

Measurement of remanent dielectric polarization in fused silica and its application to investigation into cleaning with First Contact™



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Introduction

- Lately, we studied a behavior of **real charges** deposited with contact charging on fused silica test masses. It is important because the contact charging occurs e.g. when earthquake stop touches the test mass. Additional noise may be associated with relaxation of **real charge** distribution.
- In order to study noise associated with electrostatic drive (ESD) it is important to explore effect of application of relatively strong electric field ($E \approx 1 \text{ kV/ cm}$) to fused silica.
- Electric field creates dielectric polarization of fused silica or **polarization charges**. When we measure charge distribution on the sample after switching off polarizing electric field we observe some residual charge.

It may be a result of migration of real charges in electric field or residual dipole moment in the sample. We can not distinguish between these two cases. For interpretation of experimental results we assume that the aftereffect is associated with **remanent polarization charge** on the sample.

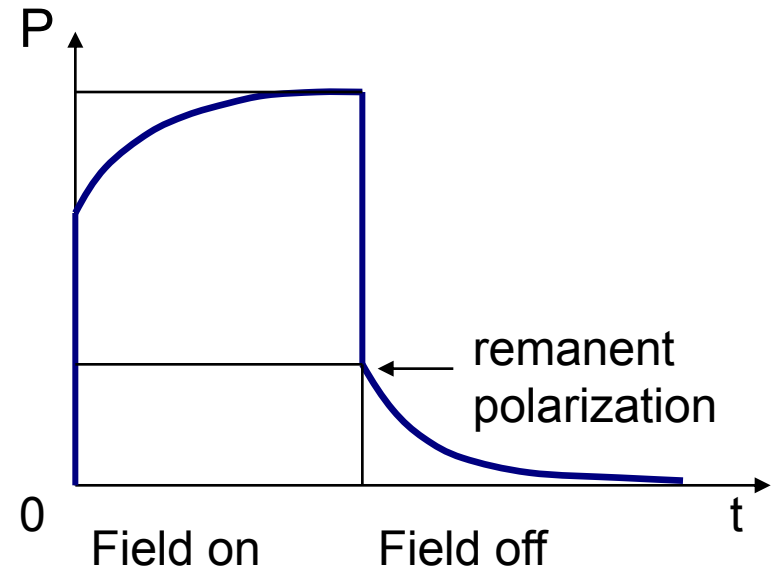
Remanent polarization charges in dielectrics

Polarization charge density σ_{pol} – charge density on surface of dielectric associated with its polarization \mathbf{P}

