LISA Pathfinder Discharge Working Group: Activities, Results, and Lessons Learned for NGO

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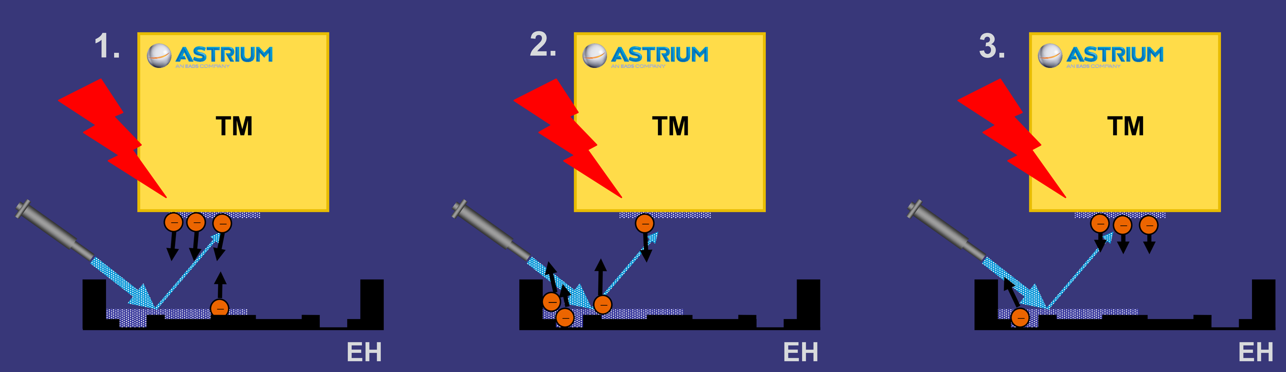
Abstract

In 2011, the European Space Agency (ESA) entrusted Astrium GmbH to take ownership of the problems with the LISA Pathfinder discharge system baseline design, after failures have occurred during the system level testing in the torsion pendulum at University of Trento (UTN). The goal was to maximize the discharge system robustness under the given constraint to minimize the impact on manufacturing and AIT process of the existing flight hardware. Astrium GmbH set-up a dedicated discharge working group (DWG) for 9 months, bringing together the expertise of surface scientists (DLR Stuttgart, Uni Würzburg, Uni Modena, BEAR Trieste) with the existing knowledge in the LTP community (Uni Trento, Imperial College London, CGS, Selex Galileo, TWT GmbH, ESA). The activities of this working group included: assessment and trade of different discharge concepts, performing several sample level test campaigns and analyze their results, advanced modeling of the discharge system, as well as its robustness and performance assessment. The findings resulted in a recommendation to modify the baseline discharge system of LISA Pathfinder, including the definition of dedicated manufacturing and AIT requirements. The findings have relevance also for NGO, although a different Astrium GmbH proposal for the LISA discharge system design is already significantly more robust.

Motivation and Problem Formulation

- Failure of test mass discharge on UTN pendulum for TM2 (2009) and TM3 (2010) campaigns
- Large variability of surface properties indicated by Uni Modena sample measurements in 2008
- Astrium GmbH gained expertise in analyzing discharge systems during development of discharge models needed for on-board software design and discharge performance assessment
- Baseline LTP discharge system design is not robust against variations of gold surface emission
  - Simple evidence: UV light energy ≈ gold surface electron emission threshold
  - System functionality relies on equality of physical parameters (quantum yield, etc.)

- Discharge rate mainly depends on absorbed light on test mass (TM) and electrode housing (EH), electric field dependent electron transition probabilities, quantum yields (QY) on TM and EH
- Possible failures to apply a negative discharge rate: (1) unfavorable QY imbalance, (2) unfavorable surface efficiencies (EH < TM), (3) combination of both



Example: Possible failures to apply a negative discharge rate

- Goal: Increase robustness to realize negative and positive discharge rate (“bipolar discharge”)

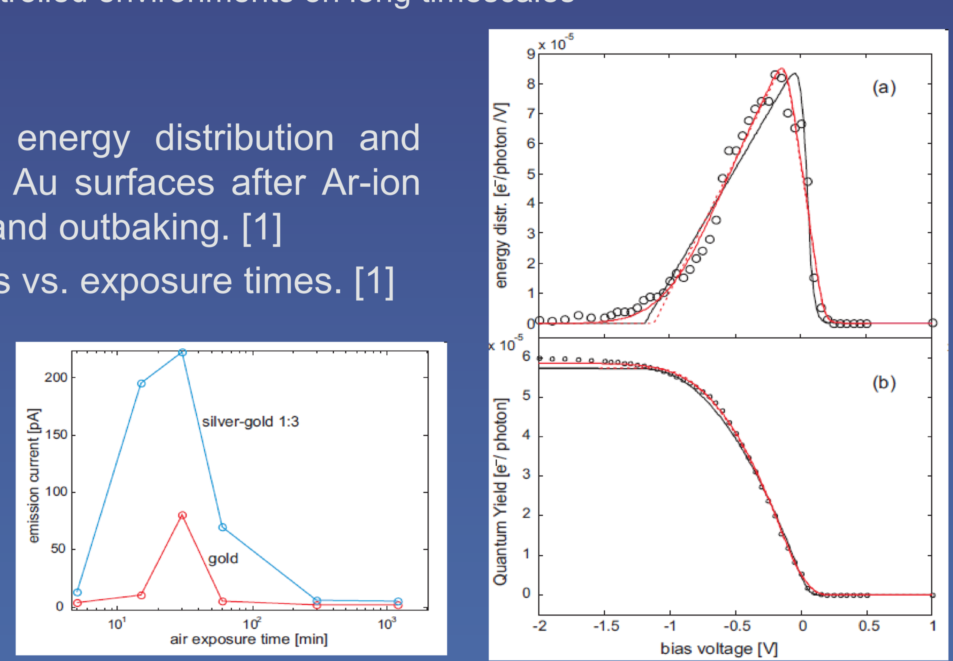
Discharge Working Group Fields of Investigation

