Relaxation of electrical charge deposited by contact electrification on fused silica sample with coating

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Electrical charges located on the test masses of gravitational wave detectors interact with surroundings by electrical forces. Time variations of the charge value or its distribution may results in fluctuating forces which act on the test mass – charging noise. In general model of this noise it depends on the charge relaxation time [1]. There is the discrepancy between measurements of relaxation time which were recently carried out in different laboratories [2,3]. Results may be dependent on the type of fused silica and on the sample cleaning.

In this preprint we present results of charge decay time measurements for Corning 7980 fused silica with coating of alternating quarter wavelengths layers of silica (SiO_2) and tantala (Ta_2O_5) doped by Ti. The outer layer of the sample's coating is a double layer of SiO_2. The polished sample had a disk shape with diameter of 76 mm and height of 25mm.

We used a fixed capacitive probe placed under a fused silica sample mounted on a turntable. The experimental setup and procedure of measurement were described in [2]. The sample clamp was modified for a disk shape sample. A schematic layout is shown in Fig. 1.

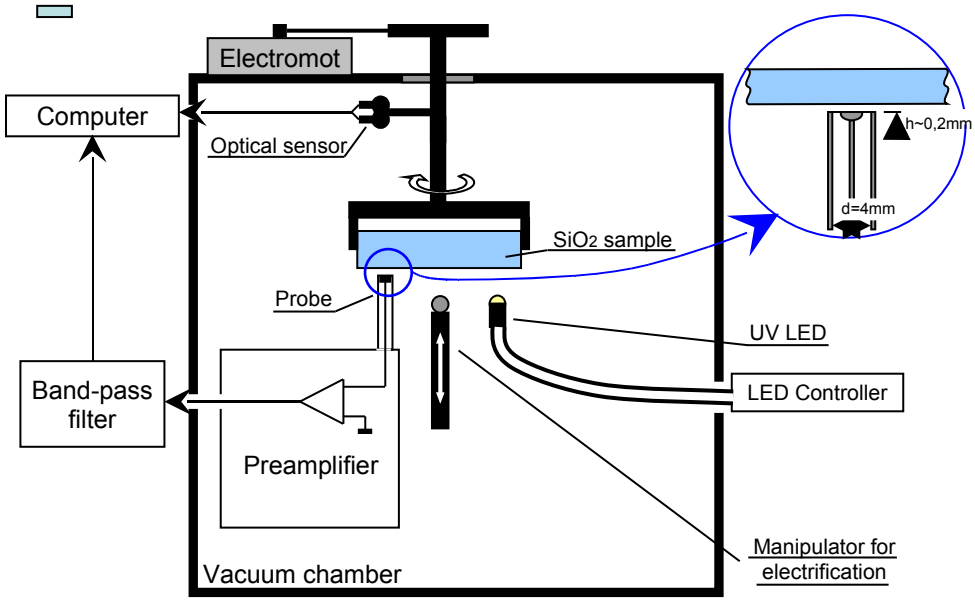

Fig.1. Schematic layout of the experimental setup

The local deposition of electrical charge on the sample was realized by contact electrification using a special manipulator. The angular distribution of the charge density located

on the scanning strip of the sample was transformed to the probe voltage when the sample was rotating. To decrease the effect of amplifier drift in long lasting measurements we used the band-pass filter for the probe signal processing. Thus we did not monitor the DC spatial component of the charge distribution and distorted its spatial profile to a certain extent. The probe voltage as a function of rotation angle is shown in Fig.2. A negative charge of about $4x10^7$ electrons was deposited on the sample in the point near the angle of $\pi/2$.

