Laser Damage investigations of 1064 nm absorbing materials in vacuum

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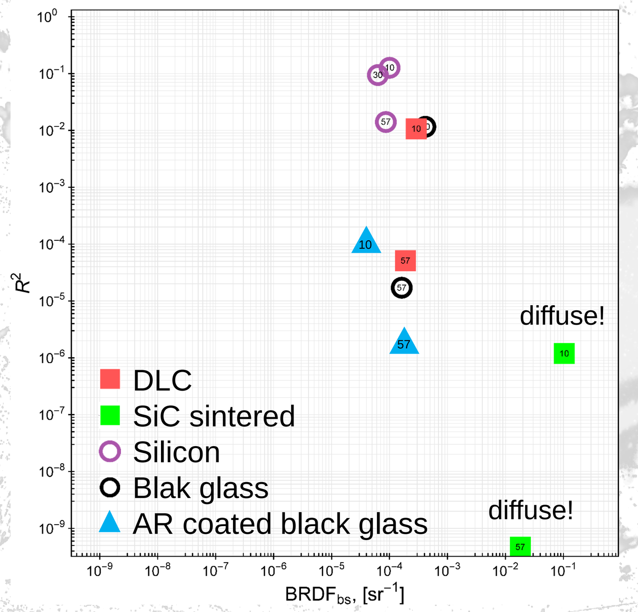
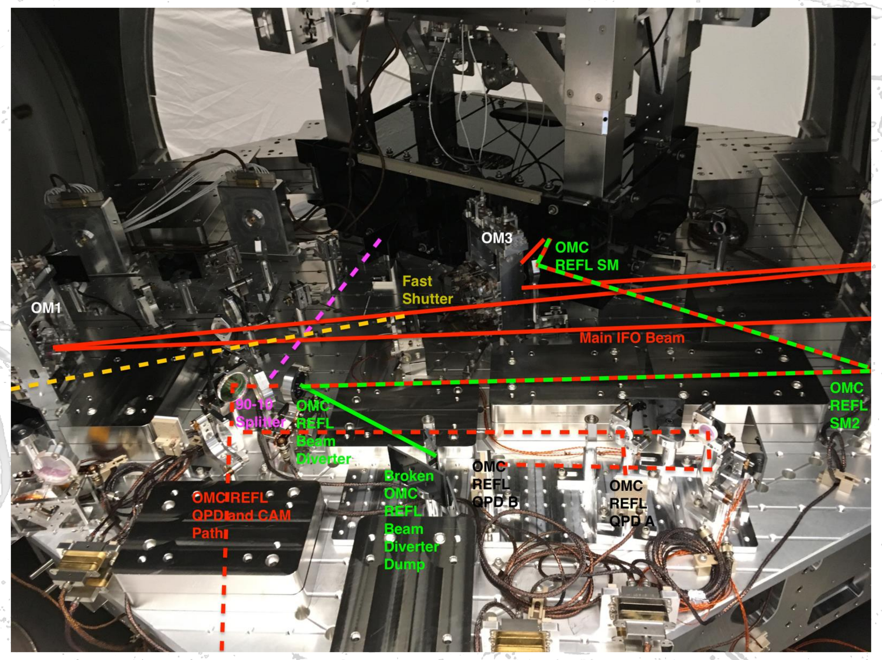
Motivation

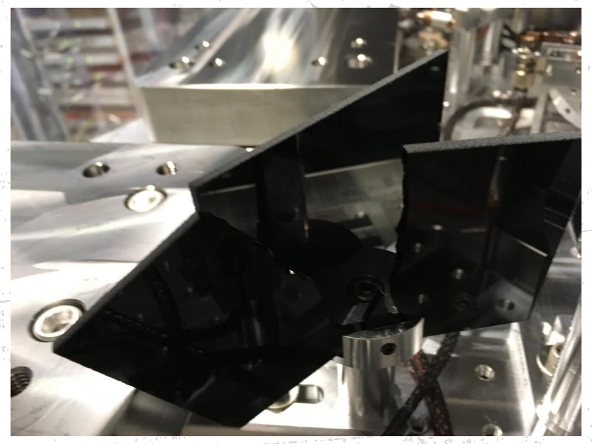
Laser damage of various IR black materials and coatings is being studied for building/upgrading beam dumps and stray light baffles for Laser Interferometer Gravitational-Wave Observatories. Requirements for these materials include:
- High damage threshold for CW 1064 nm. The exact value is defined by the power density for a certain application:
- Reflectivity (1064 nm) below 15% at normal
- BRDF back scatter below 10^{-2}
- Vacuum compatibility (for most applications) and robustness
- Availability: price, lead time, etc.