$$\sigma_{\text{pol}} = \mathbf{P} \cdot \mathbf{n}$$

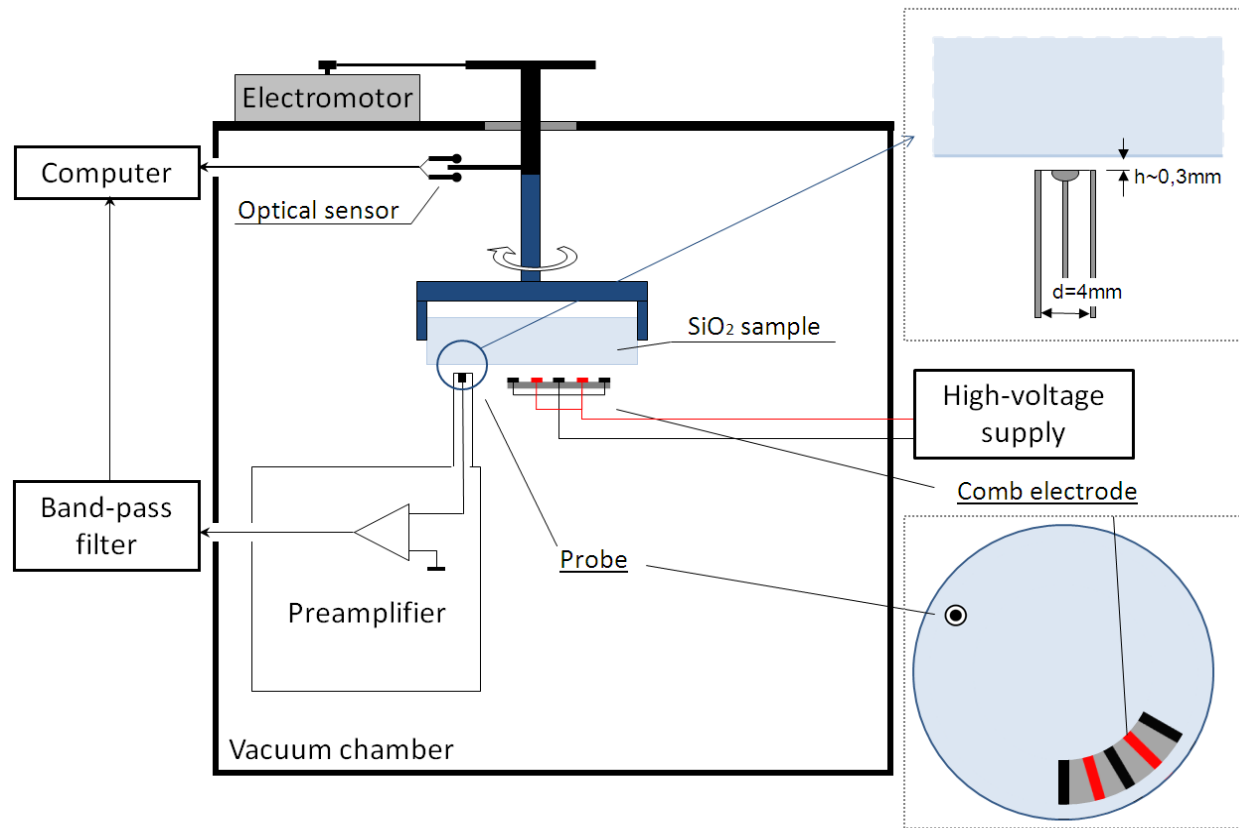
\mathbf{n} - vector of normal to the surface.

We measure polarization charge which remains in dielectric after switching off the polarizing electric field.