Surface physics (two sample level measurement campaigns at DLR and Uni Würzburg)

- Goals
  - Profound understanding of photo-emission process to characterize (quantum yield, kinetic energy distribution)
  - Understanding the impact of adsorbents on the surface properties
  - Quantifying the reproducibility of the surface properties after exposure to air and subsequent annealing
  - Identify and measure possible stable *hot-spot* materials that have a larger quantum yield compared to gold
- Achievements
  - DLR: 6 gold and 5 hot-spot samples each with 3–4 yield measurements and 12–24 hours of bake-out
  - Würzburg: 237 yield measurements on 14 samples and 11 materials (including Ni-Au, Ag-Au, Cu-Au, Cs, Hg)
  - Hot-spots are not stable in uncontrolled environments on long timescales

Right: Measured kinetic energy distribution and current-voltage curves of Au surfaces after Ar-ion sputtering, air exposure, and outbaking. [1]

Bottom: Emission currents vs. exposure times. [1]



Discharge Modeling [2]

- Surface illumination obtained from developed ray tracing tool
- Transition probabilities obtained from developed electron tracing tool including
  - Electrical fields (induced by AC voltages) imported from FE tool (MAXWELL 3D)
  - Measured and processed kinetic energy distribution
  - Measured quantum yield of air-contaminated gold surfaces
  - Measurements of light source characteristics as emitted from feedthrough

Simplified expression for neg. discharge rate:

TM surface “efficiency” EH surface “efficiency”

$$\dot{Q}_{neg}^{JF02} = \left(f_{TM2EH} \cdot \rho_{TM} \cdot \xi_{TM} - f_{EH2TM} \cdot \rho_{EH} \cdot \xi_{EH} \right) I^{JF02} \overset{!}{<} 0$$

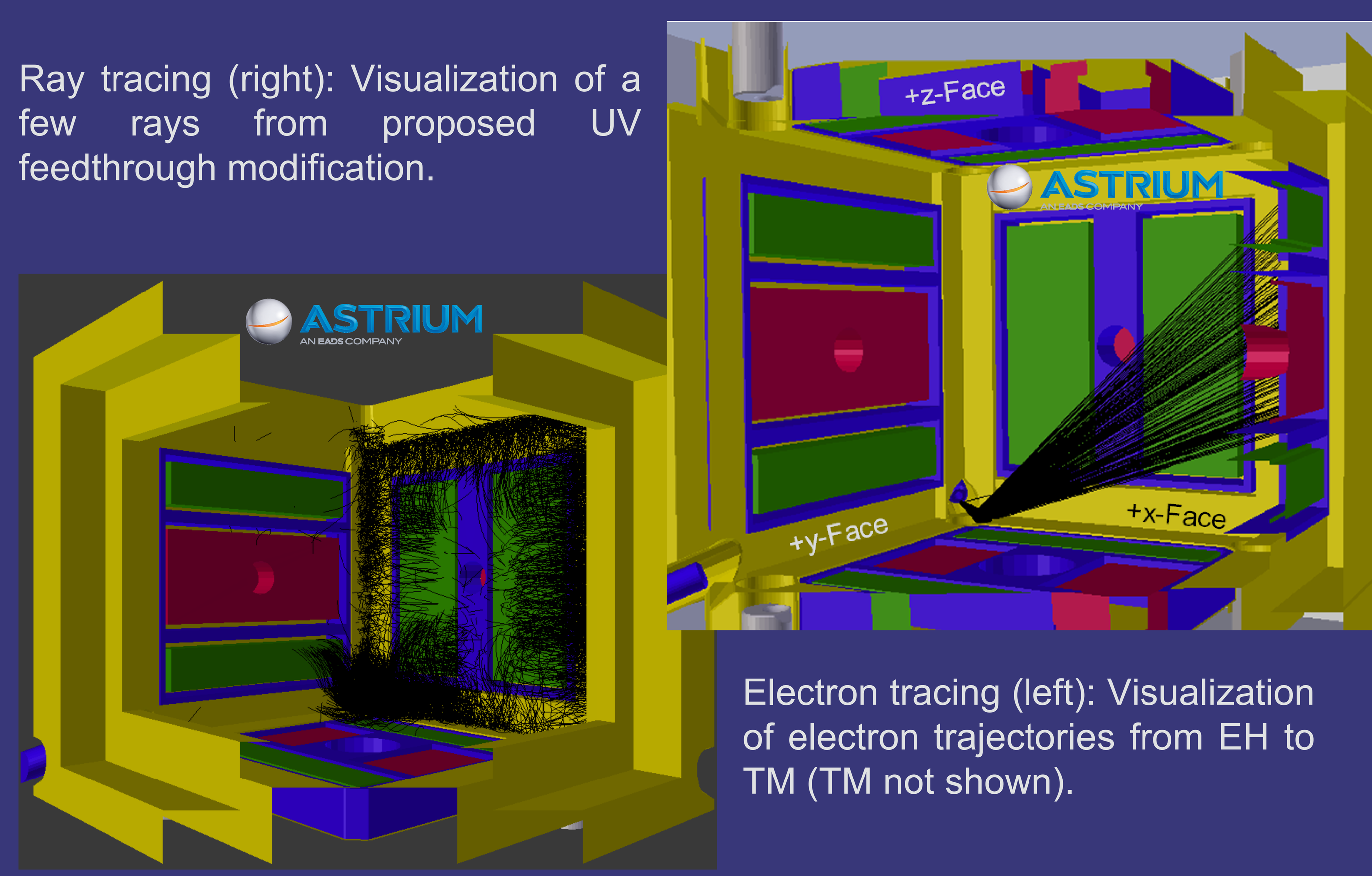
Surface transition probability (averaged over AC voltages)

