Gold Barrel Coatings- Our Savior

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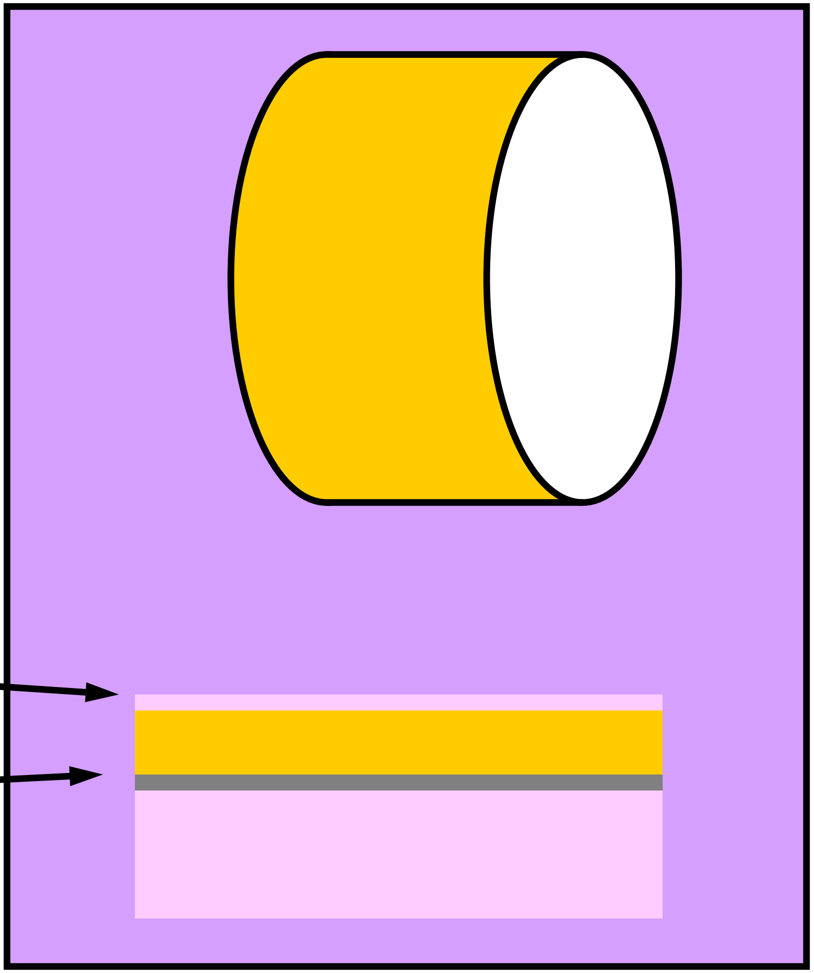
LIGO-G080144-00-R

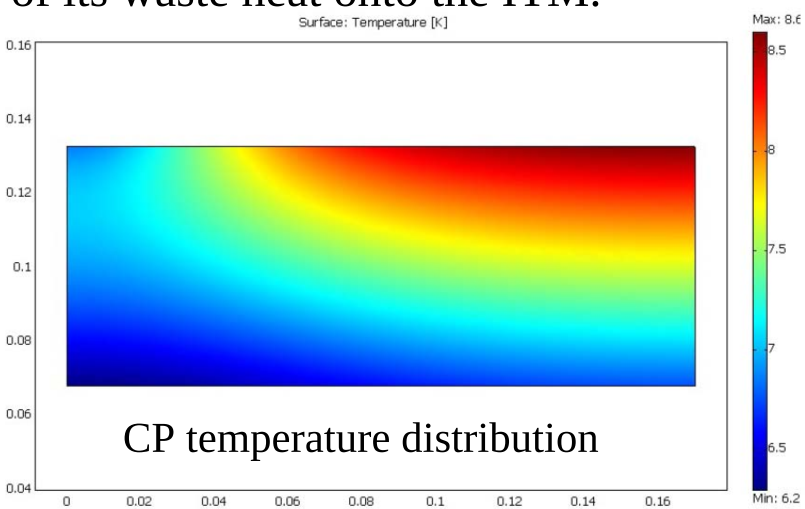
What Is a Gold Barrel Coating?