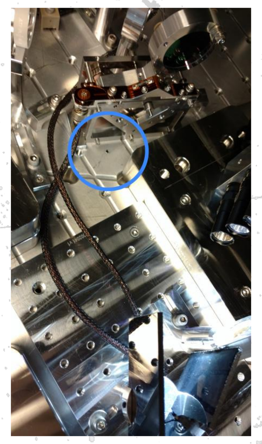


BRDFbs vs reflectivity squared

Currently black glass is used for building beam dumps at LIGO. Reflectivity of AR coated black glass is as low as 0.03% at close to normal incidence and reflectivity of uncoated black glass is below 5% at Brewster's angle. LIGO black glass is polished which provides extremely low BRDF back scatter (BRDFbs) value, ≤ 10^4 [1]. However, due to it`s fragility, black glass requires special handling and mounting. When damaged by a laser, black glass may break from overheating and cause scattered light and contamination issues. A few black glass damage incidents have been already reported at LIGO [2]. Currently LIGO is in the stage of increasing laser power which is another reason to start looking for alternative materials.







Broken black glass beam dumped due to overheating by the laser

Laser Damage Facility (LDF) at Caltech

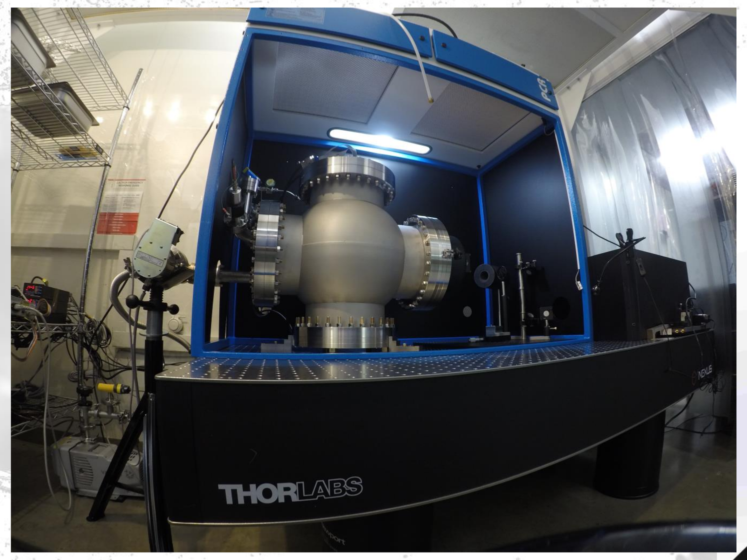
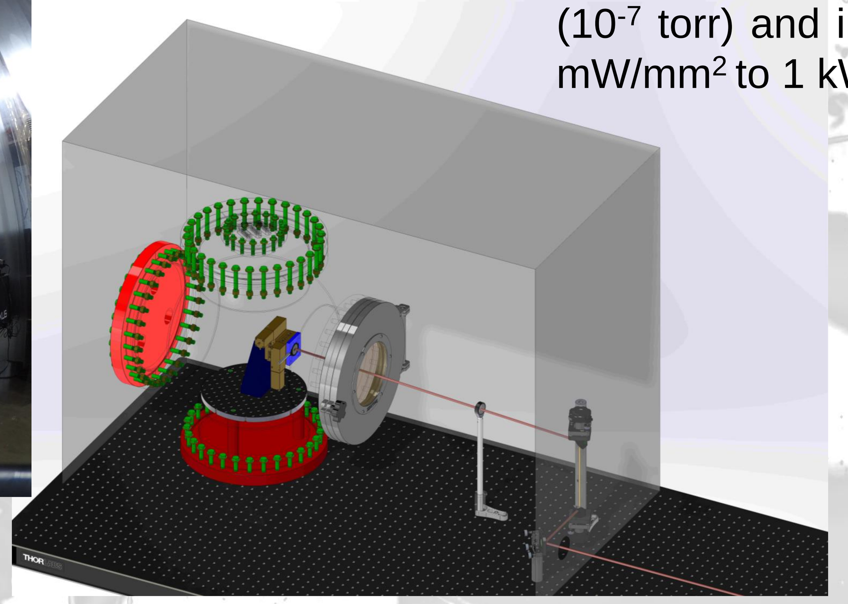


