LIGO

Point Absorber Update NSF Review June 2022

A. Ananyeva, S. Appert,
G. Billingsley,
A. Brooks, P. Fritschel, S. Gras,
M. Kasprzack, K. Kuns, L. Zhang

Addressing Charge 2.D

2. Commissioning and interferometer performance enhancements

d. Review and comment on progress to develop low absorption coatings and to mitigate challenges of operating at higher laser power during Observing Run 4.

Absorber Summary

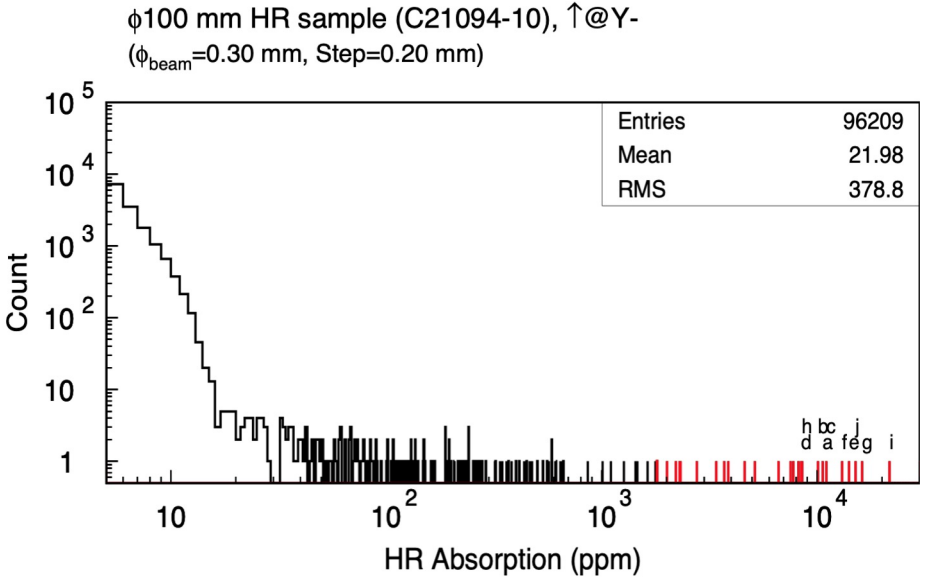
- **Installed ETM** - 4 of 4 installed have point absorbers
  - 1 or 2 at LLO to be replaced this quarter
  - No replacement planned at LHO

- **Installed ITM** - 1 of 4 installed have point absorbers
  - New absorbers since original scan - did we cause?

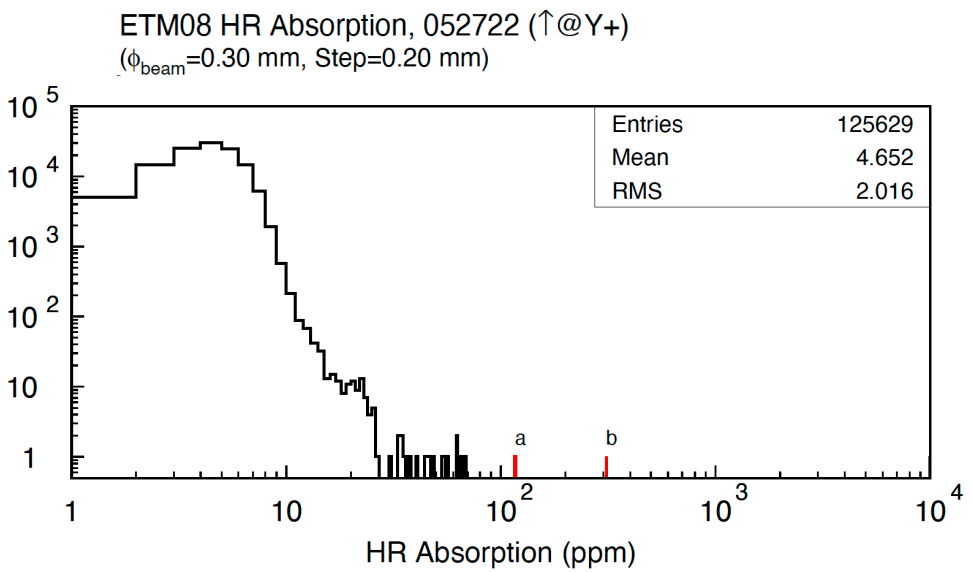
- **Reworked ETM** - 4 of 4 have been re-coated
  - 1 of 4 characterized so far
    - found 2 point absorbers, these are small enough the part is useable

