PAPER • OPEN ACCESS

240 nm UV LEDs for LISA test mass charge control

To cite this article: Taiwo Olatunde *et al* 2015 *J. Phys.: Conf. Ser.* **610** 012034

View the article online for updates and enhancements.

Related content

- The efficiency of UV LEDs based on GaN \sol AlGaN heterostructures
  A S Evseenkov, S A Tarasov, S Yu Kurin et al.

- Optical detection techniques and light delivery with UV LEDs and optical fibres
  M Belz, F A Klein, H S Eckhardt et al.

- Simulation of the charging process of the LISA test masses due to solar flares
  H Vocca, C Grimani, P Amico et al.

Recent citations

- Lifetime testing UV LEDs for use in the LISA charge management system
  D Hollington *et al*

- Ground testing and flight demonstration of charge management of insulated test masses using UV-LED electron photoemission
  Shailendhar Saraf *et al*

- Characterising and testing deep UV LEDs for use in space applications
  D Hollington *et al*

240 nm UV LEDs for LISA test mass charge control

Taiwo Olatunde, Ryan Shelley, Andrew Chilton, Paul Serra, Giacomo Ciani, Guido Mueller, John Conklin

University of Florida
E-mail: tolatunde@ufl.edu

Abstract. Test Masses inside the LISA Gravitational Reference Sensor must maintain almost pure geodesic motion for gravitational waves to be successfully detected. LISA requires residual test mass accelerations below 3 fm/s^2/$\sqrt{\text{Hz}}$ at all frequencies between 0.1 and 3 mHz. One of the well-known noise sources is associated with the charges on the test masses which couple to stray electrical potentials and external electromagnetic fields. LISA Pathfinder will use Hg-discharge lamps emitting mostly around 254 nm to discharge the test masses via photoemission in its 2015/16 flight. A future LISA mission launched around 2030 will likely replace the lamps with newer UV-LEDs. Presented here is a preliminary study of the effectiveness of charge control using latest generation UV-LEDs which produce light at 240 nm with energy above the work function of pure Au. Their lower mass, better power efficiency and small size make them an ideal replacement for Hg lamps.
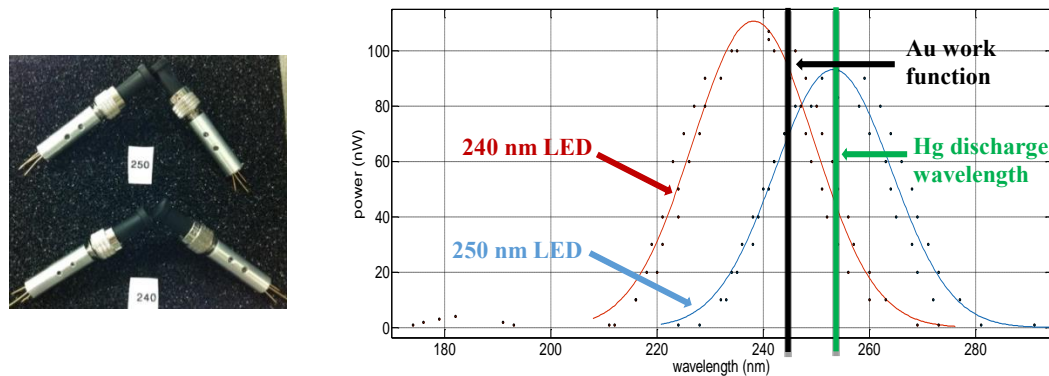
1. Introduction

The Laser Interferometer Space Antenna (LISA) will act as a space based gravitational wave observatory measuring changes in separations between isolated TMs [1]. LISA requires test mass (TM) accelerations to be suppressed below 3 fm /s^2 /$\sqrt{\text{Hz}}$ at all frequencies between 0.1 and 3 mHz. Each TM is enclosed in a housing that supports the sensing electrodes and protects the TM from many disturbances including solar wind and high energy particles from galactic and solar rays. However some of them can still penetrate and charge the TMs. Test mass charge couples to imbalanced DC biases on opposing conductors of the housing to produce random walk force noise [1, 2].

