



# Charge Mitigation Studies

---

Stuart Reid  
(on behalf of LSC charging group)

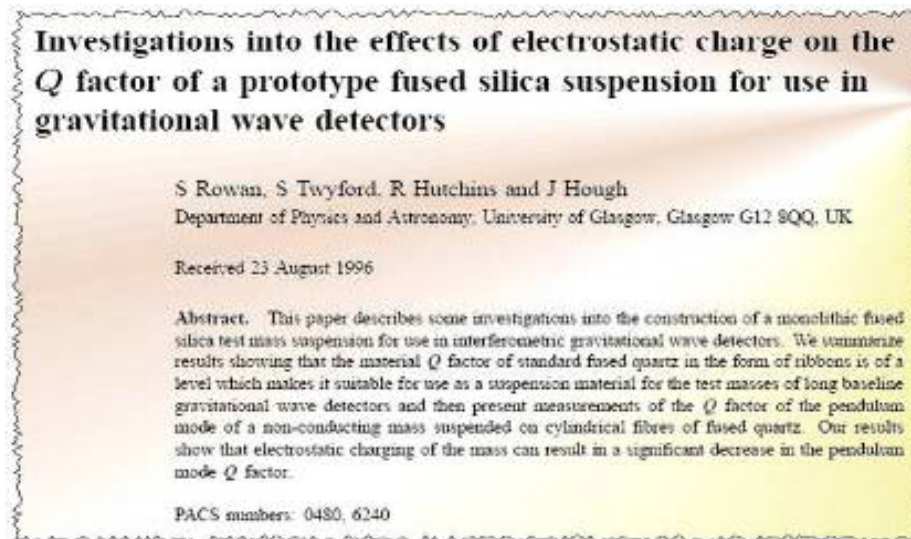
## Overview - the effect of charging

---

- 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 suggests that potential excess thermal noise may result from charging.  
e.g. Mitrofanov et al., CQG, 21, S1083-S1089, 2004



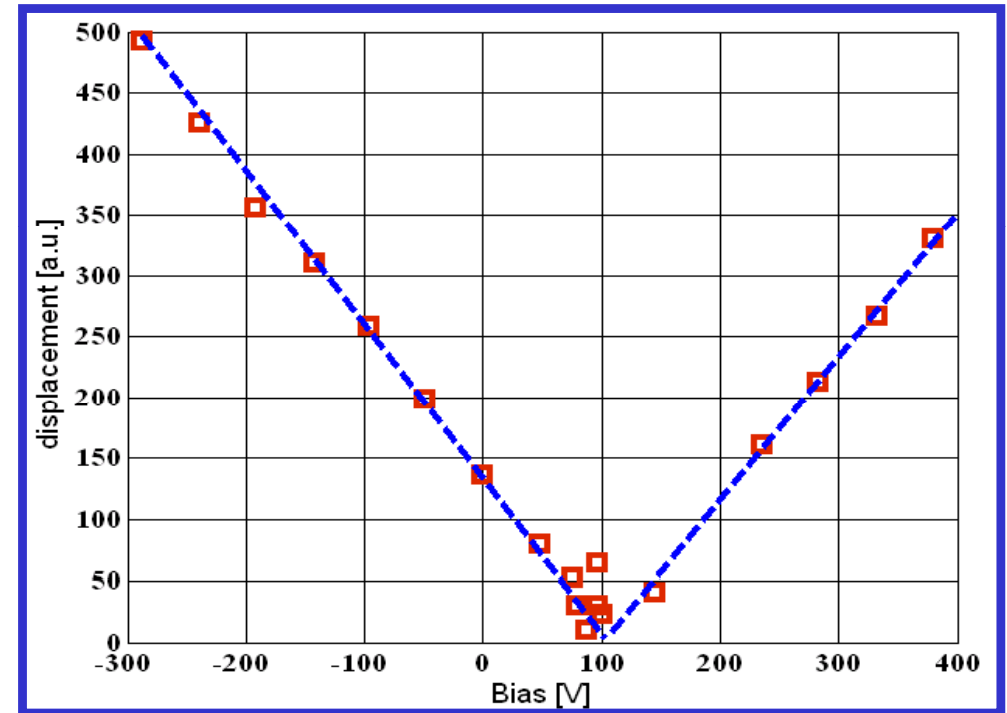
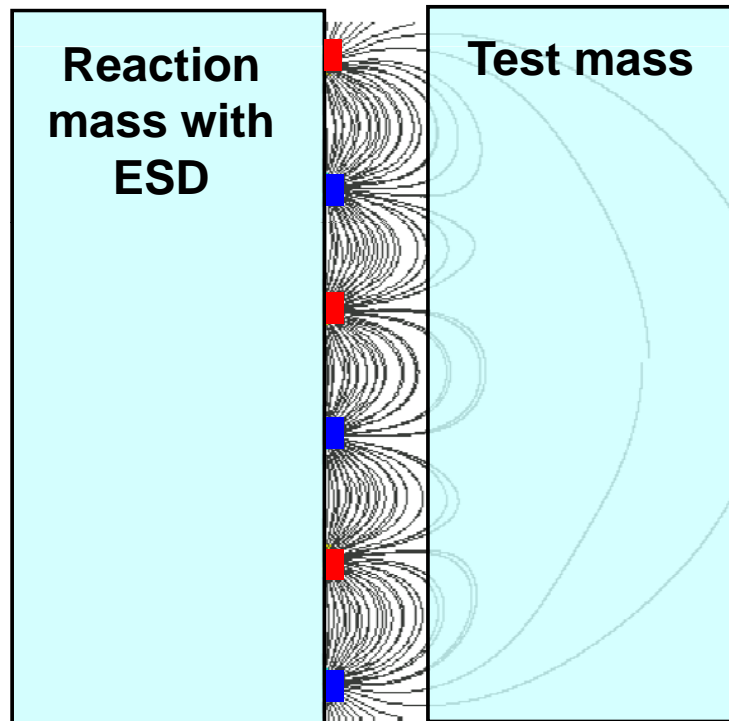
- Experiments in Glasgow observed evidence of a Macor pendulum under vacuum being charged (via UV from an ion-pump on the system)
  - The observed charge was **successfully mitigated by means of UV illumination by a UV lamp placed inside the vacuum system**