A noticeable improvement in the chamber

Foil covering sandblasted surfaces

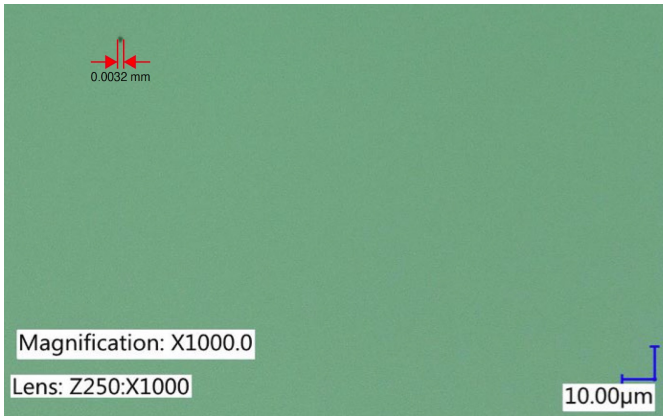


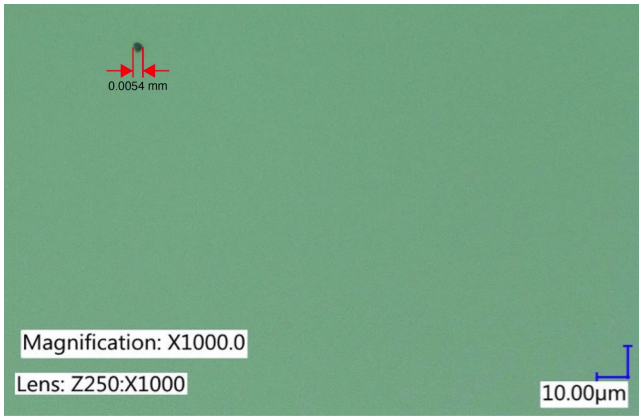
No sandblasted surfaces



First Result is “good enough” – ETM08

- 2 PA found on RTS using gentle absorption on 80 mm ø
  a. ⌀ **3.2 µm**, r = 24 mm
  b. ⌀ **5.4 µm**, r = 25 mm
- Max allowed ”equivalent diameter” 12.6 µm
  - Assumes 100% absorption by defect





* An 80 mm diameter scan takes 11 days

Causes

- During coating
  - Coating chamber panels are sandblasted and difficult to clean, may shed during coating T2200351
  - Possible Re-sputtering from the coating chamber optic mount, coating mask or shutter
- In situ
  - First contact fragments from cleaning T2000526
  - Exploding dust - we suspect this is minimal E1400010

Identification

- Photo-thermal Common-path Interferometry (PCI) absorption tests - Zhang, Catalog at T2000055, E2000079
  - Use “gentle absorption” technique, high noise floor, but no risk of damage
  - Very sensitive, absolute calibration is unknown for point absorbers
  - 11 days to scan 80 mm diameter
- Hartmann Wavefront Sensor (HWS) - Brooks G2200064
  - Deployed at the observatories to monitor change in radius of curvature due to background absorption
  - Commissioning a dedicated HWS at Caltech for incoming point detection inspection
- Material imaging and ID - Appert/Kuns/Gras/Gomez/Kasprzak, Catalog at T2000733

Mitigation

- Prevention
  - Chamber cleaning - Ananyeva T2100351
  - Masking parts near the optic with clean or new material each run
- Ablation
  - Demonstrated removal of defects by ablation - Fritschel G2001414 T2100216
    - Residual absorption caused by ablation on clean coatings can be mitigated by annealing in air at 300 C° E2000107
    - Remaining residual absorption of ablated or partially ablated points, improving with annealing, work is ongoing E2100395
- Mirror surface profile change
  - Altered from spherical to increase loss for high order modes G2001920 and G2001747