By measuring and controlling the motion of two free falling test masses located inside a single satellite, LISA Pathfinder (LPF) aims to test many of the complex technologies useful for LISA such as drag free control, inertial sensors and precision laser interferometry [3]. LISA Pathfinder discharge system exploits the photoelectric effect using UV light produced by Hg lamps following the method demonstrated by Gravity Probe B [4]. A proposed discharge system for LISA could follow the same principle, but replace Hg lamps with UV-LEDs. Feedthroughs would be used to direct light from UV-LEDs, operated at DC, towards either the gold coated TMs or electrode housing surfaces. Alternate charge control architectures would also be possible, such as AC charge control [2] synchronized with the 100 kHz injection voltage. This approach could utilize two UV injectors as in LPF, or perhaps only one injector, which illuminates both the TM and housing.

In theory, UV photons require energy above the work function of Au to liberate electrons. The minimum required illuminating wavelength for a pure Au surface with work function 5.1 eV is 243 nm. However, contamination generally leads to a lowering of the work function and allows higher wavelengths to be used [3]. If no bias voltages are used, then illumination of the TM would cause electron flow i_{TM} from the TM to the housing; light is reflected to the housing which gives rise to unwanted electron flow i_{EH} from the electrode housing to the TM. If on the other hand the housing is illuminated,
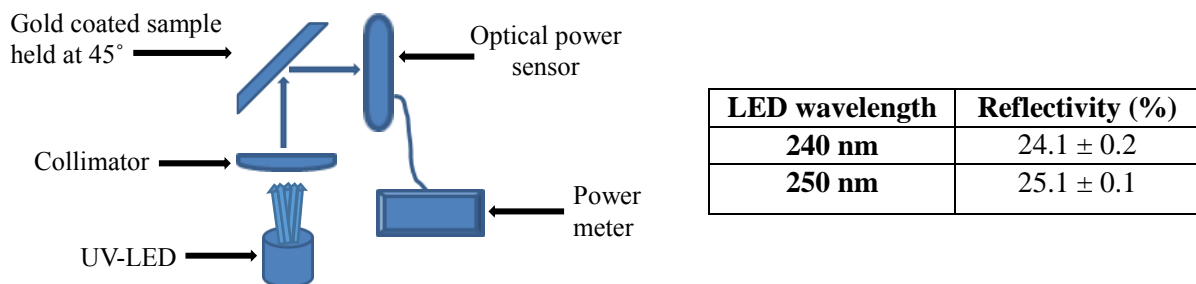
electrons i_{EH} would flow from the housing to the TM, light is reflected to the TM and gives rise to unwanted electron flow i_{TM} from TM to electrode housing. A positive test mass discharge rate is obtained if $i_{TM} - i_{EH} > 0$. Figure 1 shows the UV LEDs evaluated and their spectral properties.

Figure 1. *Left:* 240 and 250 nm UV-LEDs from SETi. *Right:* Gaussian fit to measurements of the UV LEDs' intensity spectrum compared with the work function of Au and the Hg lamp discharge wavelength.

2. Reflectivity

In the LISA Pathfinder GRS design, both the TM and the electrode housing are gold coated. When UV light illuminates the TM directly, some of the light reflects back and is absorbed by the housing. This can create photoelectrons that flow in opposition to the intended direction. Simulations show that for ideal reflection properties, the TM absorbs around 70% of the total light when it is illuminated and about 20% is absorbed by the housing. When illuminating the housing, around 25% is absorbed by the housing and about 15% by the TM [5]. The remaining percentage is lost in gaps in the electrode housing or surfaces that are not useful for charge control. Reflectivity measurements for different wavelength UV LEDs, Au coating techniques, and coating ages are made to understand and bound the effects of reflection on the performance of a UV LED based charge management system.