- The gold coating covers the circumference of the test mass, including the flats. Gaps are left for the silicate-bonded ear and for the ring heater. No gold on either face.
- Gold coatings are fragile, and do not adhere well to glass Therefore:
  - » An overlayer of silica improves scratch resistance
  - » An underlayer of nickel or Inconel provides adhesion

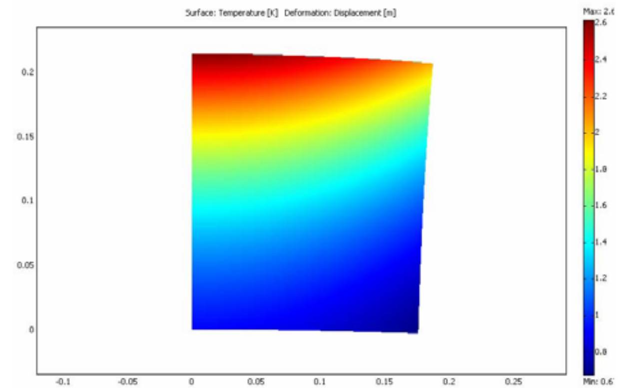


Benefits for TCS

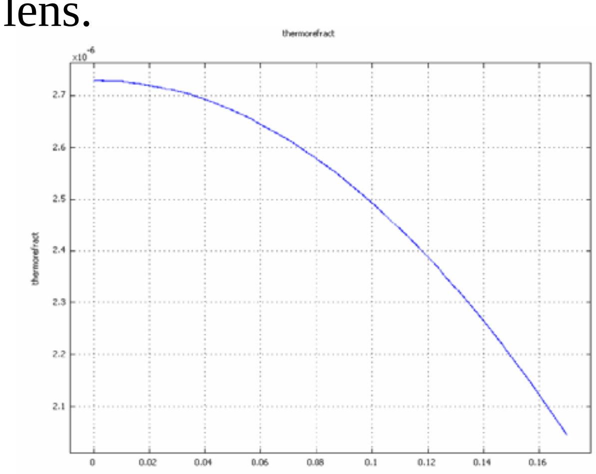
TCS heats the compensation plate to correct thermal aberration in the ITM. The CP sits directly behind the ITM and so radiates ~40% of its waste heat onto the ITM.



CP temperature distribution



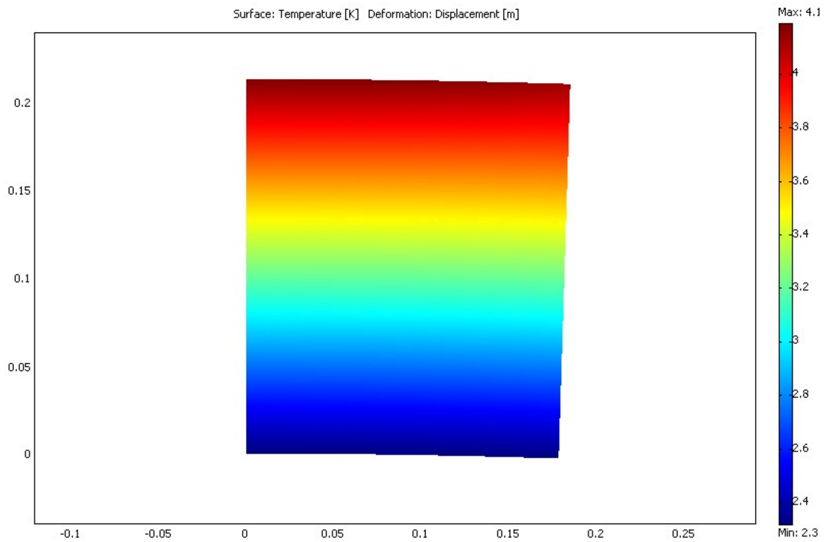
The heat falling on the ITM AR face is nearly uniform, but heat flow out the barrel creates a radial temperature gradient & thermal lens.



The resulting thermal lens in the ITM reduces the CP effect ~40%, alters the thermal lens profile, and increases the thermal time constant of the system.

Benefits to TCS

- Insulating the barrel forces the heat to flow axially- *no thermal lens along the IFO beam axis*.
- Test mass flexure is still present, but ignorably small.