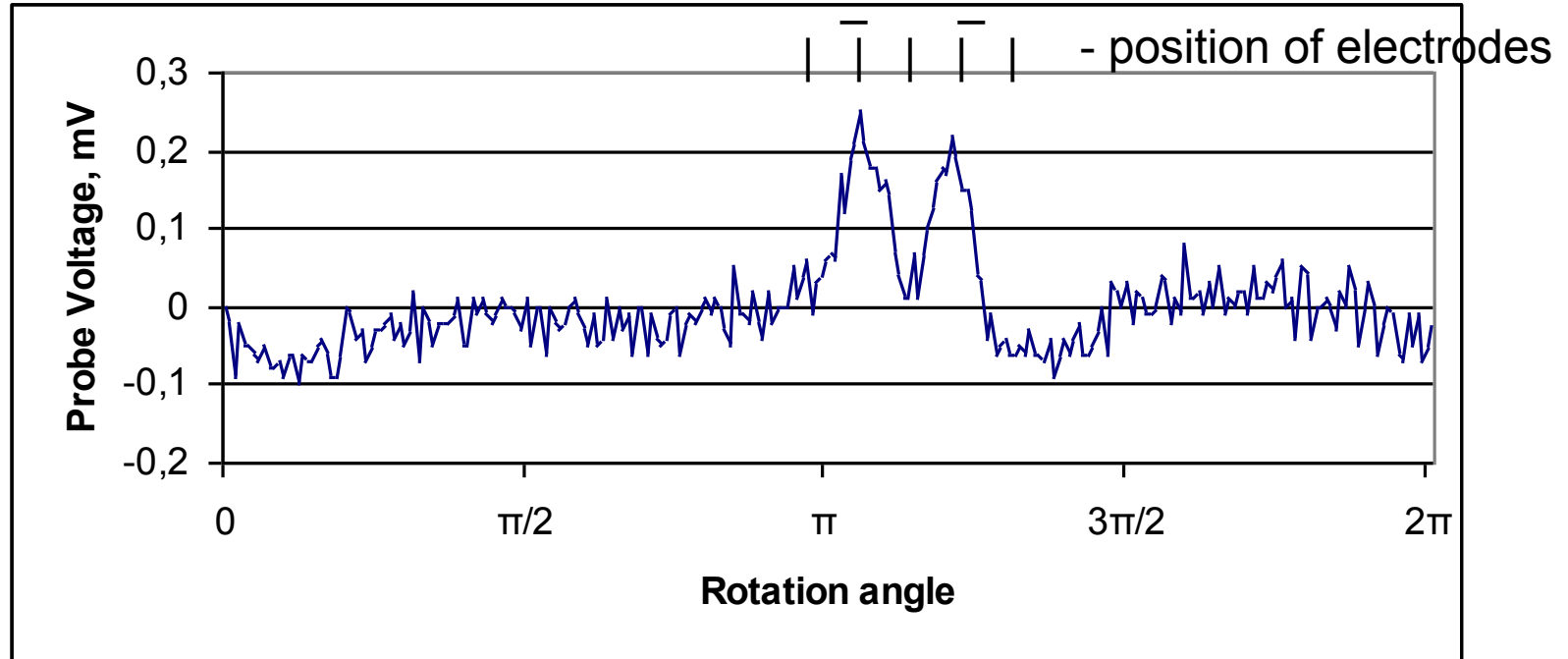


Time dependence of polarization
(general concept)

Setup for measurement of remanent polarization charge on the sample along strip of scanning



Distribution of charge on clean sample after switching off electric field



Polarization voltage of 600 V was applied to electrodes during 4 hours
(Rough estimate of polarization charge density $\sim 3 \times 10^9 \text{ e/cm}^2$)
After switching off electric field:

Amplitude of remanent polarization charge density $\approx 10^5 \text{ e/cm}^2$
Decay time of remanent polarization charge $> 10^6 \text{ sec}$

Features of cleaning of fused silica with First Contact™

- To protect and clean surface of fused silica it is coated with liquid polymer First Contact. After removing First Contact dried film one obtains very clean surface.
- People working under cleaning of fused silica samples with First Contact know about some issues of FC application ([see e-mail and telecon discussions of LIGO charging group](#)):
 - √ large charge remains on the surface after removing of dried First Contact film;
 - √ small pieces of polymer can remain on the surface especially on bevels.

Charging of sample after removing First Contact film

Results of measurements:

“Mosaic” surface charge structure (alternate positive and negative charged areas with size of order of 1 cm) was formed on the sample surface.

