# Frost and electrostatic charge formation in mirrors of future gravitational wave detectors: mitigation strategies for two potential showstoppers

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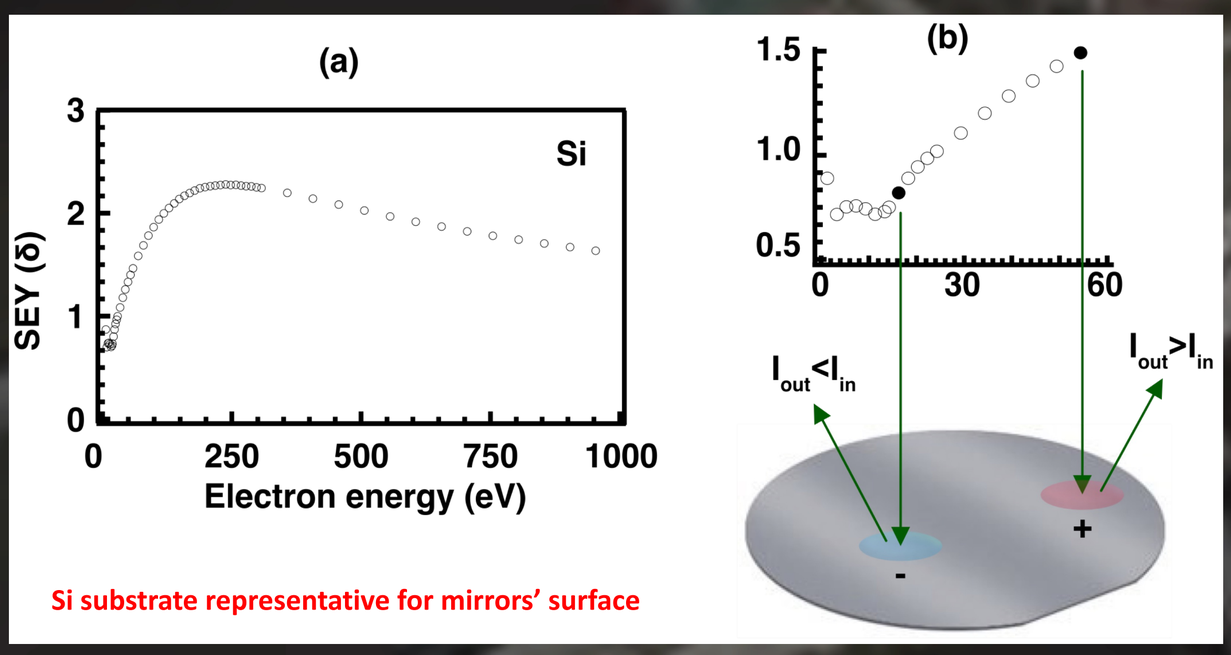
## Introduction

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 at low frequency. As already experienced at KAGRA GW detector [1], gas condensation onto the cold mirror can affect its reflectivity and induce thermal noise [2].
One more issue, occurring also at room temperature, is due to electrostatic charging of test masses. This phenomenon has been shown to be a limiting noise source for GW [3]. Within the LIGO collaboration, a mitigation method has been successfully applied and consists in exposing the mirrors to some tenth of mbar of $N_2$ plasma. Noticeably, this solution cannot be applied on cryogenically cooled mirrors without forming on its surface an unacceptably thick condensed $N_2$ layer.
Here we present an experimental proof of principle suggesting that low energy electrons (between 10 to 100 eV) could be used to mitigate both issues: electrons are known to be very efficient in inducing gas desorption [4] and can neutralize surface electrostatic charge also at cryogenic temperature [5].

## Electrostatic charge neutralization

The parameter quantitatively defining the electron interaction with a material surface is the Secondary Electron Yield (SEY or $\delta$). SEY is defined as the ratio between the number of all emitted electrons $I_{out}$ and incident electrons (also called primary electrons) $I_{in}$ :$SEY=I_{out}/I_{in}$

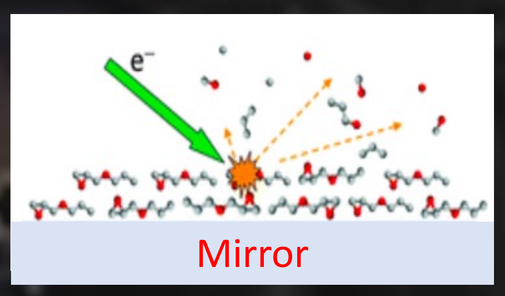
Depending on the primary electron energy, SEY can be ≤ 1 or ≥ 1, as shown in (b). Depending on the impinging electron energy, we can deposit electrons onto the surface (SEY<1) or force the surface to emit more electrons than the ones delivered by the primary electron beam (SEY>1).



