LIGO charging research at Moscow University

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Introduction

- Initial motivation for study of test mass charging:

  Possible effect on the pendulum mode Q-factor in fused silica fiber suspension due to interaction of charges with surrounding elements of suspension structure and electrostatic actuator.

- Subsequent development:

  Exploring of time dependence of charge value and spatial distribution as possible source of fluctuating electrostatic force.

  It was expected these effects will be essential in Adv. LIGO

- May 2006 Livingston event relating to LIGO ITMY has shown that electrostatic charges are likely create problems even for Initial LIGO.

Experimental setup

Vacuum $p < 10^{-7}$ **Torr**

Monolithic fused silica bifilar pendulum:

Mass M **= 0.5 kg, Fibers:** L **= 25 cm,**
d **=200** μm**,**
Torsion mode f ≈ **1.14 Hz,**
Quality factor Q ≈ 8×10^7 **,**
Relaxation time τ^* ≈ 2.2×10^7 **sec,**
Initial amplitude A ≈ **0.07 rad**

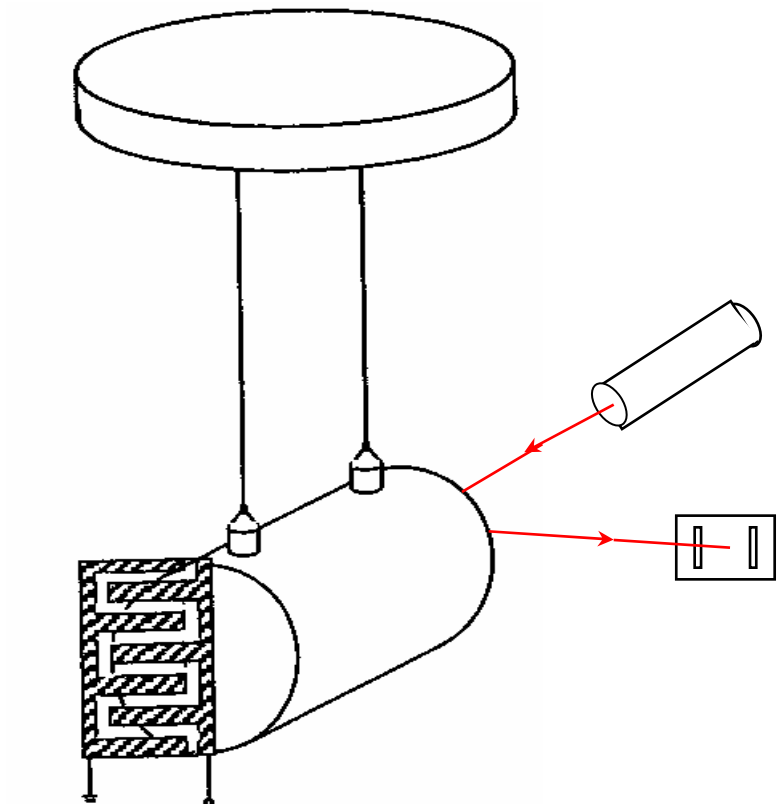
Multistrip capacitive probe

(two sets of gold strips sputter-deposited on fused silica plate) connected with high impedance amplifier.

Probe voltage $U = k\times q\times A$

q **– electrical charge on the pendulum not far from probe (distribution of charge is unknown)**

(Phys.Lett. A 300 (2002) 370.



Results of pendulum measurements (1)

√ **Some electrical charge is always present on fused silica pendulum**.

To mitigate the charge two techniques were used:

1. Venting of the chamber with atmospheric air – its humidity is sufficient to form adsorbed water conductive layer on the surface and to reduce the charge in several days
2. Ignition of low pressure (of about 0.1 Torr) glow discharge inside vacuum chamber – creates plasma and UV which discharge the mass in several minutes (but there is a danger to contaminate there surface by ions of sputtered material)

Usually we managed to discharge pendulum to ~10^6-10^7 e/cm^2 and rarely to ~10^5 e/cm^2 .

√ **Pendulum charge changes very weakly with time**.

