Charge Mitigation Studies

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Overview – the effect of charging

- Electrostatic charging of the mirrors and suspensions in GW detectors can lead to several potential problems:
  - Electrostatic damping resulting from induced currents – this may lead to excess thermal noise
  - Control issues due to forces between mirrors and nearby surrounding objects (electrostatic actuators, earthquake stops etc)
  - Calibration issues – charging of the test masses can change parameters during calibration
  - Charge fluctuation noise (hopping/migration?)

- Experiments have suggested that potential excess thermal noise may result from charging, e.g.
  - S. Rowan, S. Twyford, R. Hutchins and J. Hough, CQG **14** (1997) 1537-1541.
  - M.J. Mortonson, C.C. Vassiliou, D.J. Ottaway, D.H. Shoemaker, G.M. Harry, RSI, **74** (2003) 4840-4845.
  - V. Mitrofanov, L. Prokhorov, K. Tokmakov and P. Willems, CQG **21** (2004) S1083-S1089.
  - D. Ugolini, R. Amin, G. Harry, J. Hough, I. Martin, V. Mitrofanov, S. Reid, S. Rowan, K-X. Sun, LIGO DCC P070068-00-Z, 2007.

Example 1 – effect of charge on a pendulum suspended on fused silica fibres

- Experiments in Glasgow observed evidence of a Macor pendulum under vacuum being charged (via UV from an ion-pump on the system)
  - The observed charge was successfully mitigated by means of UV illumination by a UV lamp placed inside the vacuum system

Investigations into the effects of electrostatic charge on the *Q* factor of a prototype fused silica suspension for use in gravitational wave detectors

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Abstract. This paper describes some investigations into the construction of a monolithic fused silica test mass suspension for use in interferometric gravitational wave detectors. We summarize results showing that the material *Q* factor of standard fused quartz in the form of ribbons is of a level which makes it suitable for use as a suspension material for the test masses of long baseline gravitational wave detectors and then present measurements of the *Q* factor of the pendulum mode of a non-conducting mass suspended on cylindrical fibres of fused quartz. Our results show that electrostatic charging of the mass can result in a significant decrease in the pendulum mode *Q* factor.

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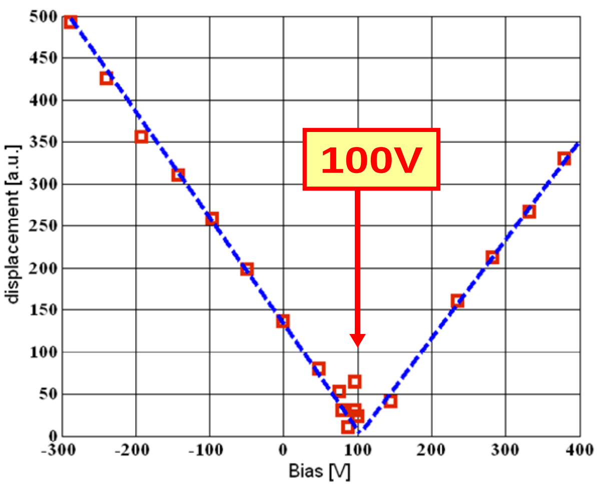
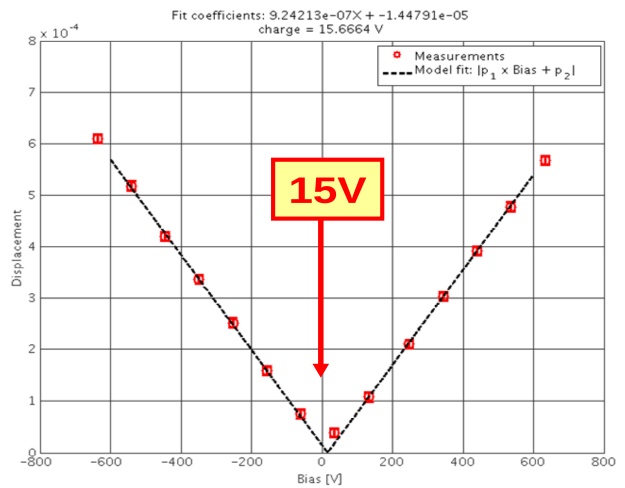
S. Rowan et al., CQG, **14**, 1537–1541, 1997.

