LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Thermal effects of aLIGO BS

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1. Introduction

The surface deformations and thermal lens in an aLIGO BS induced by the thermal heating by the absorptions in the coatings and substrates are analyzed using COMSOL. The coating absorption is the main cause of the thermal effect and the thermal lens, ~10nm length change in the central region, is the main effect and the surface deformation, ~1nm, is smaller by factor 10. Observed asymmetry of the AR coating absorption in the vertical direction seems to cause little effect on the thermal effect.

2. BS geometry

Thermal effects of the aLIGO BS by coating absorptions, 0.5ppm on HR and 1.5ppm on AR, and the substrate absorption, 0.025ppm/cm, are analyzed using COMSOL.

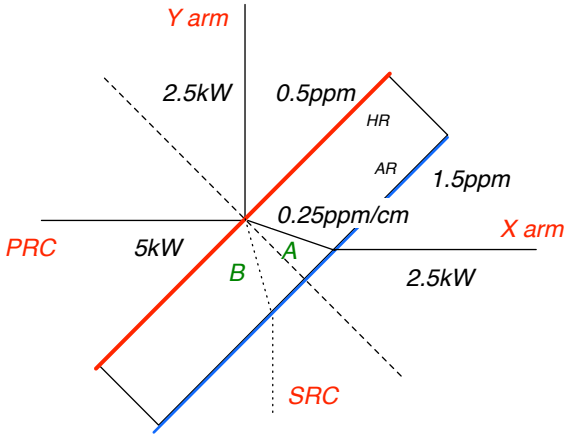

Figure 1 BS heating source

In the following discussion, surface deformations are changes of HR and AR surfaces along z axis in Fig.2, and optical path length changes are calculated along the beam propagation directions, pink lines for the PRC to Xarm and green lines for Y arm to SRC in Fig.2.

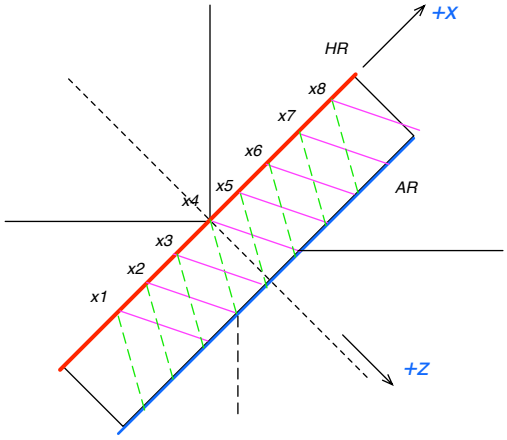

Figure 2 Surface deformation and optical path change

The optical path for a given x is calculated along a pink (green) line starting from x on the HR surface to X arm (SRC)

3. Thermal effects

Fig.3 summarizes surface deformations and optical path length change due to thermal lens. Blue line is the total effect, green due to the HR surface absorption, red AR surface absorption and light blue by the substrate absorption for the beam propagating between HR and X arm. With 0.025ppm substrate absorption, the heating by the surface absorptions are the main cause of the thermal effects.

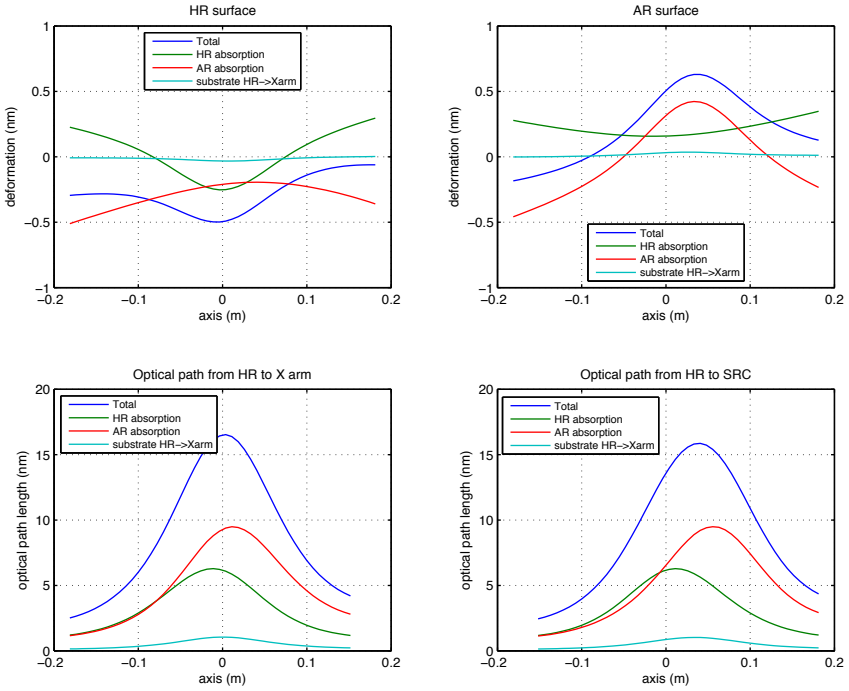

Figure 3 Surface deformations and optical path length

Negative dip in the HR surface and positive peak in the AR surface plots mean that both surfaces have bump at the center, with heights around 1nm. The optical path from HR to X arm and from HR to SRC show around 10 times higher thermal effects.

