Mitigation of the electrostatic charge on test mass mirrors in gravitational wave detectors

M. Angelucci[1], L. Spallino[1], G. Mazzitelli[1], R. Musenich[2], S. Farinon[2], A. Chincarini[2], F. Sorrentino[2], A. Pasqualetti[3], G. Gemme[2], and R. Cimino[1]

1 - LNF-INFN, Frascati, Italy *2 - Dipartimento di Fisica, Universitá degli Studi e INFN, Genova, Italy*

3 - European Gravitational Observatory (EGO), Cascina (Pisa), Italy

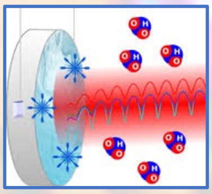
Introduction

The new generation of Gravitational Wave (GW) observatory will be upgraded using cryogenically cooled mirrors. Their use will increase the performance and the accuracy of the GW detection. In particular, cryogenic mirrors are already foreseen for the low frequency detector of the planned Einstein Telescope.

Electrostatic charging on test masses has been shown to be a limiting noise source for GW interferometers [1]. Within the LIGO collaboration, a mitigation method proposed and successfully applied consists in the exposure of the mirror to some tenth of mbar of N_2 plasma. By applying this method, a significantly thick layer of condensed gas will develop on the cryogenic mirror surface influencing its reflectivity and thermal noise [2]. The effect of cryosorbed gas on mirror surface has been observed at KAGRA GW detector. [3]

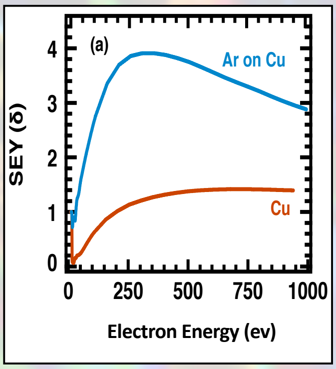
We present a novel method to neutralize test masses electrostatic charge [4]. We propose the use of selected energy electrons which can impinge on the mirror surface. According to their energy, the number of secondary electrons produced per incident ones, called Secondary Electron Yield (SEY), could be ≤ 1 or ≥ 1, i.e. removing or adding electrons to the mirror's dielectric surface or part of it.

An example of the applicability of this method is reported. We considered the SEY of a insulting layer formed by 25 ML of Argon ice cryosorbed on Copper to be representative of insulator [5].



Experimental Considerations

The physical process describing the effect of an electron impinging on a surface can be schematized with the so called three-step process: 1) production of Secondaries at a depth z below the surface, 2) transport toward the surface, 3) emission across the surface barrier. The number of emitted Secondaries is a property of the surface. This process is very surface sensitive and involve, at most, the first few nm closer to the surface [6].



This method has a number of significant advantages:

i) Electron guns operate in UHV and are compatible with a cryogenic environment.

ii) Electrons can be easily focussed or defocused and directed to regions where charge may be more significant.

iii) Electrons do not significantly penetrate into the mirror surface due to their low mean free path, so that minimal effects on mirror quality is expected.

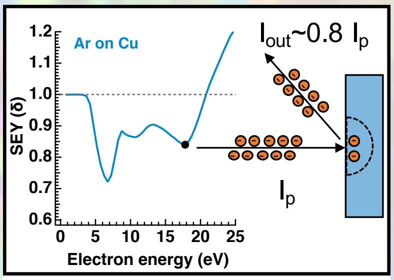
iv) Low energy-selected electrons can indeed compensate charges of both polarity on mirror optics.

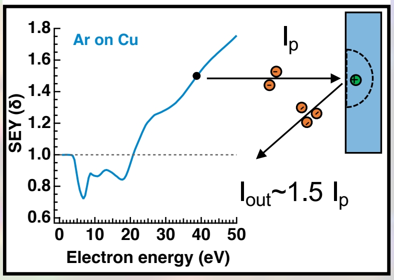
Mitigation Method

We can cure electrostatic charging by using relatively low energy (≤ 50-100 eV) electrons irradiation.

- Discharging a positive sample: In this case, all electrons increment their energy by the surface charge. Considering the recombination of low energy secondaries, due to the interaction with the positive surface, the net process should be a decrease of the positive charge on the surface. The final state of the system will depends to the initial electron energy: if the energy is low (SEY ≤1) the sample will charge negatively, if the energy is high (SEY≥1) the sample will stay positive, if we set the energy of the impinging electrons where the SEY is 1, the sample will be neutralized.

- Discharging a negative sample: In this case, all impinging electrons will be decelerated from their initial energy by the surface charge. Tuning their energy in a range where SEY ≥1, taking into account deceleration, the surface will emit more electrons than the ones deposited. This will reduce negative charge down to neutralization.





Conclusions

We have presented a conceptually simple method that could be applied to neutralize electrostatic charges formed on test mass mirrors in GW interferometers. Knowing the initial charge, or the effect on some observables of such charging, it is always possible to opportunely tune the impinging electron energy to force the surface to eject (in case of negative charge) or to keep (in case of positive charge) electrons up to neutralization. The presented method can be applied in case of cryogenic surfaces. Electrostatic charging represents one of the technological challenges for the successful operation of future GW interferometers.

References

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