We observed a monotonic rise of negative charging of order of 10^5 e/cm^2 per month which may be associated with effect of cosmic ray and radioactive background (see V.B.Braginsky, O.G.Ryazhskaya, S.P.Vyatchanin, 2006)

Results of pendulum measurements (2)

√ **Rare jump-like changes of charge were observed but they occurred when there was small separation gap (less than 100 μm)** between pendulum mass and nearby actuator plate.

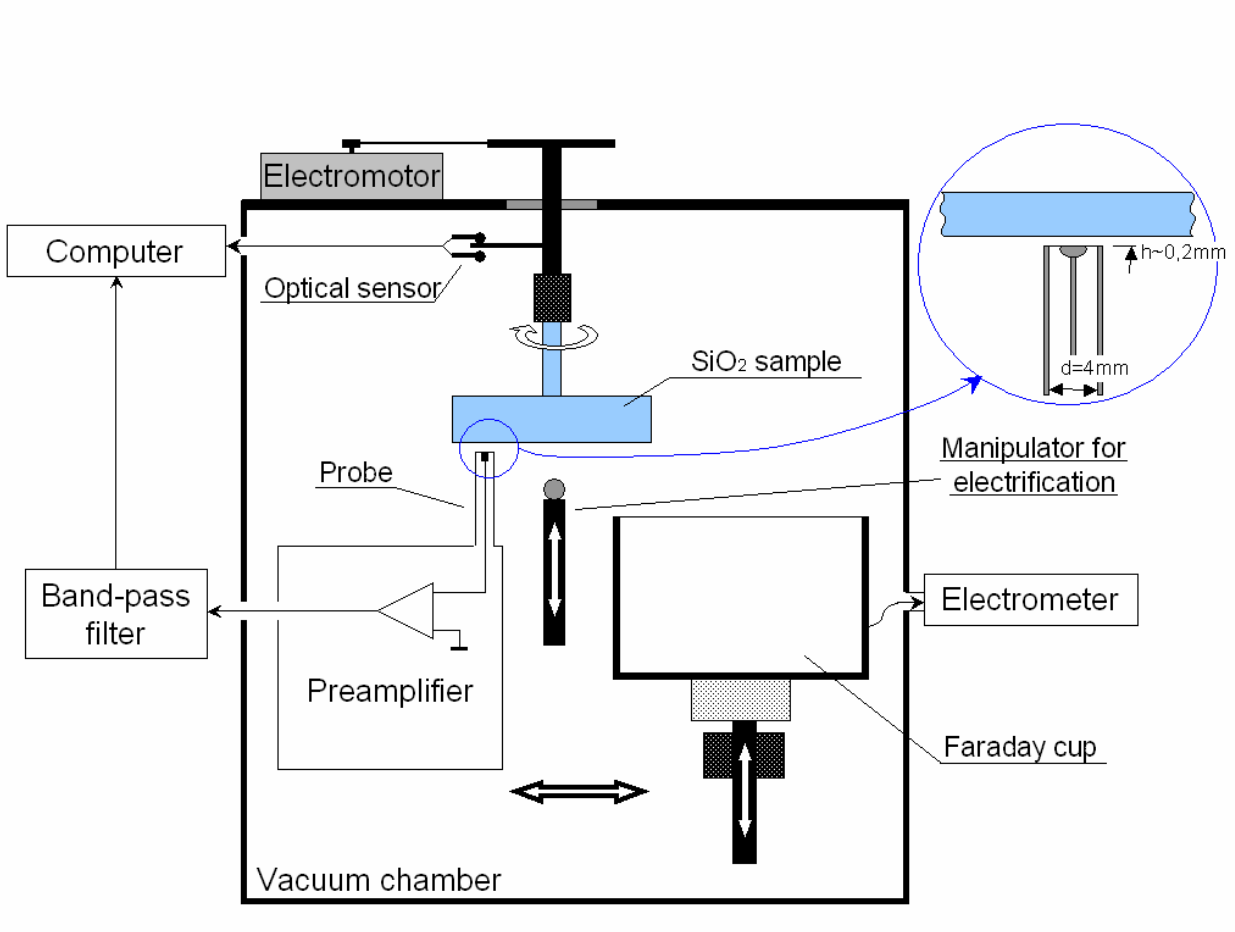
√ **Excess damping of the pendulum mode Q^{-1} did not exceed 5×10^{-9}** if charge up to 3×10^{10} electrons was deposited on pendulum mass near actuator plate.

