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Vacuum issues and possible mitigations in cryogenic gravitational wave detectors and cold mirrors test benches

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In the upcoming third generation of gravitational wave (GW) detectors, the push toward low-frequency detection necessitates the use of cryogenic optics at temperatures as low as a few Kelvin. This unprecedented technological challenge has spurred a series of R&D efforts aimed at validating the use of cryogenic optics in GW detectors. The performance of cryo-mirrors must be carefully measured and optimized to determine the best operational solution, and several promising R&D initiatives have been launched to address these challenges.

Here, we examine a simple yet critical experimental phenomenon that, if not properly accounted for, could compromise some of these observations: the unavoidable accumulation of a frost layer on cryogenically cooled mirrors. A cold surface effectively acts as a pump, allowing contaminants to build up depending on residual vacuum conditions, the cooling process, and other factors. If overlooked, this phenomenon can severely hinder the detailed optical characterization of cryogenic optics, as the unwanted and unspecified contaminant layer may reach thicknesses of several microns or more.

In this work, we present a straightforward method to estimate the thickness of this frost layer and propose a potential mitigation strategy for its removal, applicable both in test benches and actual detectors. The approach involves irradiating the optical elements with low-energy electrons (up to few hundreds eV).
We report on the experimental activities conducted at LNF-INFN and outline the necessary R&D efforts to transition this validated concept into a practical solution, potentially integrating it into the complex design of low-frequency detection systems.

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