S. Rowan et al., CQG, 14, 1537-1541, 1997.

## Example 2 - experience at GEO600

- After recent vacuum work, one of the GEO test masses was found to be positively charged:

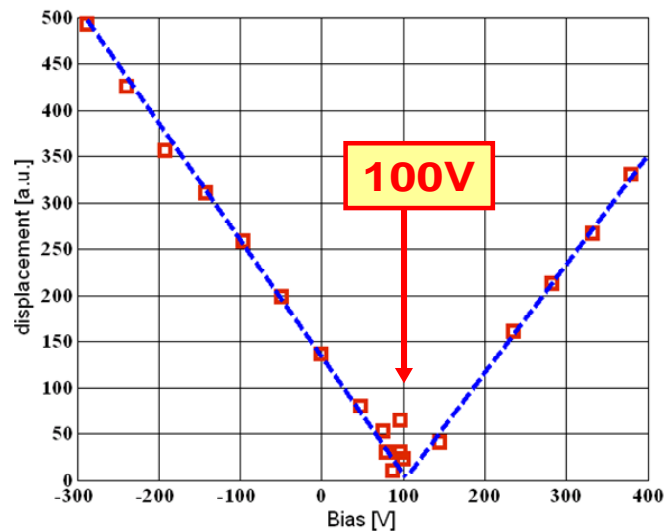
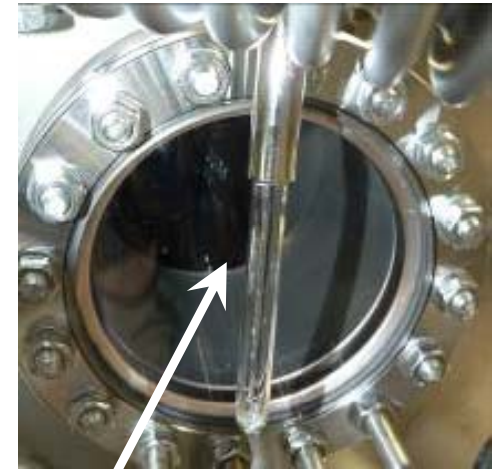


$$\begin{aligned}
 F &= U^2 \epsilon_0 \epsilon_r d^{3/2} A = (U_{\text{bias}} + U_{\text{signal}})^2 \cdot \text{const} \\
 &= F_{\text{Offset}} + U_{\text{bias}} \cdot U_{\text{signal}} \cdot \text{const} + U_{\text{signal}}^2 \cdot \text{const}
 \end{aligned}$$

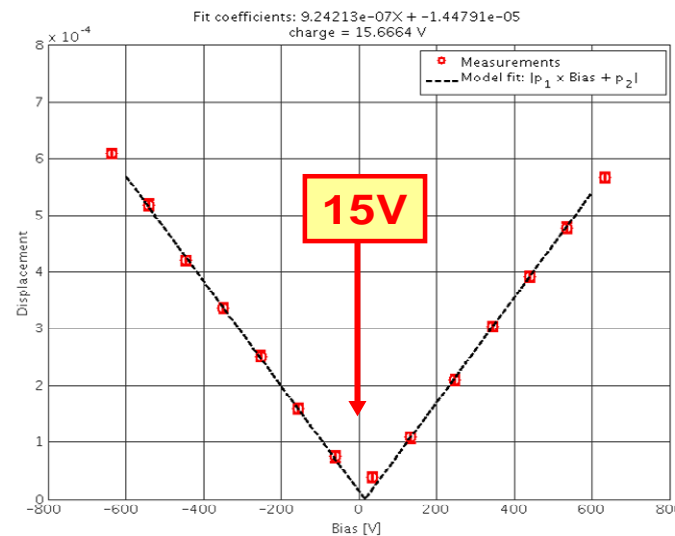
(+100V/+30V)

# GEO control issues

- 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.

