Stray light control upgrades for LIGO 4th Observation run

Alena Ananyeva on behalf of LIGO stray light team

- Baffles materials currently used at LIGO
- Overall baffles design methods we use (raytracing, CAD imaging, apertures rules, damping)
- What`s new for O4
Baffle material research since 2017 (LIGO O2 and later)

- Oxidized Stainless Steel (super #8)
- Black Glass
- AR coated Black Glass (broad band coating)
- Diamond-like Carbon on stainless steel mill finish
- Black Nickel on stainless steel mill finish
- Multi-layer AR (for 57 AOI) on SSTL (super #8)
- Chromium Oxide on stainless steel
- Diamond-like Carbon on Cr Oxide on SSTL
- “Black Nickel” on bead blasted SSTL
- Structural coating 1
- Structural coating 2
- Structural coating 3
- graphite paint on aluminum
- organic paint coating on aluminum

https://dcc.ligo.org/LIGO-G1700379
Diamond-like carbon on super#8 non-directional SSTL 304

Measurements were performed at Caltech using CASI scatter meter at 1064 nm

https://dcc.ligo.org/LIGO-T1700128/public
## Materials comparison: robustness and availability vs performance

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Handling</th>
<th>Price</th>
<th>Lowest BRDF 8° AOI</th>
<th>Lowest BRDF 57° AOI</th>
<th>Specular 8° AOI</th>
<th>Specular 57° AOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidized Stainless Steel (super #8)</td>
<td>🔺</td>
<td>$</td>
<td>$9 \times 10^{-3}$</td>
<td>$9 \times 10^{-3}$</td>
<td>$5 \times 10^{-2}$</td>
<td>$1 \times 10^{-1}$</td>
</tr>
<tr>
<td>Black Glass</td>
<td></td>
<td>$$</td>
<td>$3 \times 10^{-5}$</td>
<td>$1 \times 10^{-5}$</td>
<td>$5 \times 10^{-1}$</td>
<td>$2 \times 10^{-4}$</td>
</tr>
<tr>
<td>AR coated Black Glass (broad band coating)</td>
<td></td>
<td>$$$</td>
<td>$2 \times 10^{-5}$</td>
<td>$1 \times 10^{-5}$</td>
<td>$3 \times 10^{-2}$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Diamond-like Carbon on stainless steel mill finish</td>
<td></td>
<td>✔</td>
<td>$1 \times 10^{-3}$</td>
<td>$1 \times 10^{-3}$</td>
<td>$2 \times 10^{-2}$</td>
<td>$1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Black Nickel on stainless steel mill finish</td>
<td></td>
<td>$</td>
<td>$2 \times 10^{-4}$</td>
<td></td>
<td>$3 \times 10^{-2}$</td>
<td></td>
</tr>
<tr>
<td>Multi-layer AR (for 57 AOI) on SSTL (super #8)</td>
<td></td>
<td>✔</td>
<td>$1 \times 10^{-4}$</td>
<td>$1 \times 10^{-5}$</td>
<td>$1 \times 10^{-1}$</td>
<td>$1 \times 10^{-2}$</td>
</tr>
<tr>
<td>Chromium Oxide on stainless steel</td>
<td></td>
<td>$$</td>
<td>$2 \times 10^{-2}$</td>
<td>$2 \times 10^{-2}$</td>
<td>$2 \times 10^{-5}$</td>
<td>$2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Diamond-like Carbon on Cr Oxide on SSTL</td>
<td></td>
<td>$$</td>
<td>$6 \times 10^{-2}$</td>
<td>$6 \times 10^{-2}$</td>
<td>$4 \times 10^{-6}$</td>
<td>$1 \times 10^{-6}$</td>
</tr>
<tr>
<td>“Black Nickel” on bead blasted SSTL</td>
<td>✔</td>
<td>$</td>
<td>$7 \times 10^{-4}$</td>
<td>$5 \times 10^{-4}$</td>
<td>$8 \times 10^{-5}$</td>
<td>$8 \times 10^{-6}$</td>
</tr>
<tr>
<td>Structural coating 1</td>
<td></td>
<td>$$$$</td>
<td>$1 \times 10^{-2}$</td>
<td>$1 \times 10^{-2}$</td>
<td>$5 \times 10^{-6}$</td>
<td>$2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Structural coating 2</td>
<td></td>
<td>$$$$$</td>
<td>$1 \times 10^{-2}$</td>
<td>$1 \times 10^{-2}$</td>
<td>$5 \times 10^{-6}$</td>
<td>$2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Structural coating 3</td>
<td></td>
<td>$$$$$</td>
<td>$9 \times 10^{-4}$</td>
<td>$1 \times 10^{-3}$</td>
<td>$2 \times 10^{-6}$</td>
<td>$2 \times 10^{-7}$</td>
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<tr>
<td>Graphite paint on aluminum</td>
<td>✔</td>
<td>$</td>
<td>$1 \times 10^{-2}$</td>
<td>$1 \times 10^{-2}$</td>
<td>$2 \times 10^{-4}$</td>
<td>$5 \times 10^{-5}$</td>
</tr>
<tr>
<td>Organic paint coating on aluminum</td>
<td></td>
<td>$</td>
<td>$5 \times 10^{-3}$</td>
<td>$5 \times 10^{-3}$</td>
<td>$5 \times 10^{-6}$</td>
<td>$2 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