Notice that MIT group has not found excess damping of normal modes of fused silica disk associated with its charging (M.J. Mortonson, et al., 2003),
whereas Glasgow group has observed excess damping of charged pendulum
(S. Rowan et al., 1998)
Materials from which objects surrounding the pendulum are fabricated play important role due to electrical losses in dielectrics and oxide layers on metal surfaces. We used fused silica plate with sputter-deposited gold electrodes.

Main disadvantage of the pendulum setup: absence of information about spatial distribution of the charge

Experimental setup
(Capacitive probe sensor under rotating sample)

Detailed description is published in Phys. Lett. A 366 (2007) 145



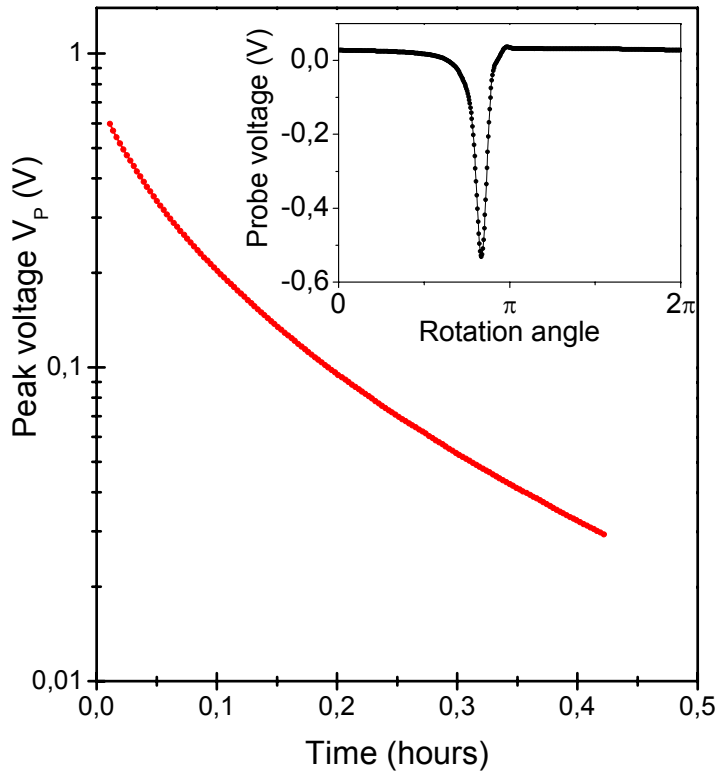
Example of measurements of charge relaxation in air

- This setup was used to measure charge relaxation and AC component of charge spatial distribution

- Local deposition of charge e.g. by contact with viton tip resulted in a peak on the time dependence of output voltage repeated with rotation period.

- Relaxation of charge manifested itself in a decrease of the peak height and a small increase of the peak width.

- Usually the charge decay was not exponential. Relaxation time t* was used as an estimate.



Results of measurements of charge relaxation (1)

● In air, decay of the deposited charge depends on humidity of the ambient air and the sample “history”.
The observed relaxation time was from ~ 0.5 hour to 10 hours (without preliminary baking of the sample).
The decay is a result of surface conductivity associated with proton H^+ transport in water adsorbed on fused silica. Charge flows to the ground via contact of fused silica with metal collet which clamps up the sample.