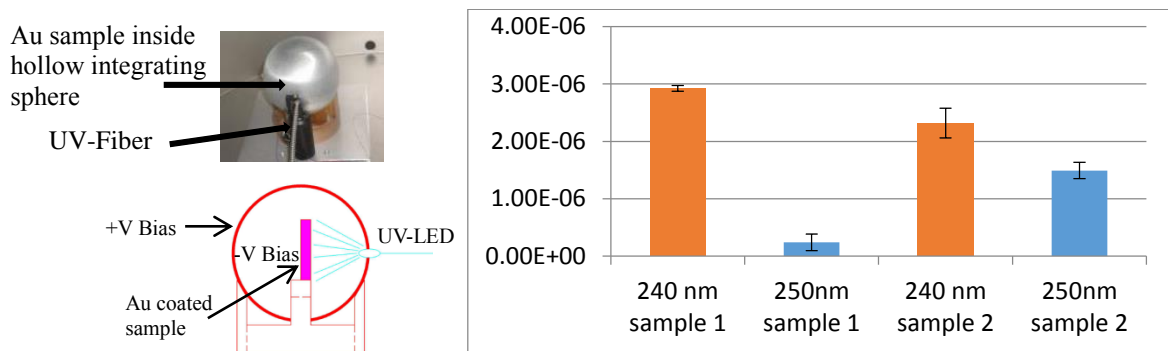| LED wavelength	Reflectivity (%)
240 nm	24.1 ± 0.2
250 nm	25.1 ± 0.1

Figure 2. *left:* Set-up for reflectivity measurements. *Right:* Results of Reflectivity Measurements

The measurement of the reflectivity of the gold coating on the TM and electrode housing is performed by shining collimated light from a single 240 nm or 250 nm UV LED at a gold coated aluminium sample held at 45 deg. The reflected light is detected by using Thorlabs PM100D power meter with S120VC detector head. A bi-convex lens with a focal length of 20 mm is used to collimate the light. Reflectivity is computed as the power measured after reflection from the gold sample, divided by the power previously measured by placing the sensor directly after the collimator. Figure 2 shows the measurement setup and measured reflectivity, which varies only slightly between the 240 nm and 250 nm UV LEDs.

3. Quantum Efficiency (QE) measurements

Quantum efficiency is the number of photoelectrons emitted from the surface per incident UV photon. It is therefore one of the critical properties governing the performance of a charge management system. A dedicated experiment for measuring QE has been assembled and is shown in Figure 3. An Au coated sample is isolated inside a 90 mm diameter hollow integrating sphere using Ultem, which has a resistivity of 10^{17} Ω-m [2]. An ultra-high vacuum UV fiber optic cable with a 600 μm core is used to direct the light from the UV-LED to the sample. The sphere is biased to +9 V and the sample to –9 V. The UV-LED current is then varied over a range of 10-24 mA, using an ILX Lightwave LDX-3200 precision current source. This range of current corresponds to 4-10 μW of UV optical power, and at their maximum current draw of 25 mA, both the 240 nm and 250 nm UV LEDs consume roughly 180 mW of electrical power. The resulting photocurrent is measured using a Keithley 6485 Picoammeter and then converted to number of photoelectrons. A zero degree incident angle is used for the QE measurements at a vacuum pressure of 10^{-5} Torr.
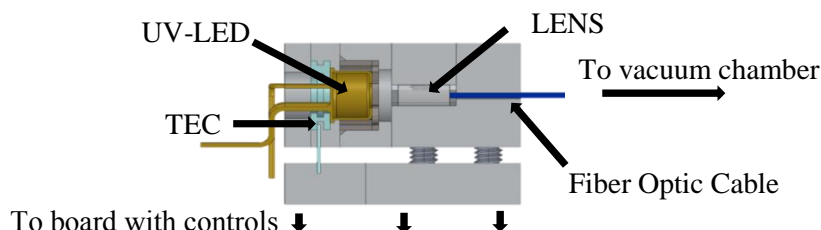

Figure 3. *Left:* QE experimental set-up. *Right*: QE measurement results

The QEs of two different samples were measured. Sample 1 with a gold layer 200 nm thick was coated in March 2013, and Sample 2 with a gold layer 500 nm thick was coated in September 2013 (6 months later). The 240 nm and 250 nm UV-LEDs are similar in terms of power consumption, reflectivity and cost, but as expected and shown in Figure 3, the 240 nm LEDs demonstrate higher QE than the 250 nm LEDs.