Photo of LDF at Caltech



SolidWorks 3D model of LDF

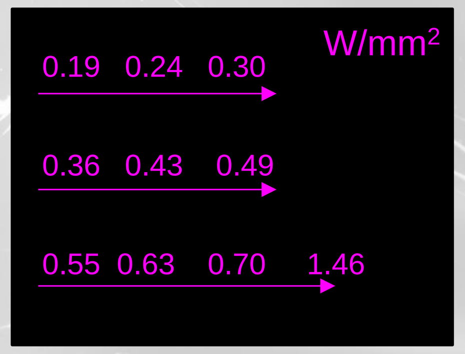
Laser Damage Facility at LIGO CIT provides a capability for in-vacuum (10^{-7} torr) and in-air destructive testing in a wide power range from 50 mW/mm² to 1 kW/mm² (1064 nm CW laser), up to 50W total power

- Target: optics, various materials/coating samples, Photodiodes, contamination control samples etc … (up to 5"×5" size)
- XY target translation ±10 mm, raster scans
- Clean vertical flow cabinet (class 10 ISO)
- GigE and a web cam live streaming
- Anodized Al safety walls
- Nikon Scanning Darkfield microscope

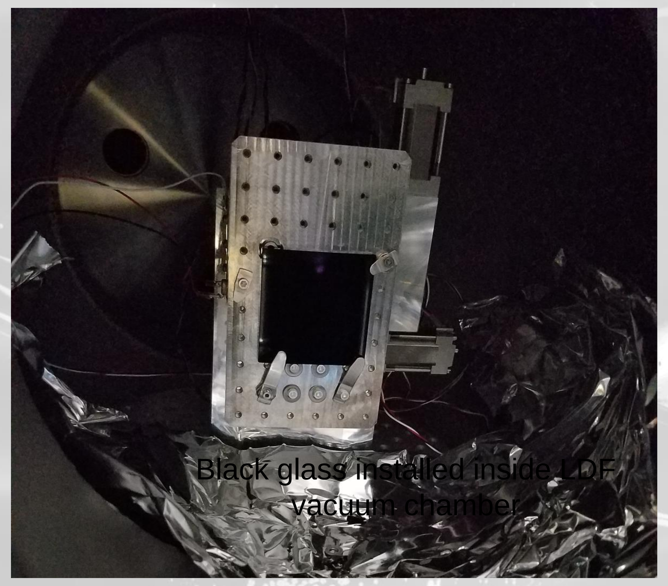
Experiment

In the present work five different materials were studied:

1) Uncoated black glass 2"×2"×0.125" (S1700633)
2) AR coated black glass 2"×2" ×0.125" (S1700635)
3) Diamond-like carbon coated (DLC) mirror-like polished non-directional SSTL 304 2"× 2"×0.05" thick (S1800001)
4) "Laser quality polished" silicon 3.63"×1"×0.120" (S1800012)
5) Sintered silicon carbide 2"×4"×0.125" (S1700637)



