Low energy electrons to actively cure frost and electrostatic charging issues in future gravitational wave detectors

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Introduction

In the upcoming third generation of gravitational wave (GW) detectors, electrostatic charging [1], and the build-up of a frost layer on cryogenically cooled mirrors [2] may represent two potentially critical showstoppers for GW detection.

We approach a possible mitigation solution for both such apparently uncorrelated issues, relying on irradiation with low energy electrons (few hundreds eV) of the optical elements [3, 4]. Here we present the main experimental activity, ongoing at LNF-INFN, demonstrating that low energy electrons may be indeed used as a mitigation method to cure surface charging and frost formation.

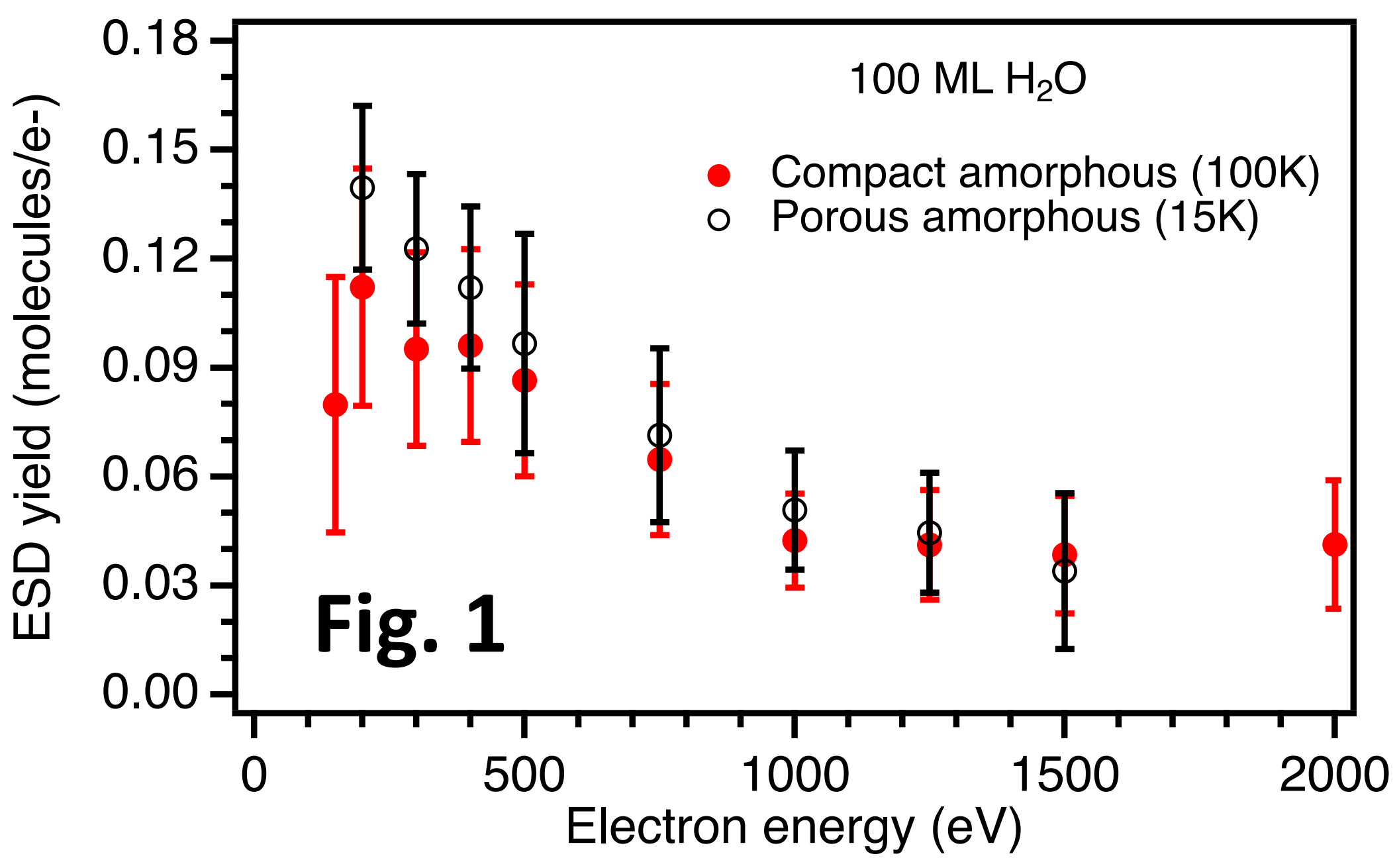
Electron Stimulated Desorption

Electrons irradiation can efficiently induce ice desorption by Electron Stimulated Desorption (ESD) processes (Fig. 1). It is known that:

V **The duration and the expected thermal power deposited on the surface by ESD (a non-thermal method [3]) should be significantly lower in respect to any thermal desorption processes [4].**

X **Electron irradiation causes electrostatic charging**

→ a neutralization method compliant with cryogenics is mandatory



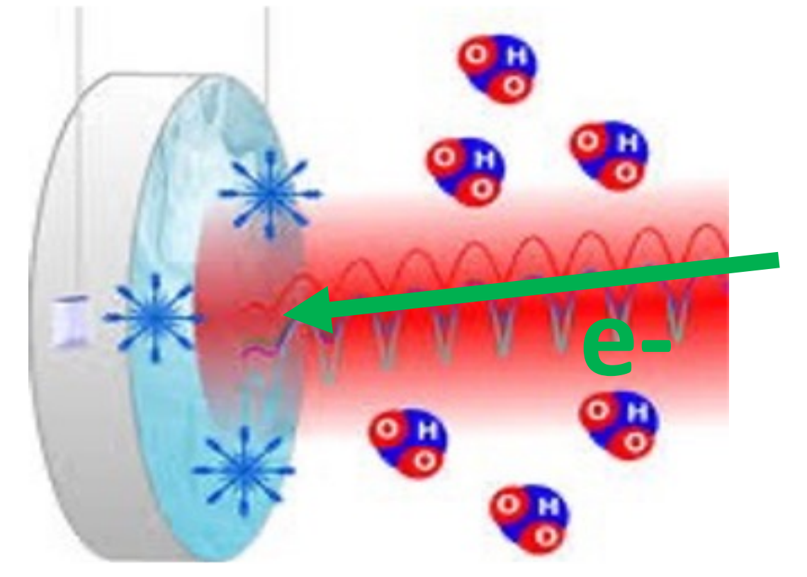


Fig. 1: ESD yield (efficiency of the electron desorption) for H_2O molecules condensed at 15 K or 100 K [3, 5]. Ice layer thickness is given in monolayer (ML), where 1 ML ~ 0.3 nm. (*Courtesy of R. Dupuy*)

Electrostatic charging neutralization

Fig. 2

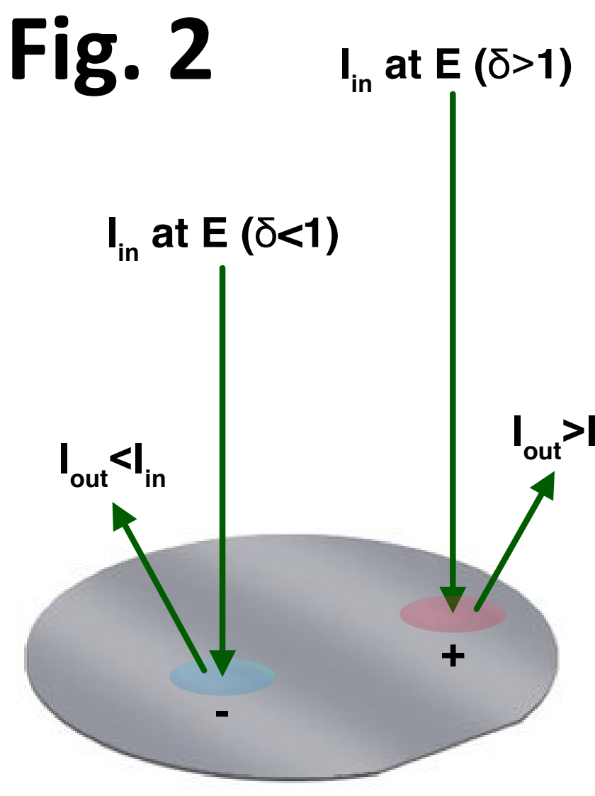


Fig. 2: Artistic view of mirror charging/discharging with electrons

The basic principle to neutralize electrostatic charge on surfaces by using selected energy electrons is sketched in Fig. 2 [5]. According to the impinging electron energy, the secondary electron yield (SEY, which is the number of electrons emitted per incident ones, $\delta = I_{out}/I_{in}$) could be ≤ 1 or ≥ 1. It is possible to remove or add electrons to the mirror's dielectric surface (or part of it) by properly tuning electron irradiation energy.

