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Understanding photo-emission on Au-coated surfaces of LISA Gravitational Reference System

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Abstract. As part of the Laser Interferometer Space Antenna (LISA) test campaign, we have developed a ground-based facility to measure the photo-electric yield of the LISA Gravitational Reference System Au-coated surfaces. In space, the free-falling LISA test masses will be exposed to and expected charging flux in the range 10-100 e/s. To keep the charge on the test masses below the required limit of $|Q|<2.4\,\mathrm{pC}$, we shine UV light onto the surfaces to discharge them using the photo-electric effect. Our facility includes a replica of the LISA Pathfinder electrode housing with inside a hollow test mass, all under vacuum. We've shown that the facility can achieve a current resolution $<1\,\mathrm{fA}$. We characterized photo-electric yield as a function of test mass voltage, injection electrodes voltage and time, obtaining results compatible with previous experiments[1, 2].

1 Introduction

Laser Interferometer Space Antenna (LISA) is an ESA/NASA space based interferometer for measuring gravitational waves with proposed launch date in 2035[3, 4]. At the core of the three spacecrafts of the LISA constellation, the Gravitational Reference System (GRS) provides the free-falling test masses (TMs)[4] and electrode housings (EHs) around them. The TMs are 46 mm side Au-Pt cubes, Au-coated, that will follow geodesics of spacetime with acceleration noise down to $2\,\mathrm{fm/s^2/\sqrt{Hz}}$[5, 4] along the measurement axis. The EHs surround them with two sets of electrodes: 12 "actuation/sensing" and 6 "injection". The first can measure the 6 degrees of freedom of the TM as well apply electric forces. The latter applies an oscillating bias at 98 kHz on the TM[4]. Any residual charge on the TM couples with electric noise from the electrodes, generating a force noise[6]. LISA requires $|Q|<2.4\,\mathrm{pC}$[7, 8] to achieve its target performance. But solar energetic particle events and galactic cosmic rays penetrate the spacecraft and the GRS charging the TM with an expected net positive rate of 10-100 e/s (1-10 aA)[7, 8]. To compensate this effect the photo-electrons are emitted from the surfaces via photo-electric effect[4, 7, 8]. The Charge Management System (CMS) employs UV LEDs with emission peak at $\sim$4.9 eV. The LEDs can be switched on just for tens of ns with a very precise delay in respect to the injection potential. This modifies the trajectories of photo-electrons emitted with kinetic energy <1 eV. The GRS testing campaign from the qualification model to the flight model, has to include measurements to verify the effectiveness of the CMS in a time efficient and reproducible way. We developed a measurement facility that allows for consistently measuring the discharge current and evaluate the photo-electric apparent yield of the surfaces, i.e. number photo-electrons emitted over number of incident photons, with the formula:

$$Y = \frac{I/e}{P_{UV}/E_{UV}} \quad \left[\frac{\#\mathrm{e}}{\#\mathrm{ph}}\right] \tag{1}$$

where I is the photo-current, P_{UV} the light power hitting the surfaces and E_{UV} the energy of UV photons.

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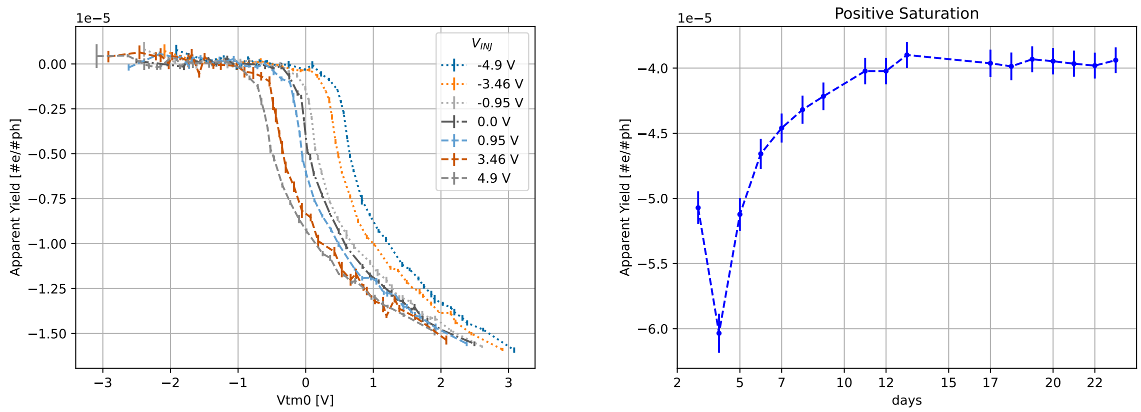
2 Facility description