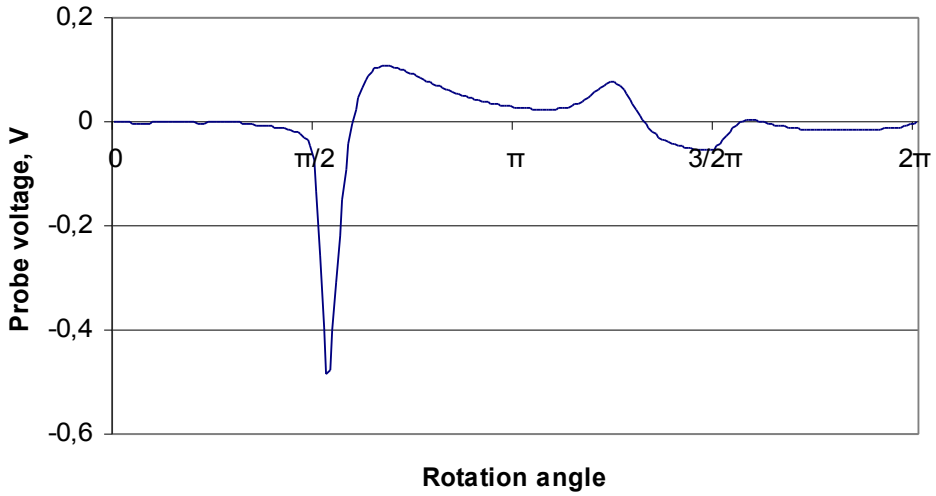

Fig. 2. The probe voltage as a function of rotation angle

Initially we have measured the charge relaxation time for the sample which was not cleaned before the measurement. It was taken from the box where it was kept during long time. In air the relaxation time was about 3 hours. Then it was placed into the vacuum chamber which was pumped down to a pressure of about 10^{-7} Torr. The measurement of the charge distribution was carried out once a day. The time dependence of the peak amplitude was shown in Fig. 3. These measurements started in 10 days after beginning of the pumping because some increase of the relaxation time was observed through time. The relaxation time was found to be (2800 ± 100) hours. The relaxation time close to this value was found for electrical charge deposited on the back side of the sample which had no coating and also was not cleaned before the measurements.

Then the sample was cleaned in an ultrasound bath with acetone and then was cleaned by methanol. After the cleaning it was quickly placed into the vacuum chamber. Two runs of measurements of relaxation of the deposited charge were carried out. The time dependences of the peak amplitude are shown in Fig. 4 and 5. The charge relaxation time was calculated assuming the exponential decay to zero value. In the first run the relaxation time was found to be 2460 days with large standard error. This run was relatively short for some reasons. In the second run the relaxation time was found to be 2580 (+1450, -660) days. One can see the relatively large (of about 1%) change of the probe voltage after 20 days of observation which may be caused by various reasons e.g. a change of the amplifier gain. But even in this case the low boundary of the relaxation time calculated for full run was longer than 1920 days or 5 years.

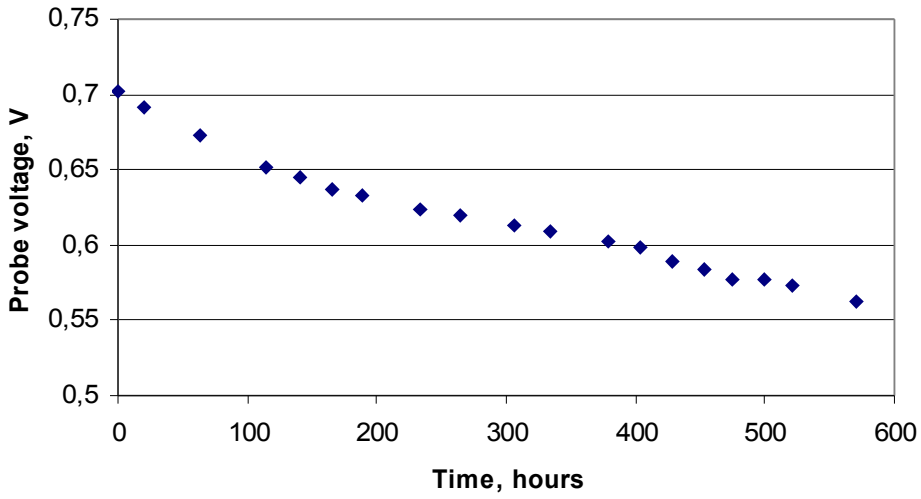

Fig.3. Time dependence of the peak amplitude (decay of the charge on the sample without cleaning)