Experimental

Charging and neutralization experiments are performed with a non-contact electrostatic voltmeter. It measures the voltage generated by a charged surface (V_s). A scheme of the set-up is reported in the Fig. 3. The sample (electrically insulated) is connected to a metallic plate (Probed surface, Ps). Under electron irradiation, a sample's image charge is induced on the PS. The voltage generated by such charge is revealed by the voltmeter sensor. Electron irradiation are performed as a function of energy, maintaining an incident current of the order of tenth of nA on a sample area ~2 mm².

Fig. 3

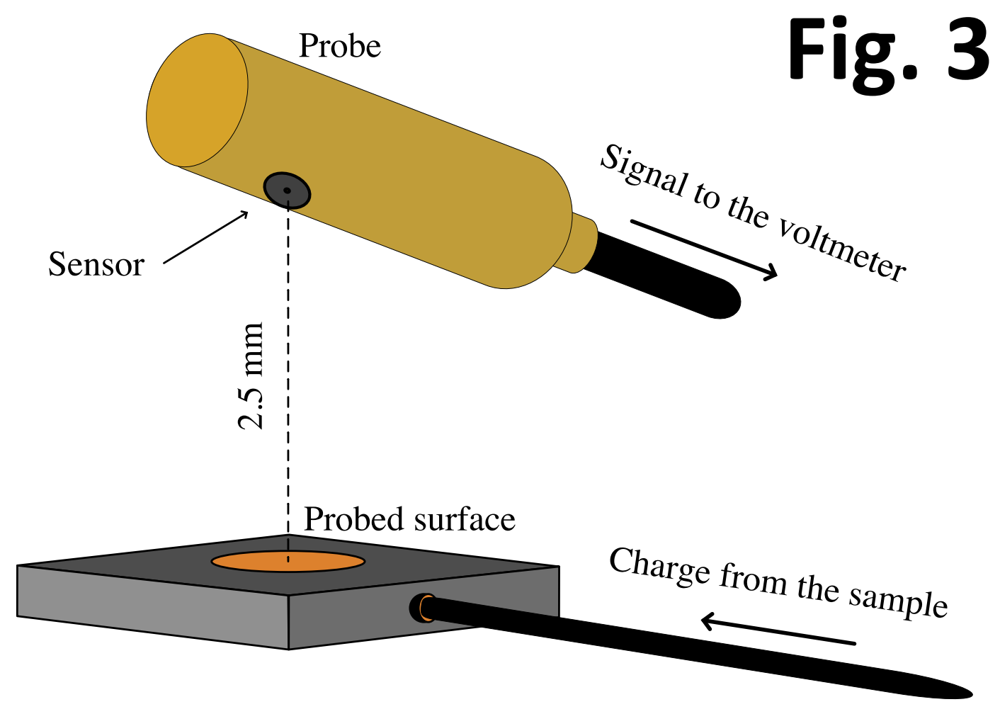


Fig. 3: Sketch for voltage measurements.