## Doping of silica substrates:

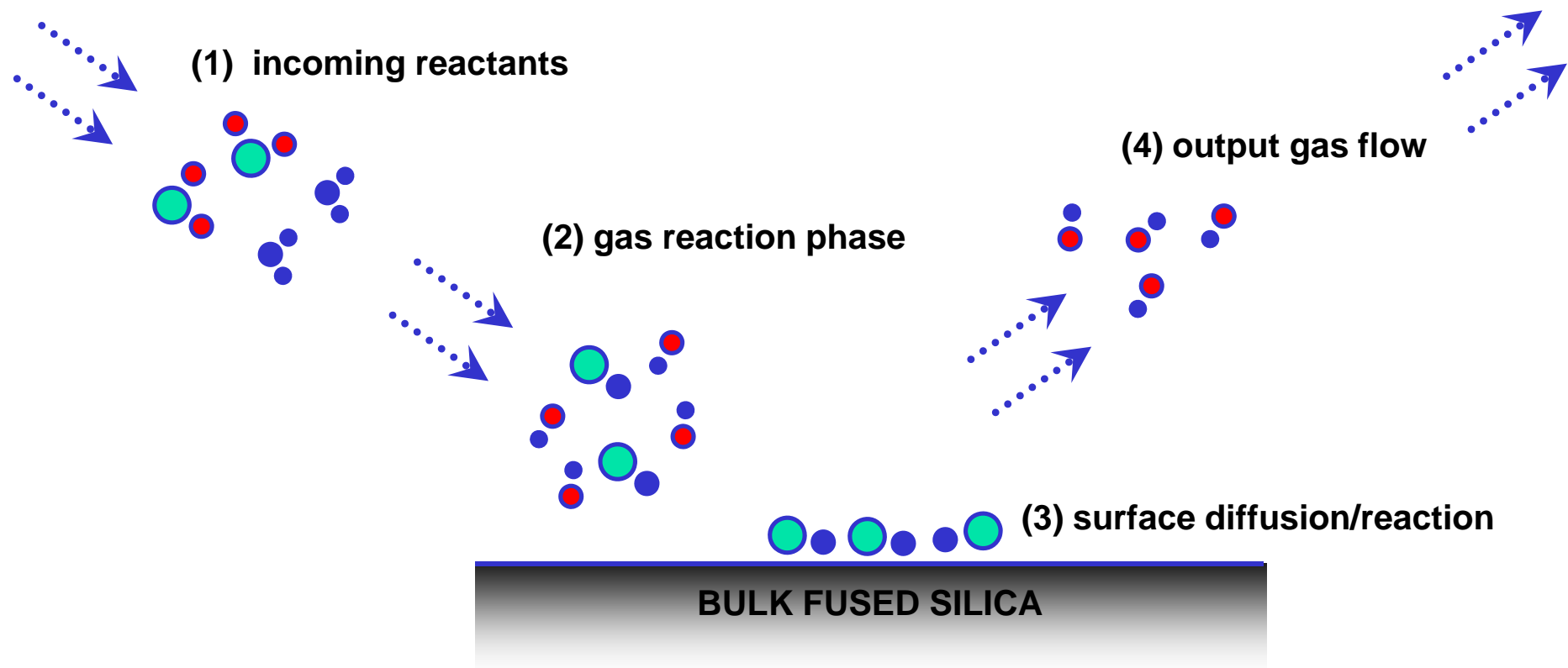
- Initial tests have been carried out to **lithiate silica surfaces** by treatment with lithium hydroxide.
- Small increase currently observed in the surface conductivity, but with apparent surface damage, and we will investigate whether increased lithium ion activation is required to increase surface 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