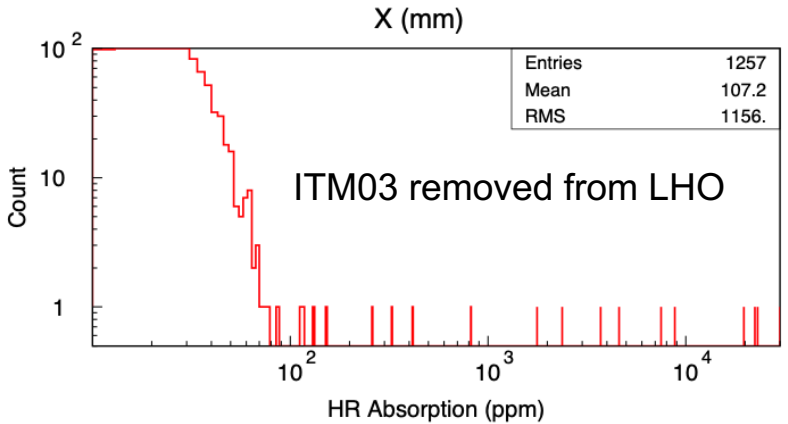
Eliminating PA sources at the Coater

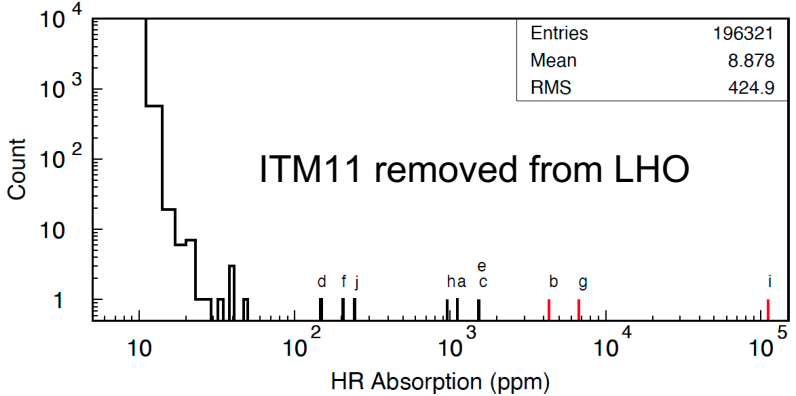
T2000055 Catalog of witness samples measured

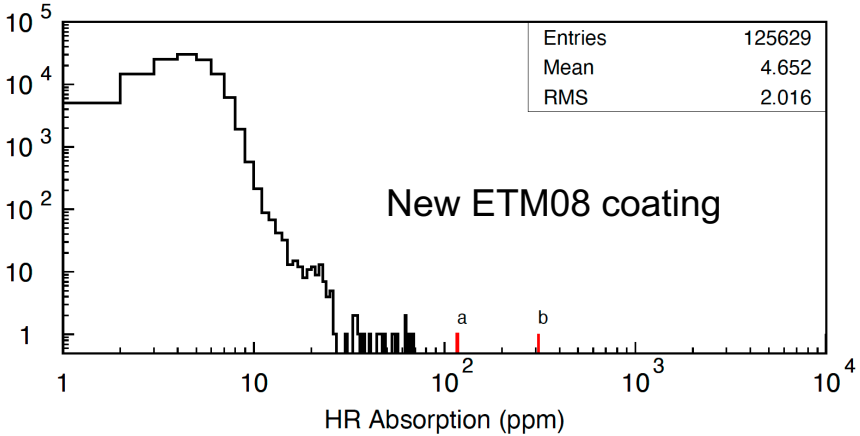
- Early focus was on elimination of re-sputtering sources near the optic
  - Change mask and shutter material from Aluminum to Titanium
  - Change optic holder to Titanium, or add Fused Silica shield
- Sandblasted panels and tooling found as a significant source of particulate
  - All sandblasted material removed, deep clean of the chamber, electropolish mask and optic holder to remove deposited coating materials.
- Even with extensive cleaning the surfaces are friable.