In the facility, the TM is an aluminum hollow cube while the EH is a prototype of the LISA Pathfinder (LPF) EH made of molybdenum, the LISA one will follow the same design. Both are Au-coated at LISA specification level. These items are set in a vacuum chamber connected outside via coax cables to an Electrical Interface Box and through this to a Keithley electrometer which measures the photo-current. The Electrical Interface Box feeds DC voltages to the EH and electrodes (only 4 out of 18, the others are shorted to EH) to emulate various in-flight configurations. In this framework the TM potential $V_{TM} = -V_{EH} - \alpha V_{INJ}$, with $\alpha = C_{INJ}/C_{tot} = 0.12$, emulates the effects of the charge (by fixing the EH voltage V_{EH}) and instantaneous injection potential V_{INJ} during the illumination. UV light from a Hg Lamp with peak at 253 nm (4.7 eV) is shone inside the EH via a fiber terminating into an emitter. The TM acts as collector of electrons. As voltages are applied across the TM-EH system a dark current flows though the leakage resistance ($\sim$10 TΩ) due to the plastic joints used to keep the TM centered inside the EH. This produces an offset in the electrometer readings. By modulating the UV light output via an in-fiber shutter, we decouple the photo-current from this offset. Working at 10 mHz, the facility can resolve photo-currents of 0.7 fA in 10 minutes.

3 Results

Our facility allows measuring discharge curves, i.e. the dependence of the current/yield as a function of the TM potential, which provides useful information on the TM and EH surfaces emissivity. Each curve shown in Figure 1(a), has been measured by modulating light at 10 mHz shone on the EH at fixed V_{INJ} while changing V_{EH} every 10 minutes. Each curve takes about 6 hours to be measured. The curves are consistent with the idea that the injection potential changes the electric field the photo-electrons travel through. Notice how the positive saturation regime starts at higher V_{TM} as V_{INJ} becomes more negative. In particular, at the maximum values of V_{INJ} the curves shift by 0.6 V (i.e. αV_{INJ}). Indeed, negative field near the illuminated region will enhance the electron flux towards the TM. These repeated measurements show the consistency of the measurement technique. The second kind of measurement we made with the facility is shown in Figure 1(b). We measured yield along a span of 20 days, after exposing the system to air and closing the chamber on day 0. Yield slowly decreases (in modulus) as the system is kept in vacuum, stabilizing after day 14. The timescale of this observation is compatible with measurements of the LPF era made on Au-coated square samples[2]. Molecules desorbing from the surfaces due to the low pressure, around 10^{-5} mbar, play a role in this change. The observed behavior is consistent with the hypothesis of the emission of water molecules from the surfaces, making a thin film which shape changes as the system is under vacuum[2]. More detailed studies are needed to understand the underlying physical process. The developed facility gives us the opportunity to expose the surfaces to a controlled atmosphere-like mix, fixing the water content. This could allow checking if yield variations are amplified by a more humid atmosphere.



(a) (b)

Figure 1: (a) Discharge curves for some values of V_{INJ}, notice that at the same V_{TM} this changes the photocurrent; (b) Apparent Yield as a function of days under vacuum with $V_{TM} = 1$ V and $V_{INJ} = 0$ V.

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