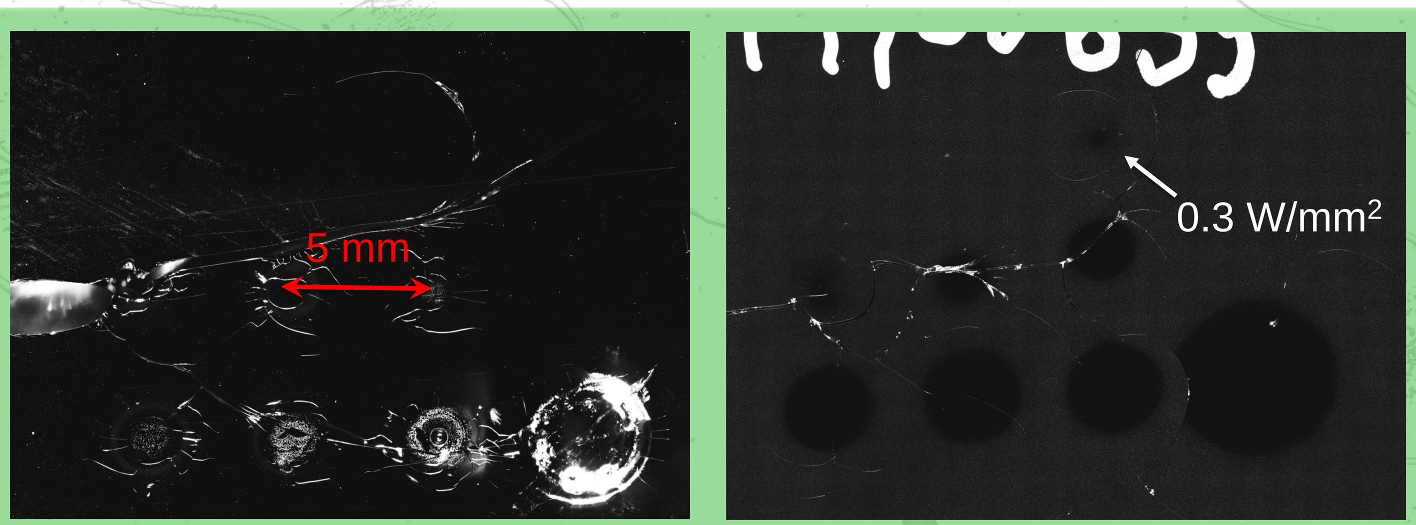
Irradiation pattern



Black glass installed inside the vacuum chamber

Each sample was irradiated for 5 min per point in order to allow the sample to reach a stable temperature [3]. Ten unique point per sample were irradiated at increasing power levels using a 2D translation stage. If no damage occurred, higher power range was applied across the same pattern. Figures on the right shows black glass mounted on the translation stage and the scheme of irradiation pattern. Every sample was top-gunned with clean nitrogen prior to irradiation. Losses in the fused silica viewport were taken into account for calculating equivalent power density. Samples were mounted using Al clips. To minimize the contact area two ¼-20 washers were added on the surface of the holder under the sample. Beam size for lower power density irradiation was 3.2×3.7 mm ellipse and 0.4×0.1 mm ellipse for higher power density runs on silicon and silicon carbide.