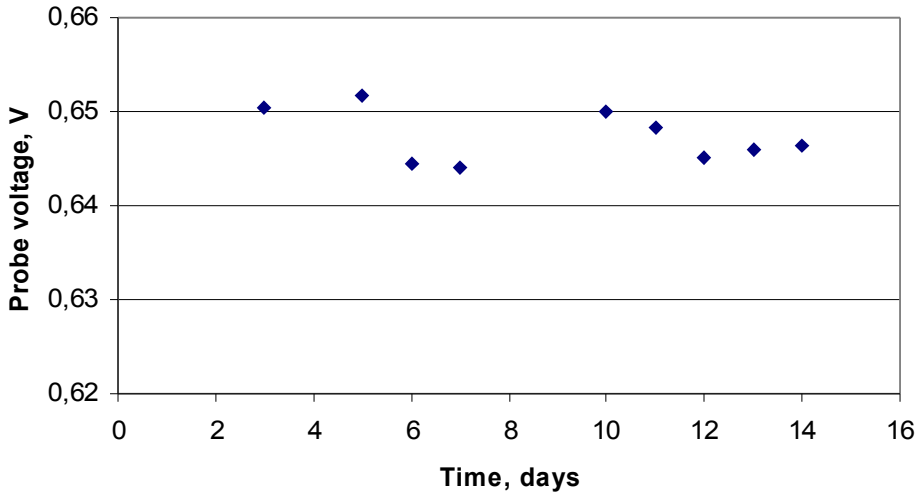

Fig.4. Time dependence of the peak amplitude (decay of the charge on the sample after cleaning, run #1)

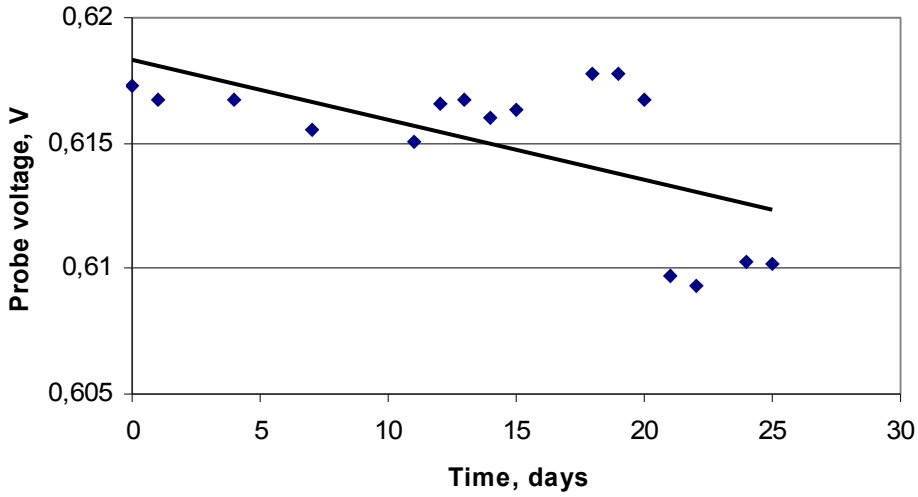

Fig.5. Time dependence of the peak amplitude (decay of the charge on the sample after cleaning, run #2)

Conclusion

The charge relaxation time depends strongly on cleaning of the sample surface. Using of an ultrasound bath simplifies the cleaning procedure but it may damage the optics. Apparently, the standard LIGO optics cleaning procedure also provides the low surface electrical conductivity and the relaxation time of several years.

It is possible to reduce the uncertainty in the measured charge relaxation time if we increase the measurement time. Nevertheless, the low boundary of the charge relaxation time for fused silica which has been obtained in the present work allowed us to reduce the estimate of fluctuating force acting on the LIGO optics according the Rai Weiss model [1]. More considerable fluctuating electrical force may be caused by charges located on the viton tips (bad dielectric) of the earthquake stops and their relaxation.

References

1 R. Weiss, LIGO technical note. Available at http://www.ligo.caltech.edu/T/T960137-00.pdf.

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