Thermal Noise

- Gold is not a low-loss material:
  - » Intrinsic Q~500-1000
  - » Q of commercial gold coating (with Ti underlayer and SiO_2 overlayer)=106+-23 (measured by Andri Gretarsson)
  - » Thermoelastic damping peak is of similar magnitude but at MHz frequency and thus inconsequential
- But on the test mass barrel a little gold won't hurt the thermal noise:
  - » Calculations of a 0.1 micron layer with Q as measured by Gretarsson show only ~1% increase in thermal noise (Coyne and Willems, LIGO-T080003-03, in preparation)
  - » Relatively small effect is due to dominant influence of HR coating on thermal noise

Reducing Test Mass Q, Reducing Parametric Instability

Parametric gain R:

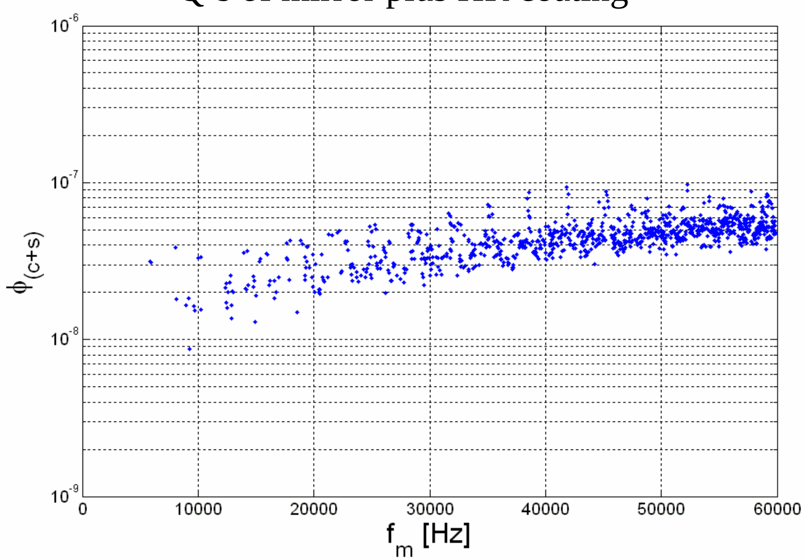
$$R = \pm \frac{4PQ_m Q_1}{mcL\omega_m^2} B$$

Reductions in Q give proportional reductions in R, or equivalently increases in power P without instability

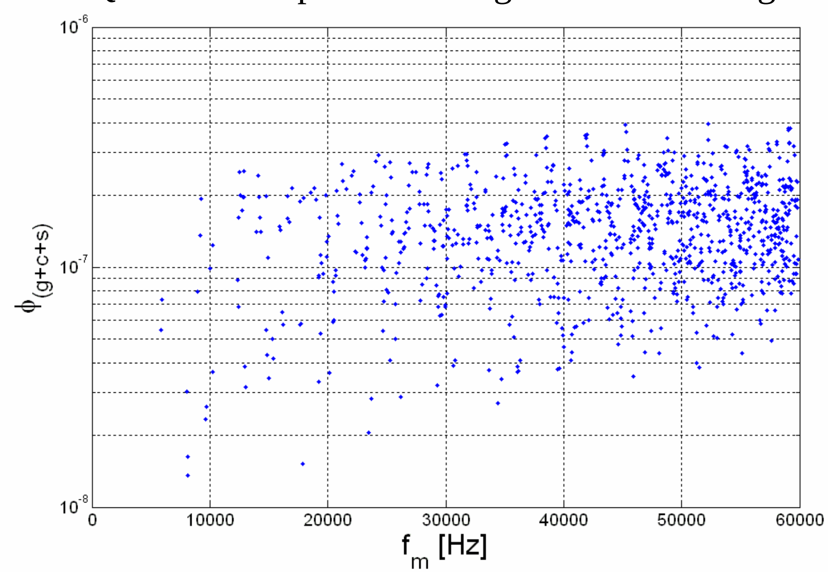
Any reduction in acoustic Q we can get without increasing thermal noise is a prudent strategy for dealing with potential parametric instability