- 🔺: Robust
- $$: Brittle/delicate
- 🛠️: Handling only with special tooling
IR absorbing low scatter coatings chooses vs oxidized SSTL

- Oxidized Stainless Steel (super #8)
- Black Glass
- AR coated Black Glass (low AOI coating)
- DLC on Super#8 large parts (like p-cal baffles)
- DLC on Super#8 medium size parts (SUS baffles)
- Black Nickel on Super#8

P.S. All of the new coatings are much more uniform compared to oxidized SSTL

Multi bounce approach is an option instead of AR coating!
O2&O3 baffles made with new coatings!
Mounts and hardware are successfully coated with DLC and black nickel!

Pliable 1145-0 Al coil (thick foil 0.003”) is considered for wrapping objects in-situ

LIGO-T2000608
Laser Damage investigations of 1064 nm absorbing materials in vacuum
A. Ananyeva, D. Coyne, C. Torrie, E. Sanchez
G1800420

At around 0.3 W/mm² uncoated and coated black glass started to melt and to break. Cracks occurred in a similar pattern which was presumably defined by the method the sample was mounted on the holder’s plate.

The DLC sample has been irradiated using the same pattern as black glass at first which did not result in any damage. Then the power range was increased. The picture on the left shows the sample surface after irradiation. Ten points have been irradiated with power density of 0.30, 0.63, 1.46, 2.10, 2.86, 3.61, 4.33, 5.04, 5.76, 6.48 W/mm². At around 5.04 W/mm² (31.8 W total power) darkening of the coating was observed. Discoloration of the coating started to occur at 6.48 W/mm². No coating cracking or peeling off could be observed.

Silicon and sintered carbide samples were first irradiated with low power levels equivalent to those used on the previous black glass and DLC samples. None of the two runs resulted in damage. The figures on the left show surfaces of the samples after irradiation at ten points at incremental power densities up to 1102 W/mm². Silicon started to damage at 371.13 (19 W total power) and silicon carbide at 798.97 W/mm² (37.05 W total power). The samples did not crack or break.

Laser damage threshold of the five materials was evaluated against their optical properties at 1064 nm. Sintered silicon carbide has the highest laser damage threshold but also very high scatter due to high porosity of the surface. It is recommended to be used only at the areas with power densities higher than 100 W/mm² and only for "V"-type of beam dump. Silicon is recommended to be used instead in high power areas. For dumping beam with up to 1 W/mm² DLC coated polished SSTL is more preferable due to lower reflectivity and lower cost. DLC coating is also very durable and easy to handle. Black glass is recommended to be used only for close to normal incidence situations when reflectivity is important and only below 0.1 W/mm² power density. In this case an AR coating is required.

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost</th>
<th>Lead time for 20 beam dumps</th>
<th>Reflectivity at 67° deg A01</th>
<th>BRDF lbs</th>
<th>Laser Damage Threshold W/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black glass uncoated</td>
<td>$$</td>
<td>&lt; 2 weeks</td>
<td>~4%</td>
<td>~2×10⁻³</td>
<td>0.24 ~ 0.30</td>
</tr>
<tr>
<td>DLC coated SSTL</td>
<td>$$</td>
<td>2-3 weeks</td>
<td>~6%</td>
<td>~2×10⁻³</td>
<td>4.33 ~ 5.04</td>
</tr>
<tr>
<td>Silicon</td>
<td>$$$</td>
<td>3-4 weeks</td>
<td>~10%</td>
<td>~6×10⁻³</td>
<td>249.20 to 371.13</td>
</tr>
<tr>
<td>Sintered SiC</td>
<td>$$$</td>
<td>4-5 weeks</td>
<td>Diffuse</td>
<td>High</td>
<td>615.02 to 736.97</td>
</tr>
</tbody>
</table>

Poster LVC 2018
LIGO-G1800420
Aperture Size

The aperture is usually defined as 20w of the beam or as large as the optic (for large beams). Hardware within the aperture needs to be covered or coated.