Some results

Fig. 4

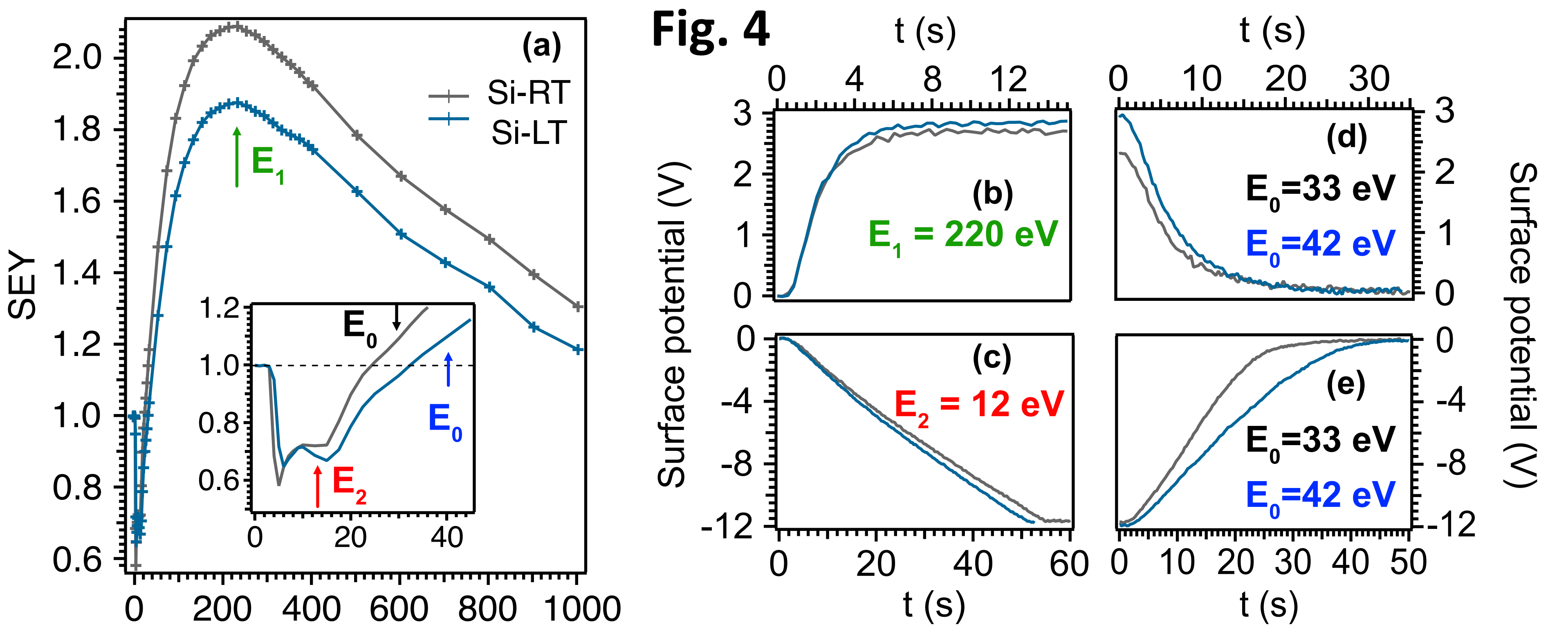


Fig. 4: (a) SEY curves of the Si sample acquired at RT and LT. The inset is a magnification of the low energy regions. Green and red arrows point to the δ values at the charging irradiation energies E_1 for positive (b) and E_2 for negative (c) charging. Black and blue arrows point to the neutralization energies at RT and LT, (d) and (e).

Both at RT and LT, we observe:

- **Positive and negative charging (done irradiating at E_1 and E_2, respectively) are here reported for the sample initially neutral. At those energies, indeed, δ (E1)>1 and δ (E2)<1. A stable potential is reached in all cases. This behavior is general whatever the initial potential surface V_s.**
- **Whatever the initial V_s, irradiating the surface with electrons at E_0 near E(δ=1), charging neutralization will occur. The experimental difference between E_0 and E(δ=1) is under study. More work is required to clearly address the physical origin of such a discrepancy in order to master the process.**

→ <u>At RT and LT as well</u>, by properly tuning impinging electrons energy, it is possible to induce at will both positive and negative charges or to neutralize them.

In Fig. 4, an example of charging by electron irradiation is reported for the specific case of a Si sample at room temperature (RT) and at 15 K (LT). The SEY (δ) curves of the sample at the two temperatures are also shown. The difference in the SEY features are ascribed to the presence of contaminants at the LT surface. As shown in the inset, E(δ=1)=24 eV and 33 eV at RT and LT, respectively.

Future work

- **Neutralization studies on insulator samples, both at RT and LT.**
- **Neutralization studies in presence of cryosorbed gas layers on different substrates.**
- **Study on the effects induced on the quality of optical surfaces.**
- **Study to combine ESD and neutralization parameters.**

References:
[1] *L. G. Prokhorov et al., Class. Quantum Gravity (2010)* ***[2]*** *J. Steinlechner et al., Phys. Rev. Res. (2019););* ***[3]*** *R. Dupuy et al., J. Appl. Phys. 128, 175304 (2020);* ***[4]*** *L. Spallino et al., Phys. Rev. D (2021);* ***[5]*** *L. Spallino et al., Phys. Rev. D (2022)*