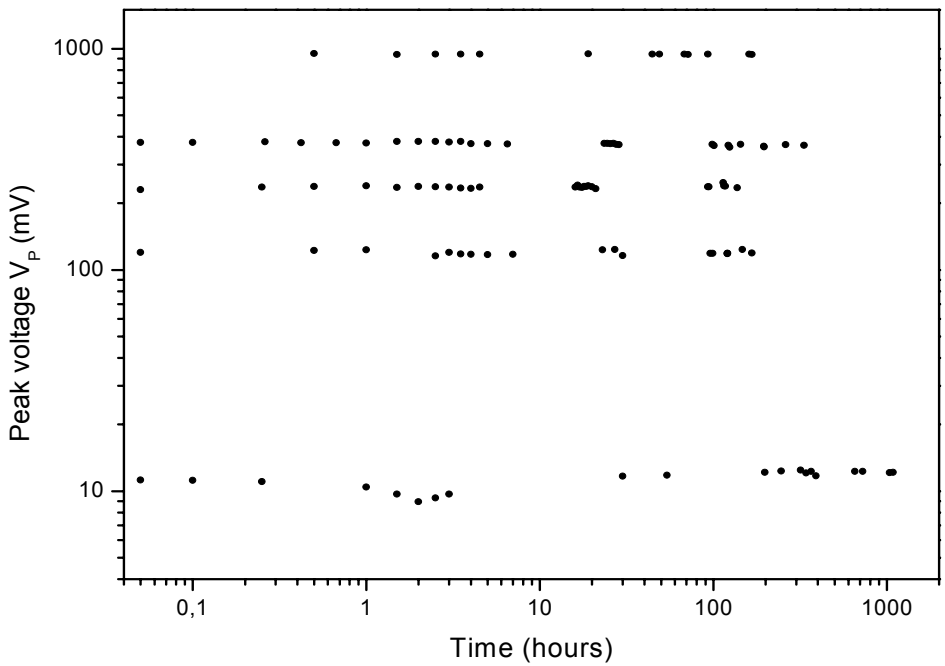
● In vacuum the relaxation time was estimated as longer than **8000 hours** for different values of deposited charges of both signs (from about $\mathbf{10^6}$ ***e*** to $\mathbf{10^8}$ ***e***) assuming that the deposited charge decays exponentially to the value close to zero.

Relaxation of the deposited charge in vacuum

Results of charge decay measurements carried out in vacuum for different values of deposited charges of both signs (from about **10^6 *e*** to **10^8 *e***) are presented in Fig.

In vacuum no relaxation of deposited charges has been found within the limits of the measurement errors which were about 2%.

The relaxation time may be estimated as longer **than 8000 hours** assuming that the deposited charge decayed exponentially to the value close to zero ($\rho > 10^{20}$Ohm●m).



Results of measurements of charge relaxation (2)

- In our recent measurements of charge decay on Corning 7980 fused silica sample with coating (SiO_2/Ta_2O_5 doped by Ti) the charge relaxation time up to **12 000 hours** was obtained.

  In fact, relaxation time was determined by errors and time of measurement.

- These measurements reduce the estimate of fluctuating force obtained according to the Rai Weiss model (LIGO: T/T960137-00)

√ How to explain the Livingston case?

To apply the model to viton tip (bad dielectric) which is coupled with optics.

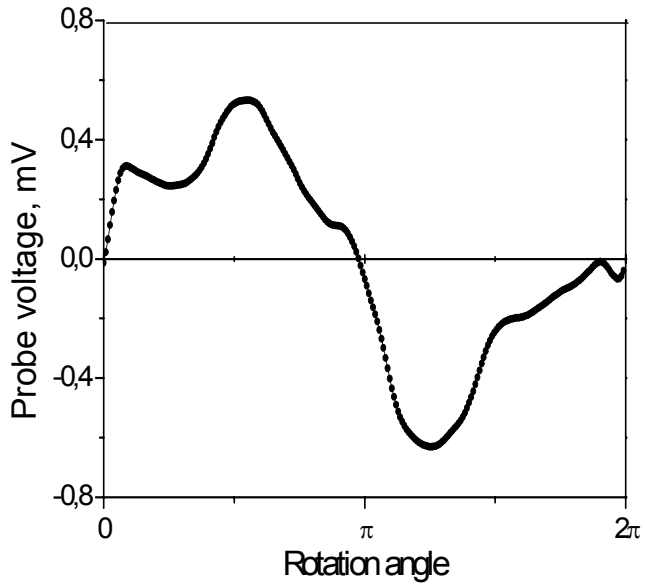
- **Notice** that sometimes we observed decay of charge in vacuum with smaller relaxation time. Likely this depends on cleaning of the sample. (e.g. the charge decay time of 2400 hours was measured for fused silica sample with coating which was not cleaned before measurements)

Residual charge distribution on fused silica sample

Charge distribution was formed In air before pumping of the chamber due to surface conductivity associated with adsorbed water.