Reference Slides

Compare Known Problem Absorbers to New Coating





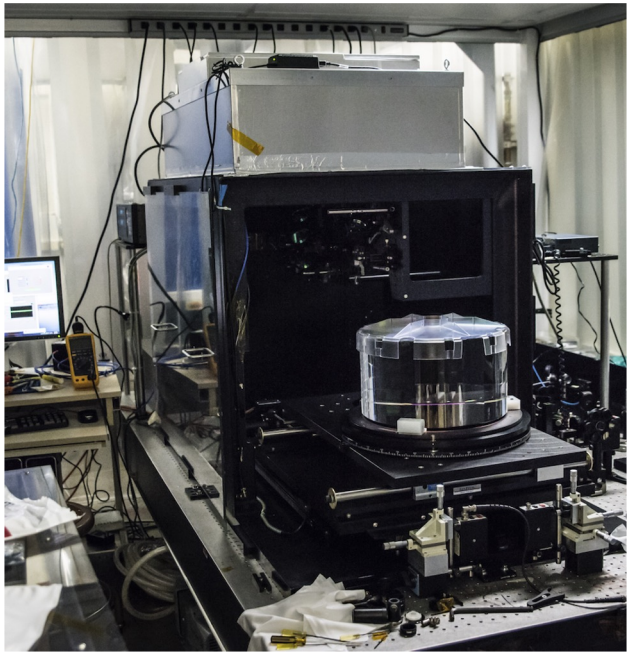


Screening

Schedule pressure on RTS, New scanner to add capacity and cross check results

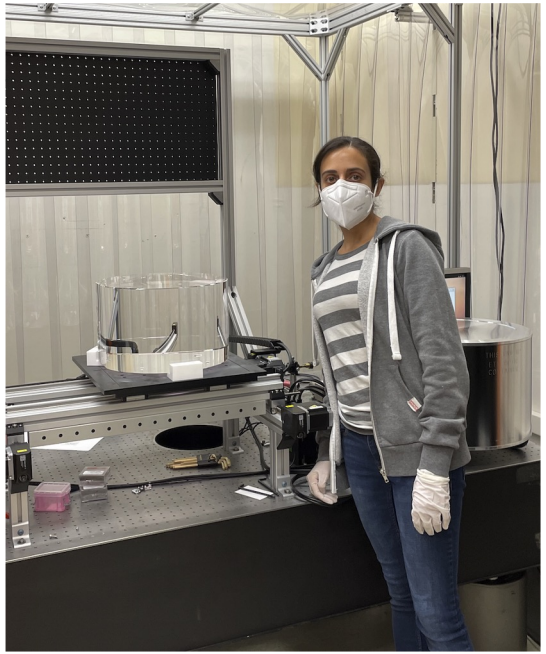
“RTS” Scanner

Reflection Transmission Scatter Absorption



Hartmann Scanner

Point absorbers



Ablation

- MIT collaboration with vendor specializing in laser micro-machining (*top right*).
  - Ablation of ~10 features across 3 visits
  - Most recent effort (November 2021):
    - 7 ablated features on 2 optics
    - All features remained absorptive afterwards
      - more pulses should do the trick in the future

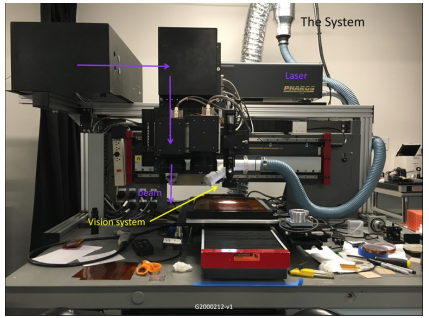
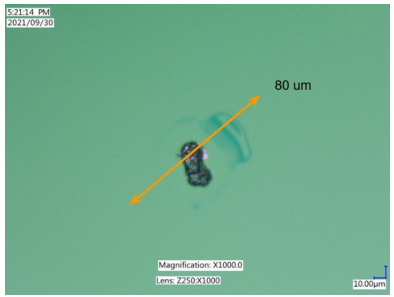
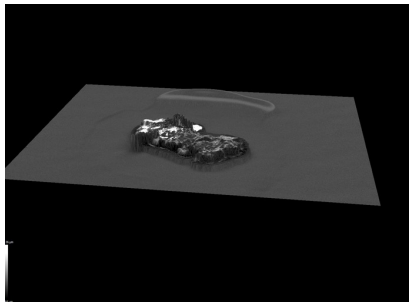


Image from G2000212-v1, credit Fritschel et. al.