Coated crew cap
Viton o-ring

LIGO-D1700232
Zemax model of A+ configuration of LIGO

The model is used for beam preparation, ghost beams hunting and other stray light analysis. The beams can be exported as a step file and added to the solid works model which helps to position baffles apertures, check for beam clippings and etc.

Tree structure Zemax model of the interferometer: (slide ref LIGO-T2000240). How to use the model LIGO-E2000223.
O2 baffles scope

LIGO-D1700361
A+ baffles scope and more

- Baffles in new chambers: HAM7 and HAM8
- Filter Cavity baffles
- Baffles for the new OFI in HAM5
- Other baffles in areas identified by commissioning
A+ baffles: filter cavity baffles

Danielle Petterson - FDR slides LIGO-E2000443

Final FC Tube Baffles Layout

- Baffle positionings checked against most updated version of FC Tube Layout [D1900456] shown on the right
- Total Number of Baffles (red dots) = 49
  - Full coverage
  - FC Entry Nozzle Baffles [D2000223] in the HAM7/8 doors replaced the first and last FC Tube baffles at either end of the tube
- Not all sections of tube will have a baffle
  - Baffles are to placed in 32 of the 48 tube sections
- All baffles are installed within 20° from the end of a section of tube
  - Details on baffle placements per section of tube on next 2 slides

FC-D

Left: 45° baffle - scatter ray retro-reflects back to the optic
Right: 35° baffle - scatter ray from near optic does not retro-reflect; scatter ray from far optic is trapped
A+ baffles: filter cavity baffles

With original configuration of beam tube section

After splitting some tube sections to add baffles

CAD camera view from FC1 to FC2 – tube baffles coverage check. Left: an area of the beam tube still exposed to optic, right: full coverage after splitting a tube section into 2 segments to allow additional baffles placement
A+ baffles: assembly and mounting

FC tube baffles consist of a mounting ring and a cone made of super#8 SSTL formed and black Ni coated. The mounting ring acts as a spring to provide damping.

Filter cavity tube baffle fit check in a tube section: near optic view

HAM7 and HAM8 baffles: Back scatter from the nozzle baffle: 10 conical nozzle baffle

Even less scatter returns from the baffle to FC2 if the nozzle baffle is same as the cone part of FC tube baffles

*back scatter will be lower as well
HAM7 and HAM8 baffles: Back scatter from the nozzle baffle: 10 deg nozzle baffle yaw

No specular reflection from the baffle returns to FC2 but some scatter does
HAM7 and HAM8 baffles: CAD model

Multi layers baffles concept is used to allow relaxed baffles apertures:
- baffles on the structure to dump low angle scatter from the far optic
- Baffle on the table to provide second layer for scatter absorption
- Vertical baffle on the table covers the chamber’s door
- Nozzle baffle covers what table baffle could not cover

FDR slides [https://dcc.ligo.org/LIGO-E2000441](https://dcc.ligo.org/LIGO-E2000441)

SW model borrowed from slide 35 CDR [E2000177](https://dcc.ligo.org/LIGO-E2000177)

CAD camera view from FC2 toward FC1
Squeezer path to HAM5: baffles for each ZM optics and coated HDS structures

ZM6 in HAM5: tricky AOI and required 20w clearance [LIGO-G2100885]

CAD camera view of ZM6 from OFI: A new type of baffles with in and out apertures due to high AOI. This example shows how “stay clear zones” are taken into account.
A+ OFI ghost beams and baffles apertures LIGO-T2000598-v5

As per the A+ OFI optical layout LIGO-D1900487, rejected S polarization from OMC can clip on the aperture of SRM HR baffle if not dumped on OFI shroud input panels or SRM AR
A+ OFI shroud and surrounding baffles in HAM5

Some of the OFI ghost beams propagate outside of the OFI shroud and damped on other baffles to allow better separation.

Main beam - pink
Ghost beam - brown
S-pol for monitoring - green
CAD camera view from OFI to ZM6 (we are inside the shroud)

The CAD camera view helps to verify all apertures are round to the beam

Ghost beam - brown
S-pol for monitoring - green
A “wall baffle” in HAM5 and HAM6 to cover the septum plate separating 2 vacuum volumes

HAM5/6 septum is a known source of noise coupling
Nozzle baffles kit for view-ports  LIGO-D1800228

The kit consists of DLC coated super-polished SSTL plates with different apertures to be used with various view-ports (unused, camera or oplev view-ports)

Nozzle baffles kit: left – incoming inspection of the coated plates, top right – scatter observed on the surface of a view-port nozzle (seen as pink light), lower right – a nozzle baffle being installed at LLO.