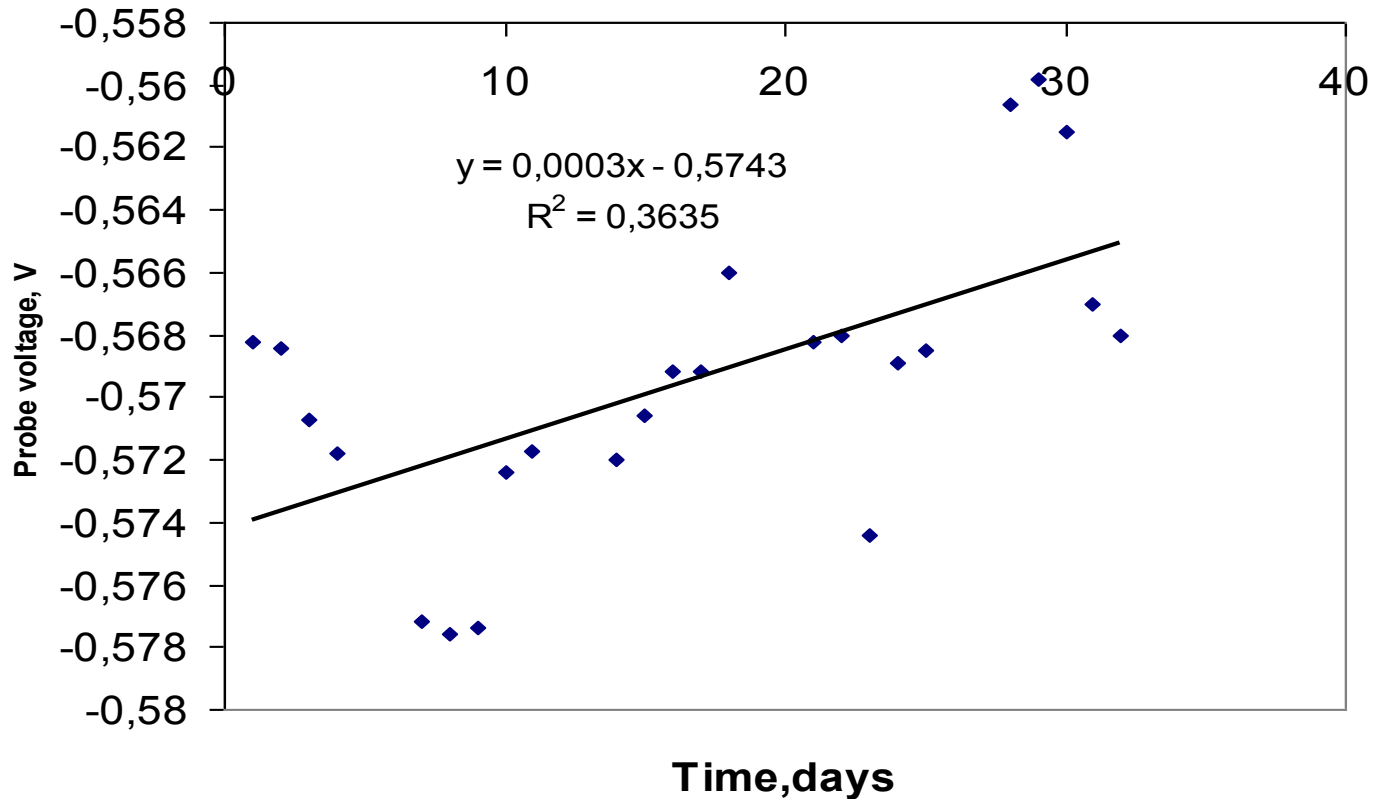
Approximate magnitude of charge density

- ✓ After removing FC film $> 10^9 \text{ e/cm}^2$
- ✓ After removing FC&CNT film $\approx 10^9 \text{ e/cm}^2$
- ✓ After discharging (neutralization of charge) by Ionizing Gun (Terra Universal) $< 10^6 \text{ e/cm}^2$
- ✓ After pumping down the vacuum chamber with sample which was discharged $< 10^6 \text{ e/cm}^2$

Issues:

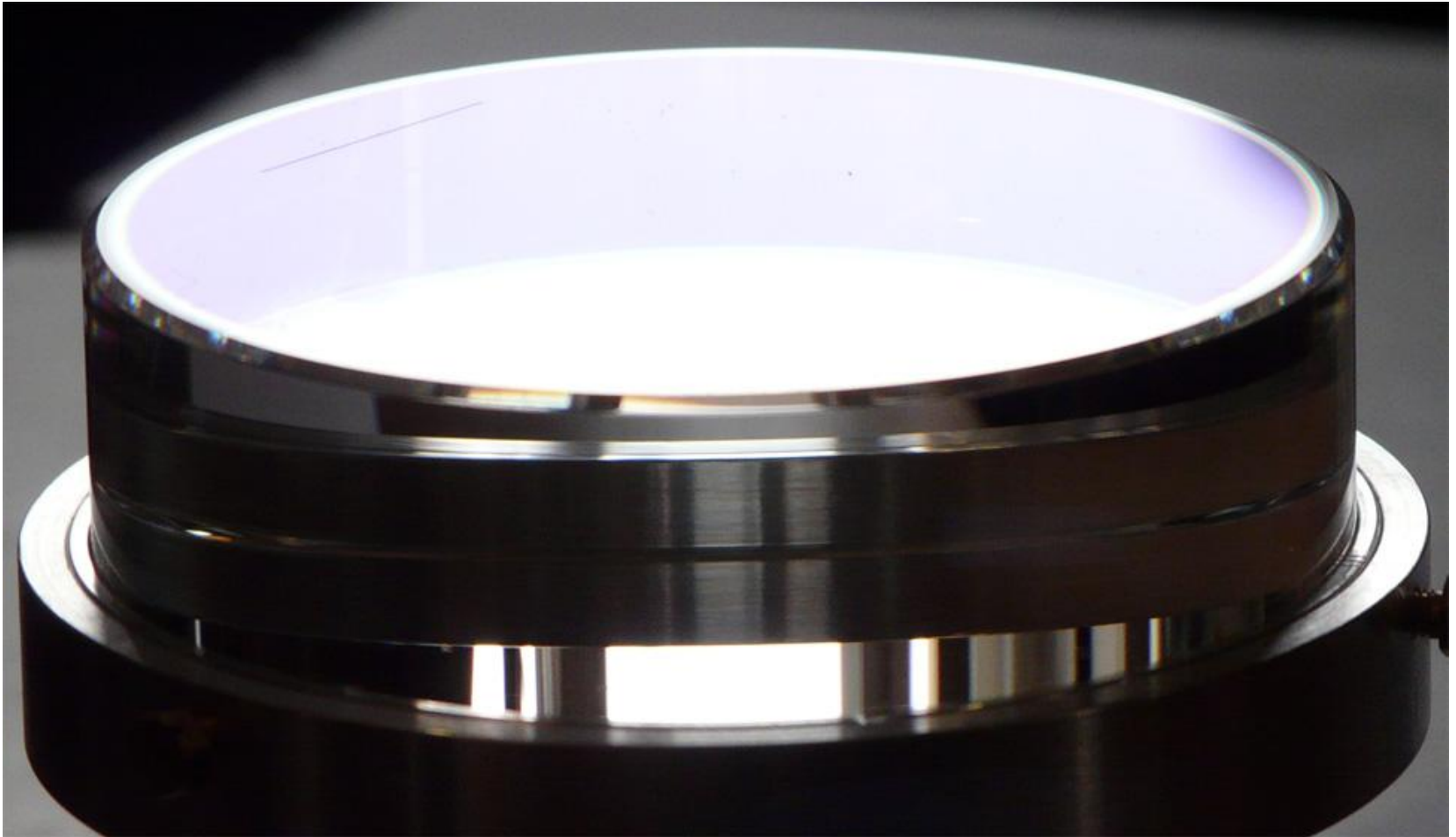
Colleagues concern about pieces of FC and dust which are attracted by charged surface until it was not discharged.