Example 2 – experience at GEO600 (see Hewitson et al. poster)

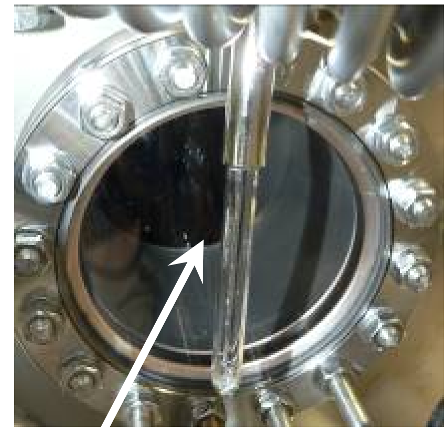
- Discharging technique demonstrated in Glasgow (S. Rowan et al, CQG. 14 1537–1541 (1997)):
- Glass viewport replaced with fused silica viewport
- UV radiation was transmitted through test mass
- Electrons were liberated from the ESD electrodes



before UV illumination



after UV illumination



UV lamp placed in line-of-sight of the charged test mass through a vacuum window in GEO600

- There is also the example of the 'stuck' ITMy at LIGO Livingston Observatory, thought to be due to charging effects.

Charge mitigation work with the LSC

- The effects of charging and techniques for mitigating charging are being studied by various institutions within the LSC
  - GEO600, as discussed
  - Ugolini et al., Trinity University
    - UV discharge lamp showing accelerated charge decay
  - Sun et al., Stanford University
    - preliminary studies using low power deep UV LEDs on the effects of the illumination on optical loss (initial results suggest no increase in optical absorption)
  - Mitrofanov et al., Moscow State University
    - comparison of discharge rates of fused silica samples in air and under vacuum
    - difference in the charging due to contacting silica substrates with different material.

Other methods for charge mitigation under investigation in Glasgow

Doping of silica substrates:

- Initial tests have been carried out to lithiate silica surfaces by treatment with lithium hydroxide.
- Small increase currently observed in the surface conductivity, but with apparent surface damage, and we will investigate whether increased lithium ion activation is required to increase surface charge migration effects without damage and thus increase electrical conductivity.
- We plan to return to high temperature baking of silica in a lithium environment and investigate other doping materials.