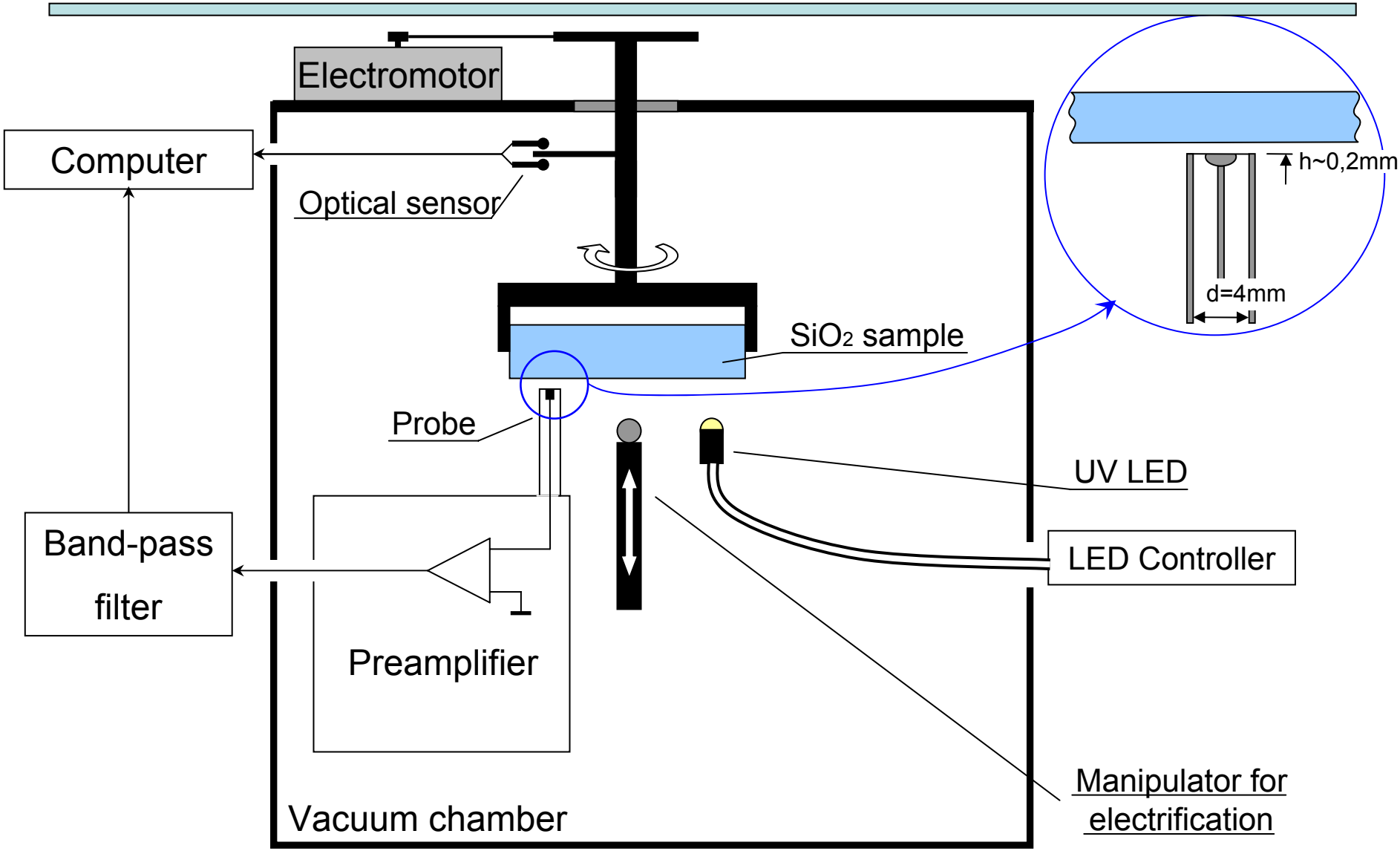
The distribution was determined by electric fields inside the chamber which depended on position of objects surrounding the sample and contact potential difference between materials. (e.g, a peak was formed over the probe)

Also we observed change of charge distribution in process of pumping due to outgassing



Typical charge distribution (AC component)
Maximum difference in charge density along the scanning strip ≈ 5×10^5 *e*/cm^2