Calculations by Slawek Gras using 1 micron gold coating

Q's of mirror plus HR coating



Q's of mirror plus HR and gold barrel coatings

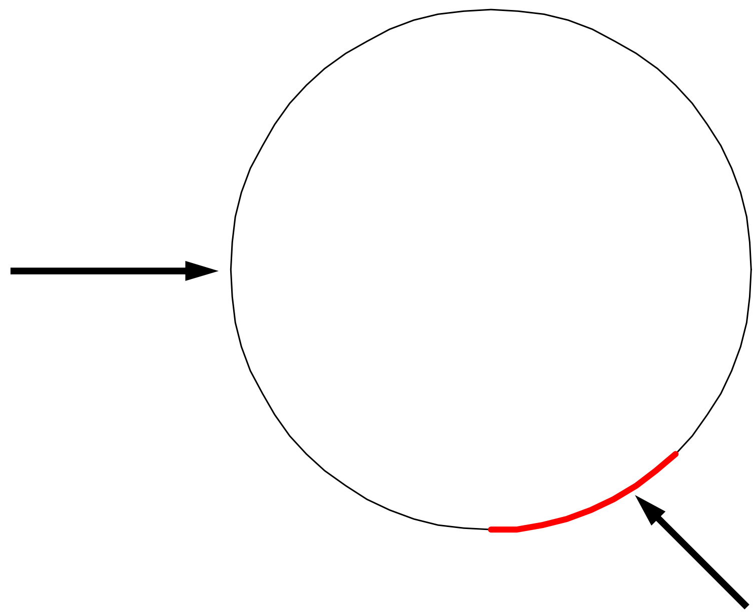


IGO R

Stray Charge Mitigation

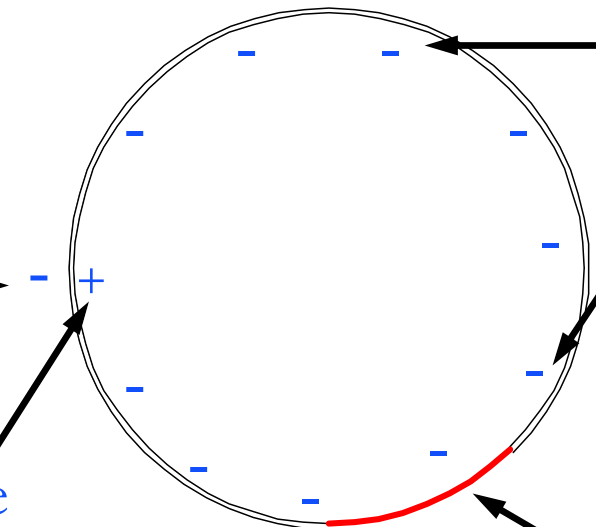
- Rai's favorite idea- cover mirror with (barely) conductive coating to bleed charge from mirror
- Rai's second favorite idea- force electric fields of stray charges to terminate on a conducting cylinder attached to the mirror (LIGO-T960137-00-E)
- This proposal- let the conducting layer/cylinder be slightly *inside* the mirror

Discharging the Conducting Cylinder



“Discharging” the Conducting Sphere with Insulating Overlayer

Charge at this part of the optic…



…plus a distributed charge over the rest of the surface.

…induces an opposite image just in the conductor just below…

The distributed charge can be removed here…

…leaving an isolated, harmless dipole.

Stray Dipoles Are Very Preferable to Stray Charges

- Electric field falls as $1/r^3$ instead of $1/r^2$, so much poorer coupling to nearby charges and ground planes
- Migration of surface charges becomes effectively migration of surface dipoles
- Stray charges could *possibly* become pinned in their local surface potential wells due to attraction by nearby image charges (image potential is of order 1eV)

Can We Do This on the Mirror Face?

- Now absorption becomes an issue. A simple model:
  - » Absorption in a conductive layer goes as $I(z) = I_0 \exp\left\{-\sqrt{2\mu\omega\sigma}\, z\right\}$
  - » For 1ppm absorption require $\sqrt{2\mu\omega\sigma}\, d \approx 10^{-6}$
  - » Surface conductivity of a conductive layer of thickness d is σd
  - » Ratio goes as $\sigma d / \sqrt{\sigma}\, d = \sqrt{\sigma}$ so we want large σ and small d
  - » Choosing $d = 1\text{nm}$ sets $\sigma = 2 \times 10^{-4}\,\text{S/m}$
  - » Surface resistivity is then $1/\sigma d = 5 \times 10^{12}\,\Omega/\text{square}$