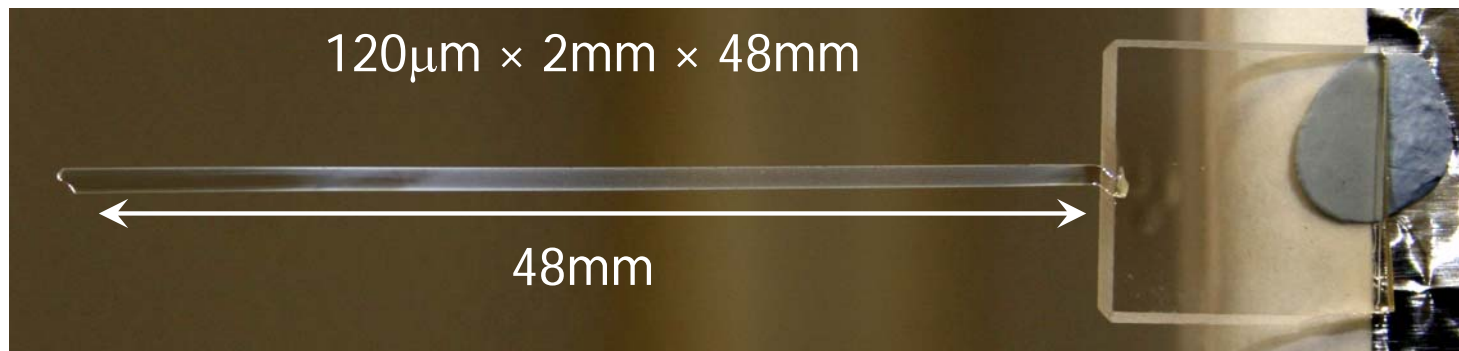
- Deposited tin oxide coating formed through the reaction:





# Coating procedure

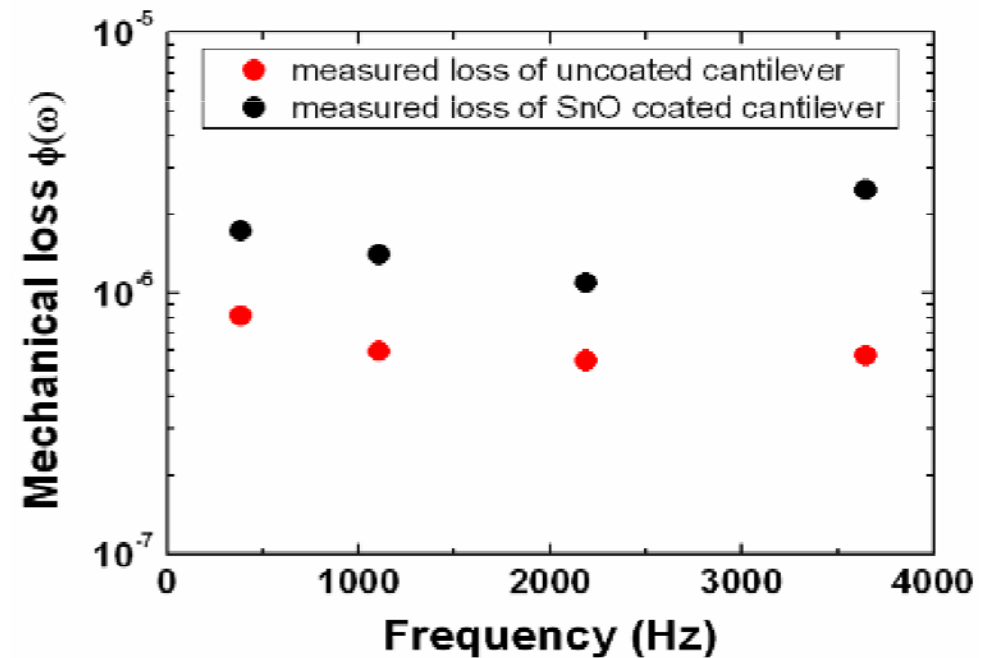
- Fused silica cantilever fabricated by flame pulling a Heareus Suprasil 3 polished slide.
- CO<sub>2</sub> welded to 1mm thick fused silica clamping block.
- Coating deposited by pulsed spray pyrolysis using methanol solution of tin (II) chloride as precursor at 600°C
- Faint whitening was observed over approximately  $\frac{3}{4}$  of the cantilever perhaps due to silica vapour deposition during welding. This effect only became apparent after SnO coating.



SnO coated SiO<sub>2</sub> cantilever  
(illuminated to highlight whitening)

# SnO coating characterisation - 1

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



- 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 a thermal noise point of view (assuming coating mass surface below subsequent mirror coating)

## SnO coating characterisation - 2

---

- Typical thickness of our coatings ~70nm.
- This results in  $\phi_{\text{coating material}} = \sim 1 \times 10^{-3}$
- Comparison with a typical dielectric coatings of loss  $\sim 2 \times 10^{-4}$  with a thickness of  $\sim 4.5 \mu\text{m}$  is broadly acceptable. Thus a coating of 70nm would appear to be acceptable from a thermal noise view point.
  
- Measured optical loss  $\sim 150 \text{ppm}$ .
- Therefore to meet the optical requirements of less than 1 ppm requires a thickness less than 0.5 nm and thus may rule out the use of SnO on mirror faces (barrel coatings 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 proposed gold barrel coatings in advanced LIGO for aiding thermal compensation should help.
- 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<sub>2</sub> 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.