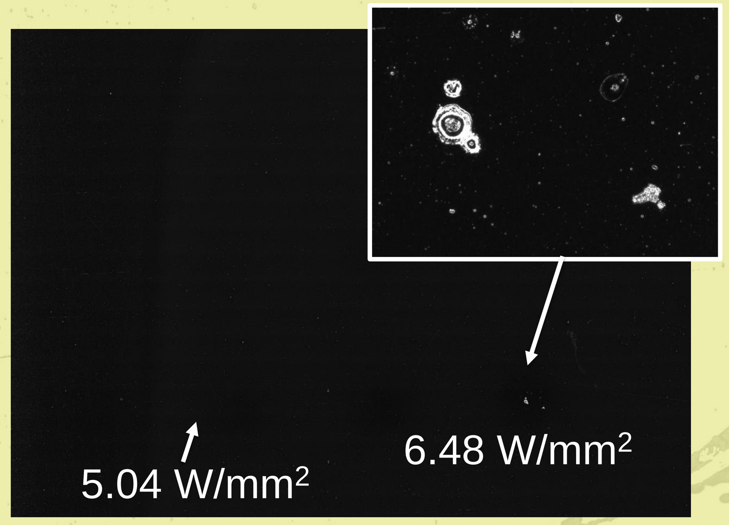
Results



AR coated blk glass sample S1700635 Uncoated black glass sample S1700633

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

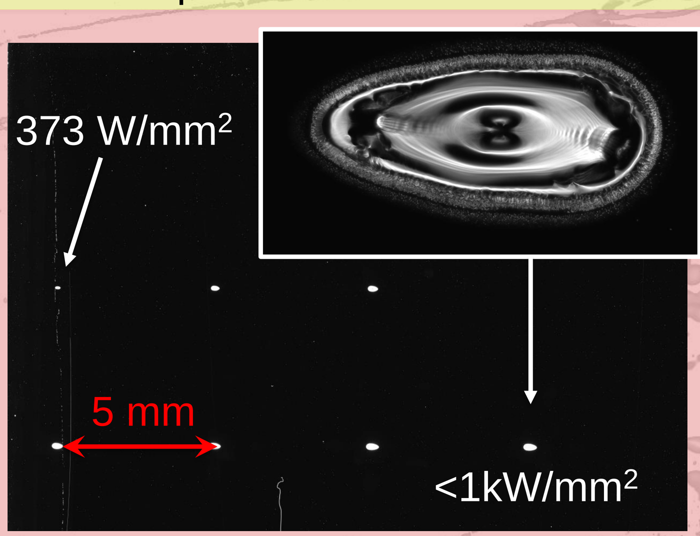
<1.5 W/mm²



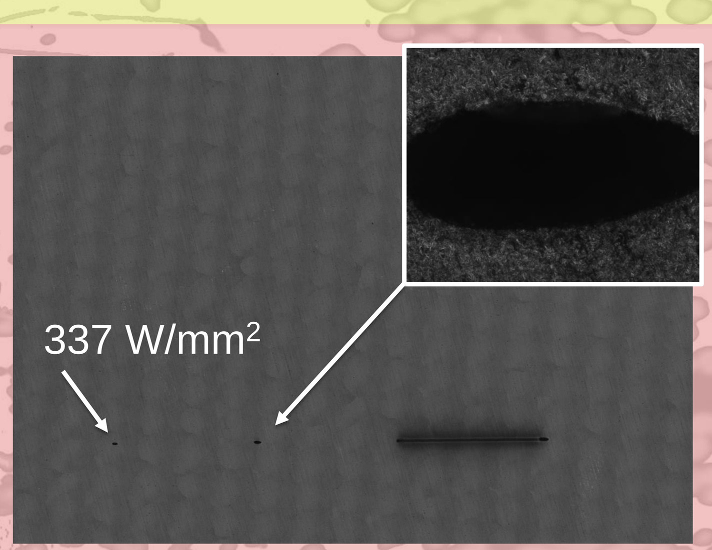
DLC sample S1800001

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, 2.18, 2.9, 3.61, 4.33, 5.04, 5.76, 6.48 W/mm² , 5 min per point. 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 pilling off could be observed.

<6.5 W/mm²



Silicon sample S1800012



Sintered silicon carbide S1700637

Silicon and silicon 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 1102.80 W/mm². Silicon started to damage at 371.13 (16 W total power) and silicon carbide at 736.97 W/mm² (37.05 W total power). The samples did not crack or break.

<1.1 kW/mm²

Conclusions

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 dumps. Silicon is recommended to be used instead in high power areas. For dumping beams 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.

Material	Cost	Lead time for 20 beam dumps	Reflectivity at 57° deg AOI	BRDFbs	Laser Damage Threshold W/mm²
Black glass uncoated	$$	< 2 weeks	~ 4%	~ 2×10^{-4}	0.24 - 0.30
DLC coated SSTL	$$	2-3 weeks	~ 6%	~ 2×10^{-4}	4.33 - 5.04
Silicon	$$$$	3-4 weeks	~ 10%	~ 8×10^{-5}	249.20 to 371.13
Sintered SiC	$$$	4-5 weeks	Diffuse	High	615.02 to 736.97

Up Next

- Adding pulsed laser option to the existing laser damage facility
- In vacuum laser induced damage test on mirror coatings with different contamination levels. Experiments on artificially dusted samples and witness samples removed from LIGO`s chambers are being planned. Testing more materials, coatings and photodiodes

References

[1] G1700379
[2] aLog LHO 38988
[3] T1700210