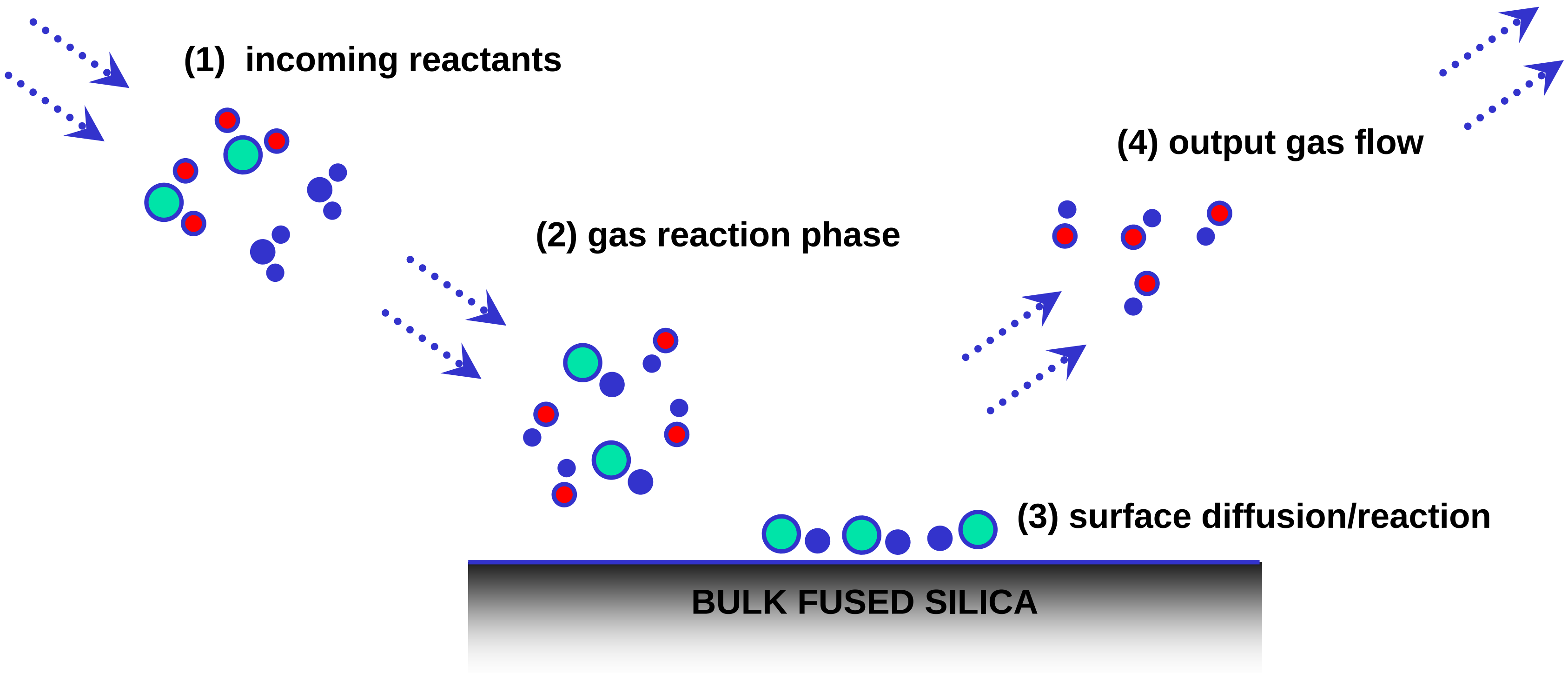
Conductive coatings of Tin Oxide deposited on silica substrates:

- Initial experiments carried out using the spray pyrolysis deposition method.
- Well known, successful method for conductive oxide coatings.

Deposition of conductive oxide coatings on silica substrates

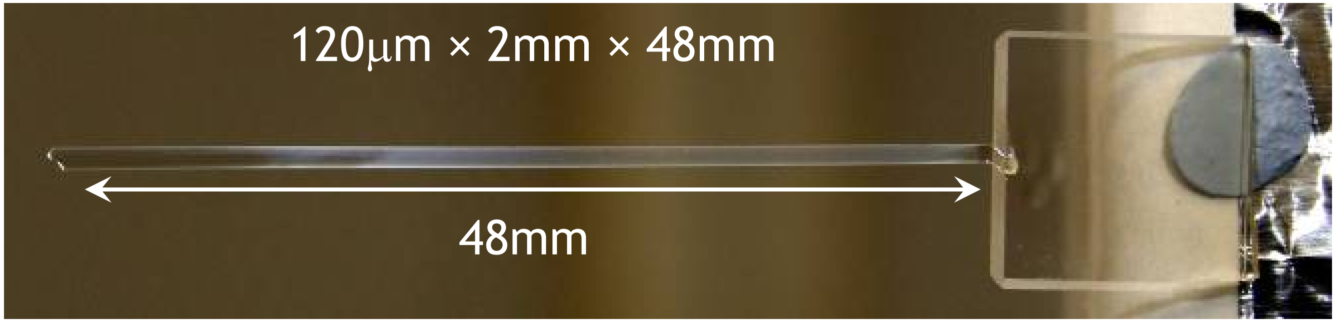
- Deposited tin oxide coating formed through the reaction:

$$SnCl_2 + H_2O \rightarrow SnO + 2HCl$$



Coating procedure

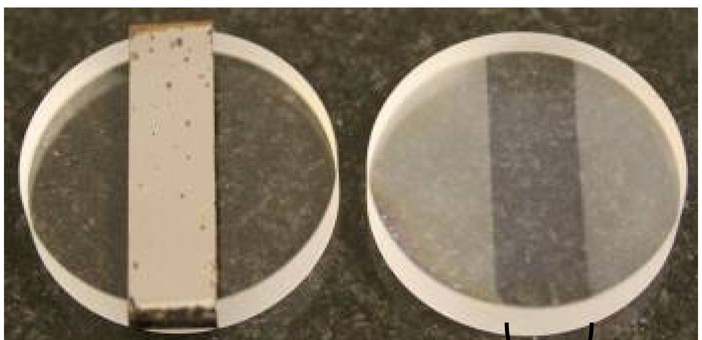
- Fused silica cantilevers were fabricated by flame pulling a Heraeus Suprasil 3 polished slide.
- CO_2 welded to 1mm thick fused silica clamping block.
- Coating deposited by pulsed spray pyrolysis using methanol solution of tin (II) chloride as precursor at 600°C
- Faint whitening was observed over approximately ¾ of the cantilever perhaps due to silica vapour deposition during welding. This effect only became apparent after SnO coating.

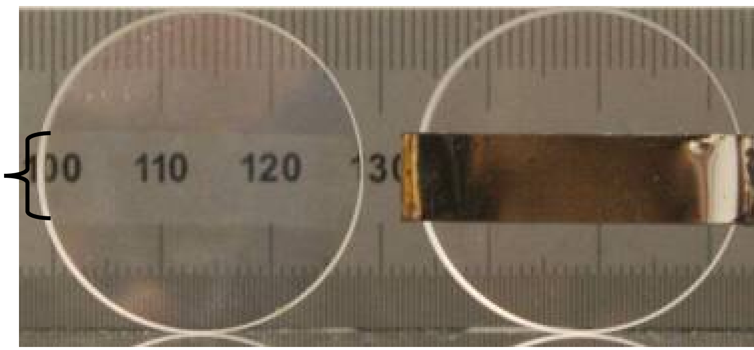


SnO coated SiO_2 cantilever
(illuminated to highlight whitening)

SnO coating characterisation - 1

- The coating thicknesses were directly measured from witness samples placed alongside the cantilever during coating. Measurements were taken using a Talysurf stylus profiler.
- Variations in coating thickness across the surface of these 1” samples was observed to be within the range of ±10%.





stainless steel mask mounted prior to coating

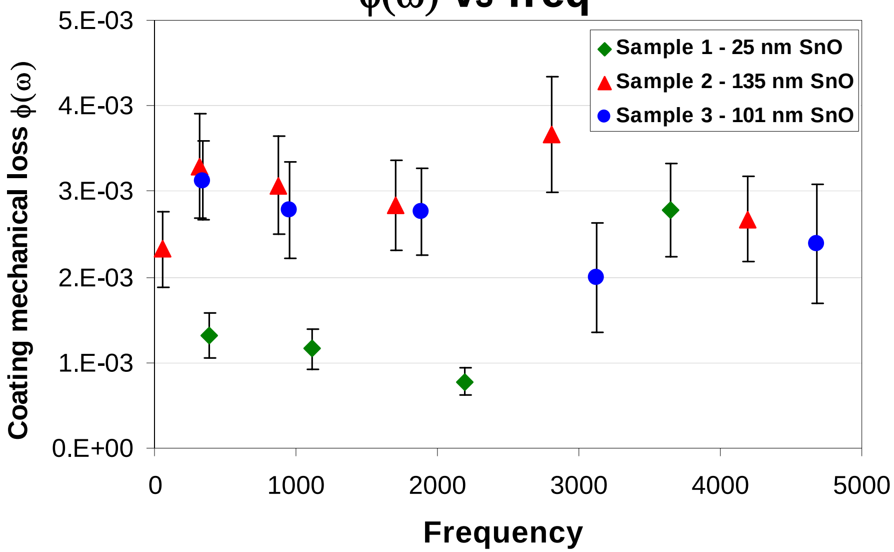
central uncoated region

- Resistivities were also measured using a 4-pt probe.