Absorbed UV light

Quantum yield

Injected photon current

Ray tracing (right): Visualization of a few rays from proposed UV feedthrough modification.



Electron tracing (left): Visualization of electron trajectories from EH to TM (TM not shown).

Manufacturing and AIT Process

- Reviewed all discharge related manufacturing and AIT processes, procedures, and requirements
- Assessed adaptations including
  - UV light re-direction through tip-modification of the feedthrough (refractive and reflective micro-optics)
  - Adaptation of test mass coating
  - Cleaning of flight model parts before and after AIT process (plasma cleaning, outbaking, UV cleaning)
  - Handling and storage of flight model parts during AIT process

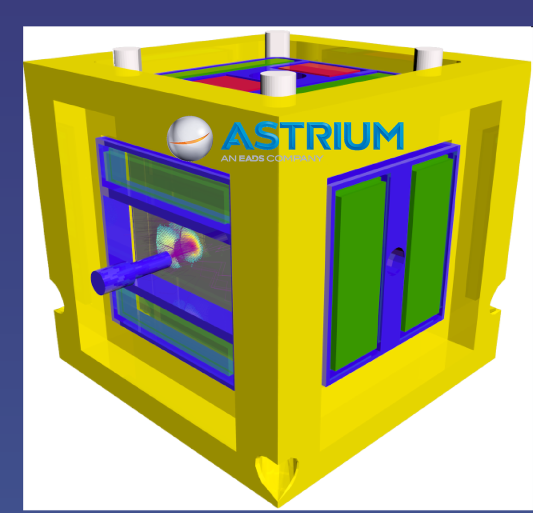
Recommendation for LPF Discharge System

- Apply reflective micro-optics (“tube mirror”) to UV light feedthrough pointing on EH
- Adapt gold coating of TM spheres
- Apply plasma cleaning to discharge relevant surfaces before AIT process
- Realize handling requirements from defined “no-touch” zones on discharge relevant surfaces
- Realize nitrogen storage of discharge relevant surfaces at all possible times
- Apply bake-out of discharge relevant surfaces in integrated flight hardware at 125°C
- Apply UV cleaning of the discharge relevant surfaces in the integrated flight hardware

→ minimal invasive, but optimal robust solution within the given design constraints

Proposal for Future NGO Discharge System

- More robust discharge system can be achieved by two major design changes [2]
  - Different UV light injection into the inertial sensor (through EH y-injection electrode hole)
  - Other UV source and actuation strategy (pulsed UV LEDs synchronized with injection bias voltage)



Visualization of proposed UV light injection for NGO. [2]

- Robustness and performance assessed with ray tracing and electron tracing tools
- Discharge system can be realized with the existing LPF inertial sensor
- Proposed already in 2010 in the scope of the LISA Mission Formulation study

References

[1] G. Hechenblaikner et al., “Energy distribution and quantum yield for photoemission from air-contaminated gold surfaces under UV illumination close to the threshold,” Accepted for publication in Journal of Applied Physics, 2012.

[2] T. Ziegler et al., “Modeling and Performance of Contact-Free Discharge Systems for Space Inertial Sensors,” To be published in IEEE Transaction on Aerospace and Electronic Systems.

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