CIT Feature ID and Location



3D Mapping Before Ablation



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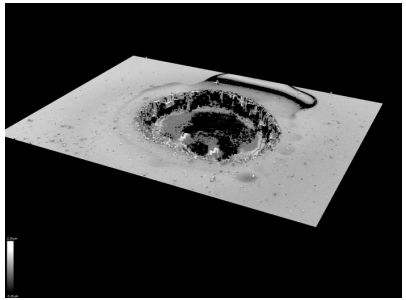
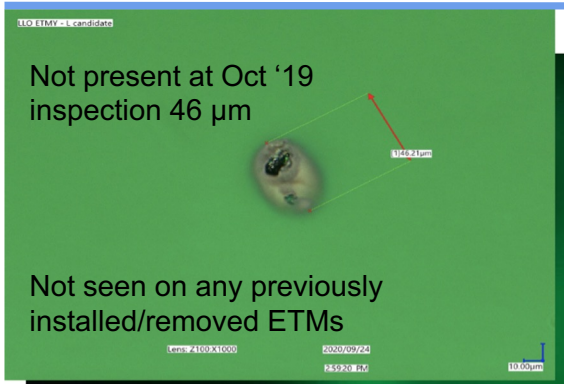
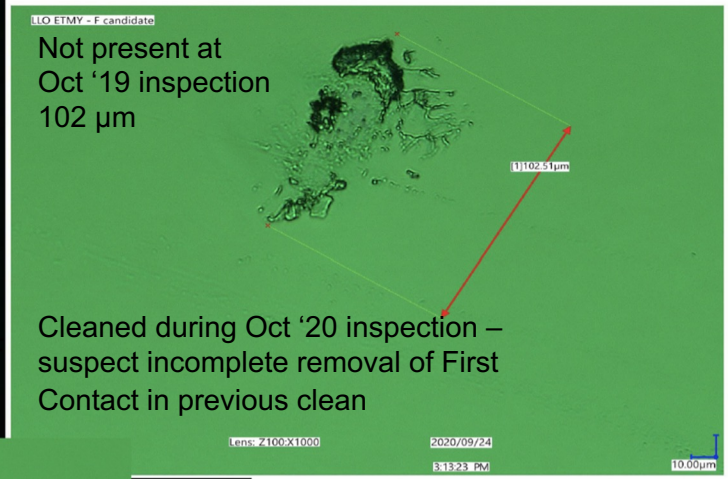


Images from E2100466 –v2, credit Fritschel et. al.

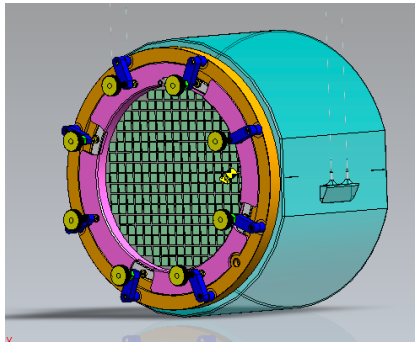
Livingston ETM In-Chamber Inspection

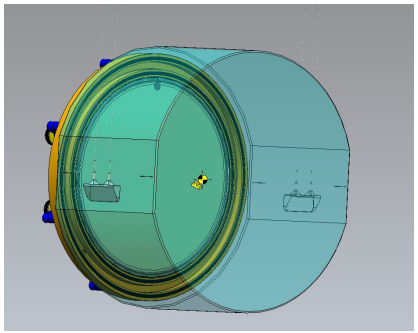




L1 ETMy Alog [Source]

Improved cleaning





Vertical pour of First Contact
Thicker layer = better cleaning
Better layer removal