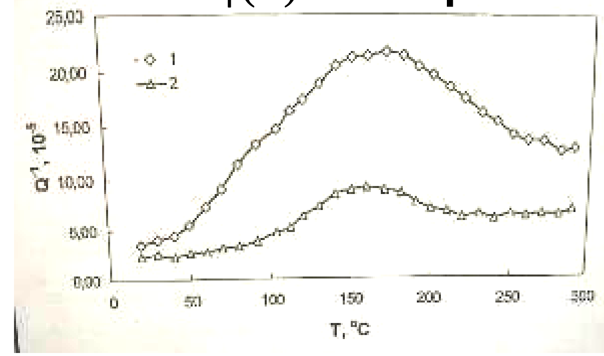
SnO coating characterisation - 2

- The mechanical loss was measured before and after coating for 4 resonant bending modes.

$\phi(\omega)$ vs freq



$\phi(\omega)$ vs temp



Mitrokhin et al., $\phi(\omega)_{SnO\text{-}Hydrolysis} = 2.5 \times 10^{-3}$,
$\phi(\omega)_{SnO\text{-}Magnetron\text{-}Sput} = 3.6 \times 10^{-3}$
over the frequency range 5-20kHz.

- Measuring the mechanical loss associated with conductive coatings will allow the tolerable thickness to be calculated from the thermal noise point of view.
- Measuring the optical loss will likewise allow the tolerable thickness to be calculated from an optical point of view (assuming that the SnO coating is deposited below the dielectric HR mirror coating)

SnO coating feasibility

- The loss of $\phi_{coating\ material}$ ~$\underline{3\times10^{-3}}$, when compared with a typical dielectric coating of loss ~2×10^{-4} and thickness of ~4.5um, would suggest a coating of ≤~300nm would appear to be acceptable from a thermal noise view point.

- Measured optical losses were in the range $\underline{17\rightarrow290\text{ppm}}$.
- Therefore it is not *as* clear that SnO coatings will meet the optical requirements necessary (<1 ppm above HR coating, although <66 ppm permissible below the HR coating for the same power loss (heat deposition) in the Advanced LIGO design).
- This may rule out the use of such coatings on mirror faces – however barrel coatings remain an option.

Charge Mitigation - conclusions

- UV illumination is clearly a candidate technique for controlled charge mitigation for the test masses in current and future detectors using silica substrates
  - Successfully used in experiments in Glasgow (1997) and in GEO (2007).
  - UV lamps either mounted inside vacuum or line-of-sight illumination through fused silica windows.
- The use of gold coatings on the barrels of optics in Advanced LIGO, which have been proposed for thermal compensation reasons, may help charge mitigation (see LIGO DCC: G070146-00-Z).
  - $\phi(\omega)_{GOLD} \sim \sim 2\times10^{-3}$ (single crystal Au coating)

    B.S. Lunin *Physical and chemical bases for the development of hemispherical resonators for solid-state gyroscopes*.

  - Charge mitigation may also be required for fused silica suspension elements – and conductive elements will provide a direct path to for charge to be carried away.
  - Plans in Glasgow to investigate integrating conductive oxide deposition during CO_2 laser pulling.
  - We also plan to continue and extend the study into the effect of these coatings on mechanical loss, optical loss, mechanical strength and durability (many of these oxide coatings are known to be chemically resistant (“hard”) and may therefore protect the surface of silica suspension elements from contamination and micro-cracks that can otherwise be detrimental to strength.