4. UV LED fiber coupler and temperature controller

The lifetime of the 240 nm and 250 nm UV-LEDs are reported by SETi to be 1,000 and 1,650 hours respectively, when driven at 20 mA, near their maximum power, corresponding to roughly 10 μW of optical power. Although, during charge control only ~100 nW of UV power is required. The maximum operating temperature is 30 ˚C at the case of the package and every additional 10 ˚C cuts total operating hours in half. Proper heat management can dramatically improve the lifetime of these devices. A UV LED fiber optic coupler with built in temperature control is being developed for space applications of the UV LED. The design of the coupler is depicted in Figure 5.
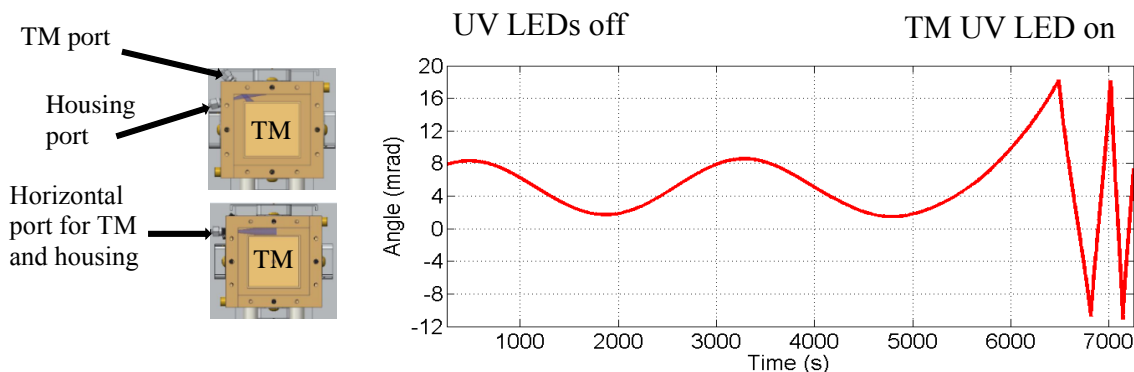

Figure 4. Proposed heat dissipation management design

Light from the UV-LED is coupled to a fiber optic cable by means of a fused silica bi-convex lens with a focal length of 10 mm. A fused silica ferrule and a borosilicate glass sleeve are used to hold the fiber against the lens. The whole assembly is glued using a UV-curable low outgassing optical epoxy. The holder securing the fiber/lens in front of the UV-LED includes a Thermo-Electric Cooler (TEC). A set of driving electronics controls the TEC and applies current to the UV LED. Heat from the TEC due to contact with the UV-LED dissipates through the body of the assembly to a supporting electronics board.

5. Initial TM charging of the UF torsion pendulum.
The UF torsion pendulum is a technology development facility aimed at testing the performance of new inertial sensors like the LISA GRS and related technologies [6]. Both GRS mock-ups in the pendulum, shown in Figure 5, have three UV ports. One port is directed at the TM, the second toward the housing, and the third illuminates both. As an initial test of the effectiveness of the UV LED charge control system, a 240 nm UV LED was used to charge up the TM using the UV port directed at the TM. Figure 5 shows a plot of the pendulum angle as a function of time. At roughly t = 5000 s, the UV LED is turned on and within 5 minutes the pendulum becomes unstable due to positive charge on the TM relative to housing.

Figure 5. Plot of UV LED building up charge on TM

6. Future Work
UV LEDs are an attractive alternative to Hg lamps as UV sources for the LISA charge management system. They offer relatively high optical power (10 μW) at wavelengths near 240 nm and reduced volume, mass and power with respect to Hg lamps. The 240 nm UV LEDs consistently exhibit higher quantum efficiencies with Au surfaces compared with 250 nm UV LEDs, with little change in power consumption and reflectivity. The 240 nm LEDs have also been used to demonstrate movement of the TM charge using the UF Torsion Pendulum. In the near future, we plan to construct custom UV LED fiber couplers with built in temperature control and perform thermal, vibration and shock tests to verify their compatibility with the space environment. Finally, both DC and AC charge control using various UV light injection directions will be demonstrated using our torsion pendulum facility.

References
[1]   Shaul DNA, et al 2008 *Int. J. Mod. Phys. D* **17** 993-1003
[2]   K Balakrishnan, et al arXiv:12020585v1
[3]   T Ziegler, et al 2009 *J. Phys.: Conf. Ser.154 012009*.
[4]   JW Conklin 2008 J. Phys.: Conf. Ser. 140(1) 114002.
[5]   Daniel Hollington 2011 Ph.D. Thesis Imperial College London
[6]   Andrew Chilton, et al 2014 *J. Mod Phys. this series*.