Fig.4 shows power absorption on the AR side. Because the beam from the X arm hits around 3.35cm off from the center of the BS surface, the peak of the power absorption in the horizontal direction is asymmetric. This causes the asymmetric pattern in the optical path from HR to SRC in Fig.3. In Fig.2, temperatures along pink lines from x3 and x5 are around the same, but temperature along the green line from x3 is lower that that from x5.

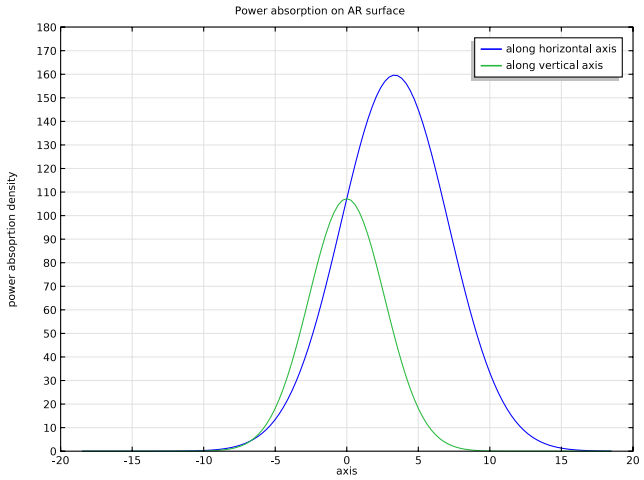

Figure 4 Heating on the AR surface

4. Y direction asymmetry

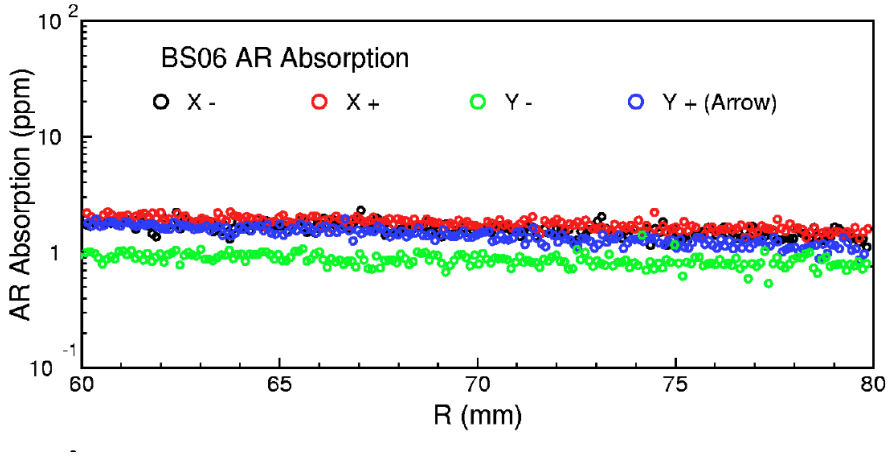

Figure 5 Absorption asymmetry of BS06 AR coating (E1200817)

Asymmetry of the AR side coating of BS06 was found by the measurement at OTF in Caltech. These are measured along 4 lines 6cm outside from the center, and the full pattern is not known.

To estimate the effect of this asymmetry, the y direction data points in Fig.5, green and blue, are fit by a smooth line, as is shown in Fig.6. Outside of this range, +-8cm, the absorption is set to 0.5ppm where the fit value is less than 0.5.

By using this absorption pattern, thermal effects are calculated. The asymmetry in the vertical direction due to this coating asymmetry was found to be negligible. The fit in Fig.6 may be a optimistic fit, but the asymmetry in the horizontal direction due to the heat off centering, shown in Fig.4, causes much larger asymmetric effect.

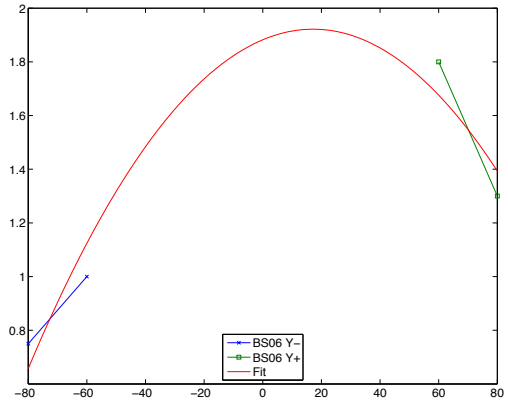

Figure 6 Parameterized asymmetry in y direction
The horizontal axis is the y axis, and the vertical axis is the absorption in ppm.