Decay time of charge on the surface after cleaning with First Contact

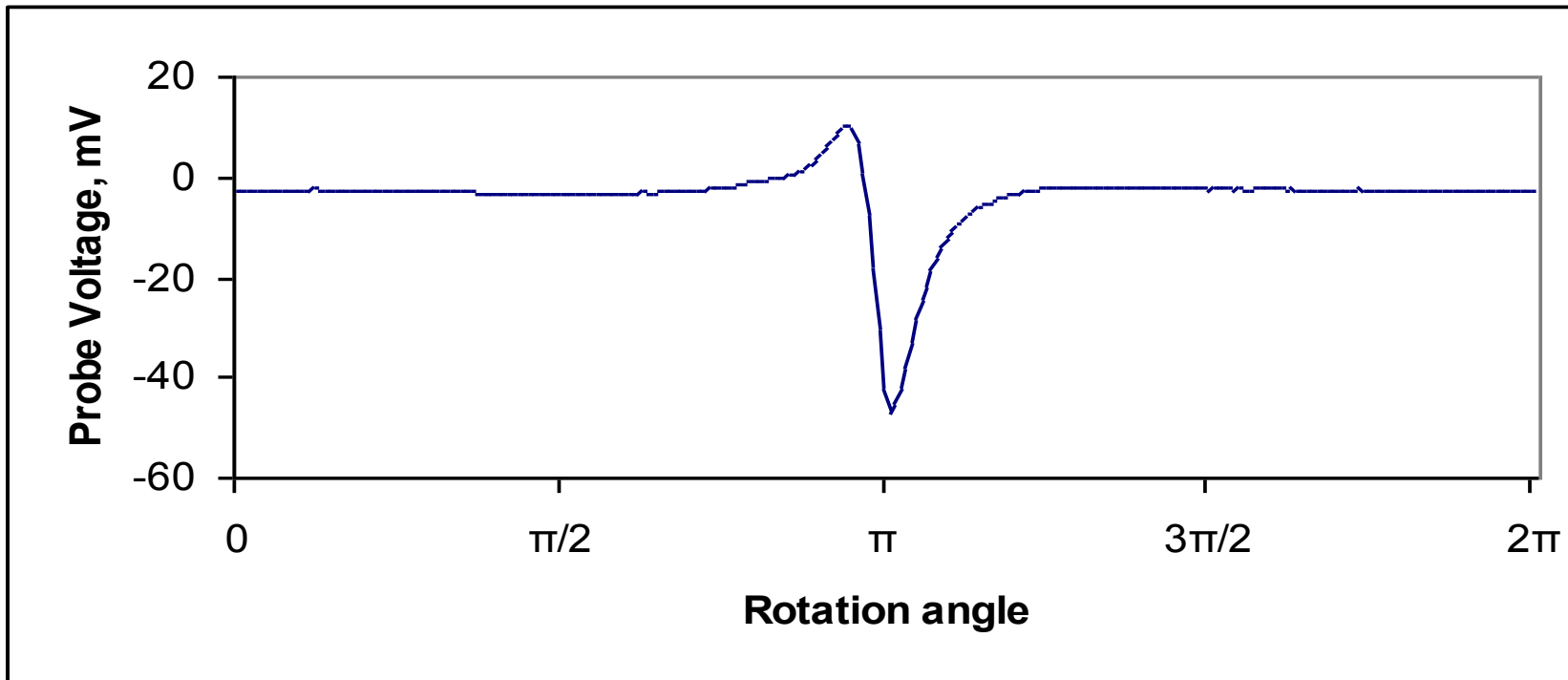


Time dependence of the negative charge peak amplitude for sample cleaned with FC&CNT (Decay time > 3 years)

Sample #31 with scratch on surface



Remanent polarization charge on the sample #31 (polarizing field was applied near the scratch)



Amplitude of remanent polarization charge $\approx 3 \times 10^7 \text{ e/cm}^2$
(increase by a factor of **300** as compared with surface without scratch)
Decay time of remanent polarization charge $\approx 3 \text{ hours}$ (non-exponential law)

Results of measurement of remanent polarization charge on the sample #31 with pieces of FC and FC&CNT on the surface

In order to check a hypothesis that contaminations (especially remains of FC polymer) inside the scratch determine the remanent polarization charge we deposited small pieces of FC and FC&CNT on the sample surface and carried out measurements.

Results:

- 1) large remanent polarization charge is formed in areas with pieces of FC and FC&CNT
- 2) decay time of remanent polarization charge in areas with FC and FC&CNT is about 150 sec (3 hours for the scratch)

Strong dependence of magnitude of the remanent polarization charge on surface contaminations was also observed for other samples.

Conclusion

- Measurement of remanent polarization charge allows us to determine contaminated areas on the surface of fused silica. Clean surface gives small remanent polarization charge with large decay time. Contaminations on the surface (in particular pieces of First Contact film) result in appearance of large remanent polarization charge with relatively small decay time. It may produce additional noise.
- Scratches may be a source of remanent polarization charge with relatively small decay time.
Even through there are no scratches on the surface of optics they may appear on bevels after hitting of fused silica tip of earthquake stop. It is worth more detailed analysis.