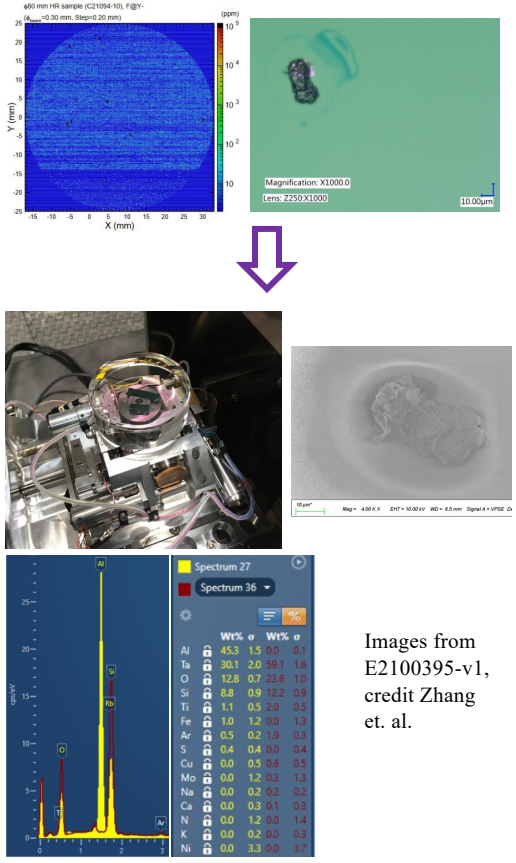
LIGO-G2200853

ETM Inventory – 14 total including A+

- 4 re-worked ETMs coated
- Zygo is under contract to polish
  - 2 more on OPS funding
  - 4 more ETMs for A+ on UK funding
  - 2 more ETMs for A+ on US funding
- We hold 2 optics for India (ETM11/ETM14) that have point absorbers found with RTS

Investigating the Composition of Absorbers: Workflow

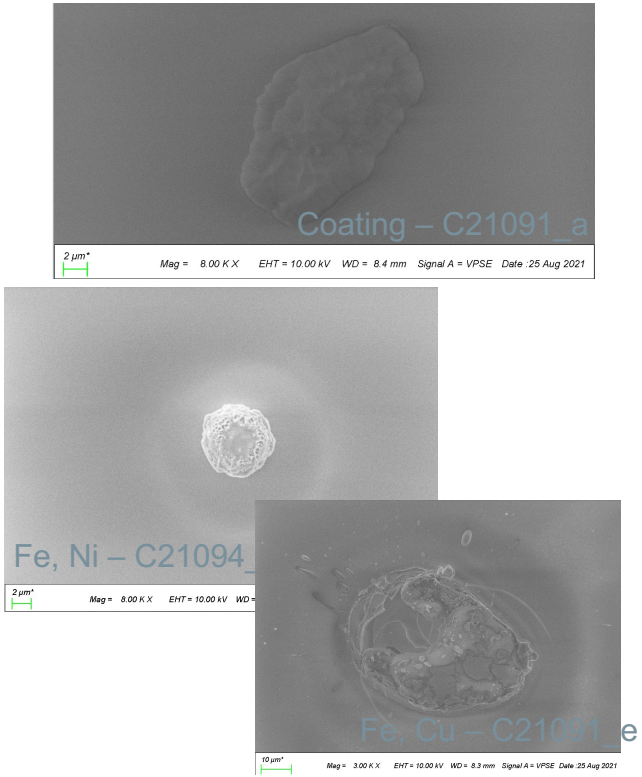
- Composition investigations have been a primary focus of CIT and MIT Lab efforts since 2020.
  - COC cataloged witness samples, traceable to LIGO coating runs.
  - CIT absorption measurements locate absorbing features (*top right*).
    - >30 aLIGO witness samples, >100 samples total – more statistics at T1900340
  - Energy Dispersive Spectroscopy (EDS) used to conduct elemental analysis (*bottom right*).
    - Scanning Electron Microscope (SEM) facilities at MIT and CIT.
    - MIT has used FIB to section some features, a technique with the highest certainty.



Images from E2100395-v1, credit Zhang et. al.

Composition

- Composition has been investigated for features on 15+ optics from a wide range of coating runs.
  - Cataloged at T2000733
- Many absorbers are Aluminum, many have Carbon, and we have also seen Titanium, Copper, Iron, Nickel.
- Many absorbers appear to have compositions similar to coating layers.



Images from T2000733, credit Appert