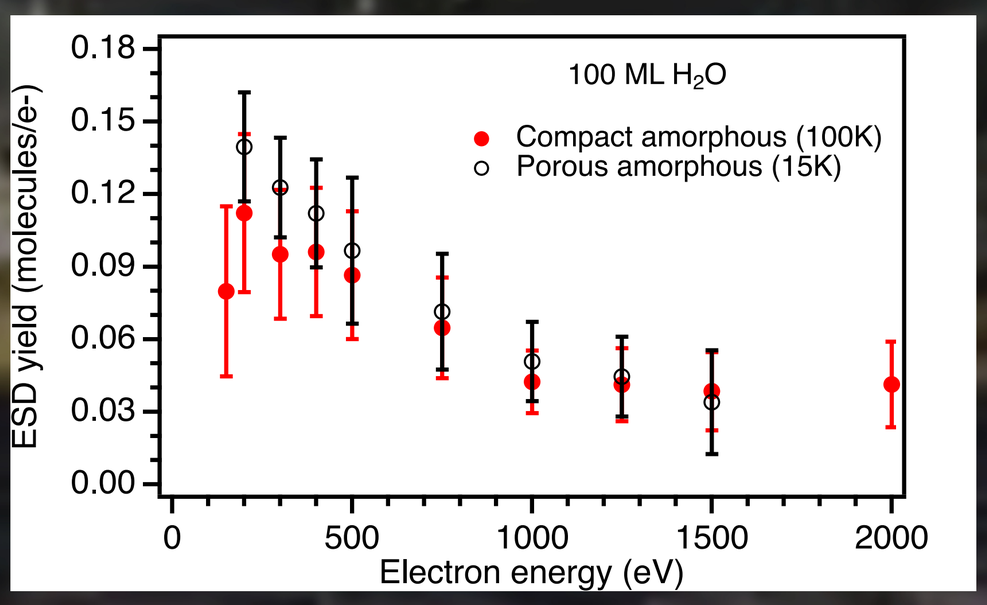

Si substrate representative for mirrors' surface

This basic concept suggests the possibility to tailor electron energies to induce positive or negative charge on a neutral surface

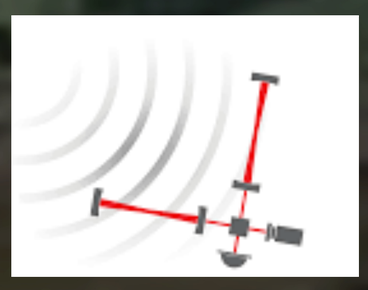
## Electron stimulated desorption




Electron Stimulated Desorption (ESD) is a **non-thermal method** [5,6]. The **duration** and the **expected thermal power** deposited on the surface by ESD should be significantly lower in respect to thermal desorption processes.
Due to their very low mean free path (of the order of 1 nm, for electrons energies between 10 and 1000 eV [7]), electrons do not significantly penetrate below the surface, with a minimal effects expected on mirror quality

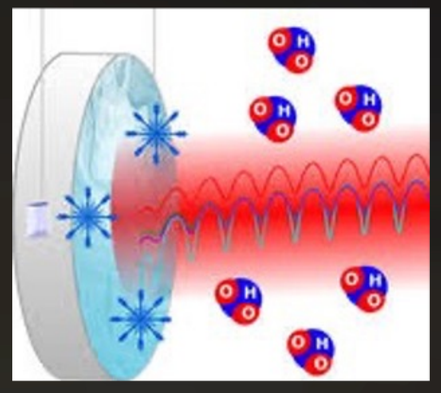



ESD yield ($\eta$) measures the efficiency of the electron desorption.
In the figure, $\eta$ is reported for $H_2O$ molecules condensed at 15 K or 100 K. The thickness of the ice layer is given in monolayer (ML), where 1 ML ~ 0.3 nm. (*Courtesy of R. Dupuy*)



## Conclusions

Using electrons to stimulate desorption requires not to induce any surface charging.
Here we show that electrons can be used both to remove the frost from mirrors' surface of future GW detectors and to mitigate charging issues.
An intense R&D activity has to be targeted to pass from the idea here presented to its refinement and implementation in the real system.



**References:**

[1] J. Steinlechner and I.W. Martin, Phys. Rev. Research 1, 013008 (2019)
[2] K. Hasegawa et al., Phys. Rev. D 99, 022003 (2019)
[3] A. Buikema et al., Phys. Rev. D 102, 062003 (2020)
**[5] L. Spallino et al., Phys. Rev. D, 104, 062001 (2021)**
**[4] L. Spallino et al., Phys. Rev. D, 105, 042003 (2022)**
[6] R. Dupuy et al., J. Appl. Phys. 128, 175304 (2020)
[7] R. Cimino and T. Demma, Int. J. Mod. Phys. A 29, 1430023 (2014)