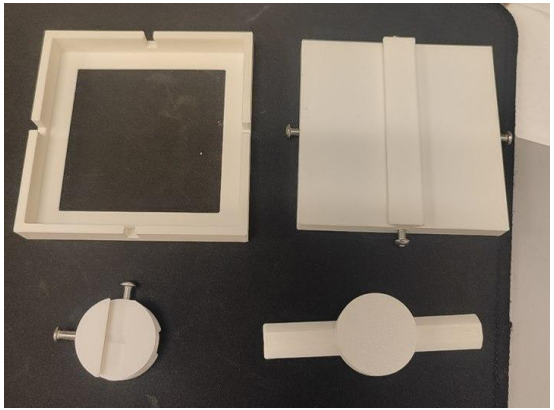
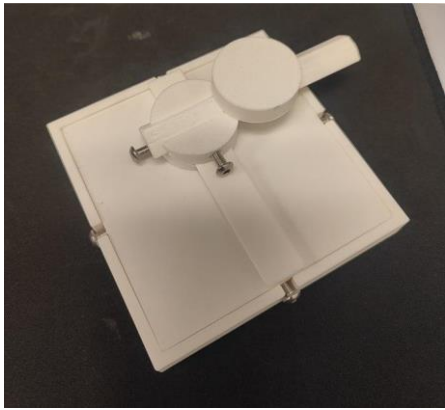
System Hardware Updates

I had some time to finalize the design of my new test stand holder. Unlike the old holder, this new mount can move the mirror sample in the X-Y plane to measure different points on the mirror surface easily, for example a dark spots at the corner.



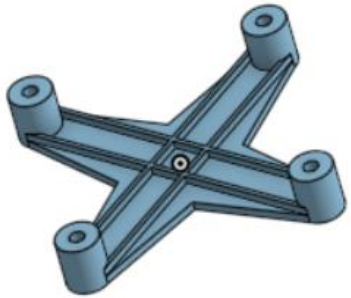




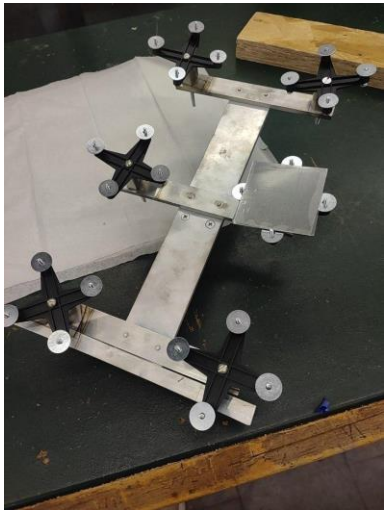
Day 37 7/22

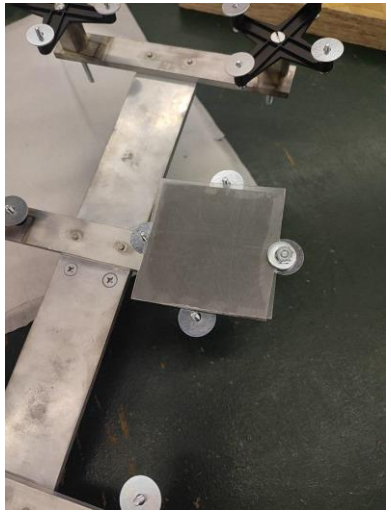
Plans for future coating

In our theory, “stress” is one of the factor from “dark spot at where the mirror is press and attach on the frame”, in order to conduct a variable controlled experiment, we want this factor to exclude from our testing. Therefore, I made a mirror holder that may prevent any external pressure when attaching and removing the mirror from the frame.



3D printed





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