Modification of setup for charge mitigation



Charge mitigation by UV illumination

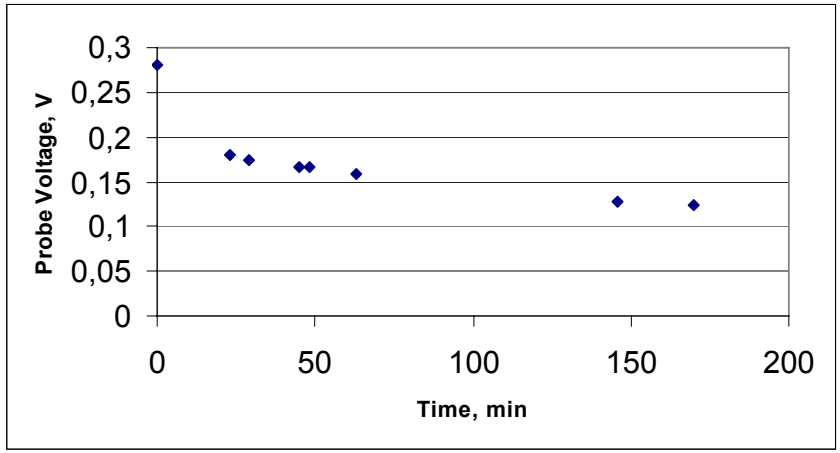
- To mitigate charge located on fused silica sample with coating we used UV LED S265T3F-2C1-TO-39 SEOUL OPTODEVICE (λ= 265 nm, $P_O \approx 100$ μW, viewing angle =100°, distance to sample = 20mm).

- Photon energy (4.67 eV) is too small to create photoconduction in SiO_2 (band gap $E_g \approx 9$ eV) and may create photoconduction in Ta_20_5 ($E_g \approx 4.4$ eV), but the outer layer of the sample coating is a double layer of SiO_2 .

- Two procedures of illumination: 1) LED is under the charge on immovable sample
  2) LED is under rotating sample

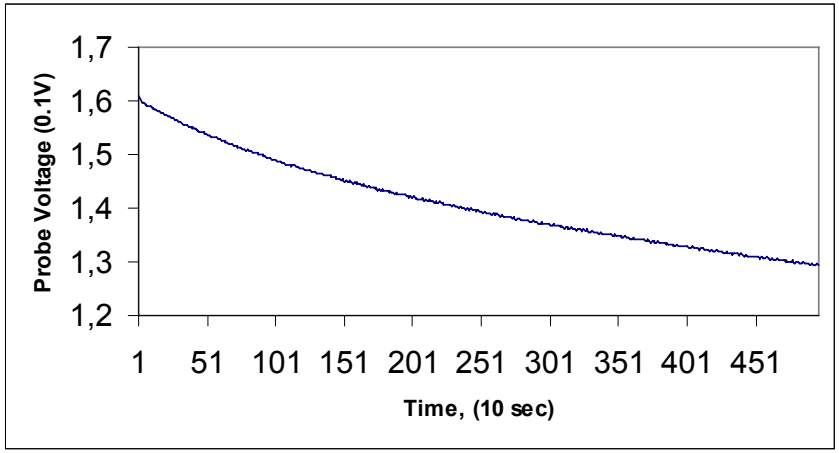
- Results of experiments (see subsequent plots in this presentation):
  Rate of mitigation of positive local charge ~ $5x10^6$ e/min (in the beginning)
  ~ $5x10^5$ e/min (in ½ hour after beginning)
  Rate of mitigation of negative local charge < $1x10^5$ e/min

UV lead mitigation of positive charge deposited on the coating



Mitigation of positive charge deposited on the coating

UV lead mitigation of positive charge deposited on the coating (fragment)



Time dependence of the peak height
(fused silica sample with coating rotates, LED is switched on)

Conclusion

- Experiments have shown that in vacuum electrical charge sitting on clean fused silica as well as on the coating is fairly stable. More question are about mechanical and electrical properties of elements surrounding optics which are coupled through the field generated by charges.

- In any case it is necessary to provide minimal charge on optics before closing of chambers e.g. checking charge by means of a simple electrometer.

- The GEO experience of charge mitigation is very interesting, useful and looks promising. But questions remain about possible increasing of total negative charge on optics and about possible damage of optics by UV.

- Adv.LIGO may require more detailed exploring of charging effects.