Scattered Light Measurements for Advanced LIGO's Output Mode-Cleaner Mirrors

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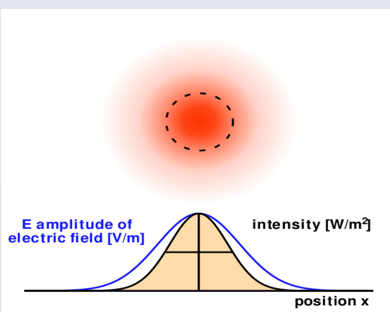
LIGO

Abstract

➢The Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO), with sites in Livingston LA and Hanford WA, and its international partners, Virgo, GEO600, and KAGRA, are being built to detect gravitational waves, a phenomenon theorized by Einstein in his Theory of General Relativity (GR). A direct prediction of GR, gravitational waves are ripples in space-time that propagate at the speed of light and are created by violent astrophysical processes. The gravitational-wave detectors are all based on the Michelson interferometer, which has an input laser, a beam splitter, and two perpendicular arms with mirrors at each end. However, their configurations have significantly more complexity to augment the sensitivity. Higher order spatial modes can create 'junk light' that decreases the shot-noise limited sensitivity of the detectors. To combat this, each LIGO detector has an Output Mode-Cleaner (OMC) at its detection 'dark port'. Scattered light from the OMC mirrors can reduce the shot-noise limited sensitivity of the instruments, and add noise via stray and counter-propagating light. Thus it is important that the light scattering from the OMC mirrors in Advanced LIGO be minimal. This poster will describe measurements of the scattered light from sample Advanced LIGO OMC mirrors.

What is an Output Mode-Cleaner?

➢ An output mode-cleaner is an optical cavity located at the output port of an interferometer. It is composed of multiple highly-reflecting mirrors, and is designed to be resonant for TEM_00 Gaussian spatial modes of laser light, and not resonant for higher order (n,m > 0) modes. The x-y cross-section of a TEM_00 mode for light that is propagating in the z-direction is circular, and has an exponential (Gaussian) decay of intensity from its center. Higher-order spatial modes increase shot noise on the output photodetector without adding signal, so it is important that they be filtered out by an OMC.



✧ This figure represents a TEM_00 Gaussian Spatial Mode along with a Gaussian curve. (Credit: Wikipedia/ FDominec)

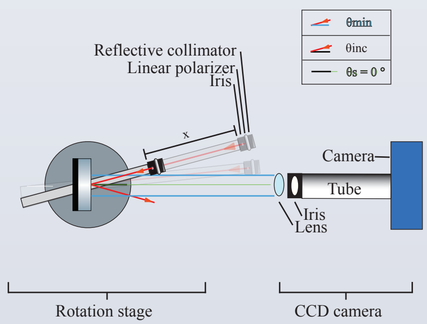
What is scattered light and why must it be reduced?

➢Scattering of light in optics occurs for a number of reasons; such as, surface roughness, and density fluctuations in the bulk material. These effects scatter the light particles onto the surface of the optic. Scattered light reduces the shot-noise limited sensitivity, and can cause non-linear noise by scattered light re-entering the main beam.

Materials and Methods

➢Used an imaging scatterometer to measure the light scattered from the surface of an output mode-cleaner optic. A 1064 nm laser beam is incident on the optic at an angle of four degrees. A lens and iris are used to form an image of the optical surface on a CCD camera. The rotation stage moves in one degree increments and the camera records a photo for each angle. These are processed in Matlab to extract the scattered power.

➢To observe the backscattering of the OMC mirror close to its specular reflection, the scatterometer was amended to allow measurements at scattering angles as small as four degrees.



✧The figure above shows both our scatterometer prior to change and, shown with a fading finish, the scatterometer with the amendment of moving back the iris, polarizer, and collimator back ~25cm to achieve an incident beam angle of 4 degrees.

➢A technique called "Drag Wiping" was used to reduce the scatter on the Output Mode-Cleaner. Drag wiping consists of lightly damping a cloth with methanol, which then is carefully applied onto the optic so that it sticks, and then dragged off the mirror.

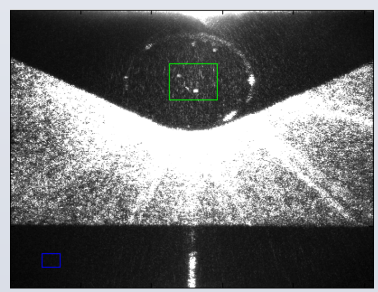
➢Scattering of light on an optic is measured by a function which takes the ratio between scattered power and incident power. This function is called the Bidirectional Reflectance Distribution Function or BRDF [1], where:

- P_s is the scattered power
- P_{inc} is the incident power
- Ω is the solid angle
- $\cos(\theta_s)$ is the cosine of the scattering angle

$$\mathrm{BRDF} = \frac{P_s}{P_{inc}\Omega\cos(\theta_s)}$$

$$\Omega = \int\int \sin(\theta)d\theta d\phi$$

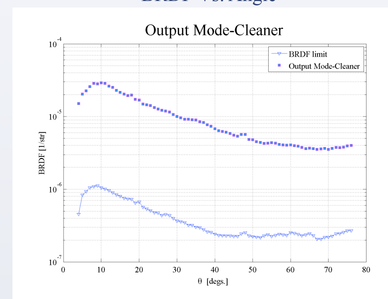
Results



✧This figure displays the Output Mode-Cleaner optic with noticeable scatter. The green box surrounding the scattered light on the surface is our Region of Interest (RoI).

➢The following preliminary angle-resolved scatter data were produced using a Matlab script that sums up the scattered power in a region of interest for each image, and calculates a BRDF for that angle.

BRDF Vs. Angle



✧The BRDF Vs. Angle graph shows the BRDF of the OMC mirror and the BRDF limit of our instrument.

Conclusions

➢Although we obtained a low BRDF of order 10^{-5} for angles greater than 30, the scatter for this mirror was measured to be higher than for a comparable high-reflectivity mirror measured in previous work [2].

➢However, during these measurements we encountered a problem with our laser, and were not able to measure at our nominal input laser power. We also have only done a small amount of drag wiping and we found that the scatter from the mirror holder was very high and may influence our measurements.

References

1. J. C. Stover, *Optical Scattering* 2nd ed. (SPIE, 1995).
2. F. Magaña-Sandoval, R. X. Adhikari, V. Frolov, J. Harms, J. Lee, S. Sankar, P. R. Saulson, and J. R. Smith. "Large-angle scattered light measurements for quantum-noise filter cavity design studies," JOSA A, Vol. 29, Issue 8, pp. 1722-1727 (2012).

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