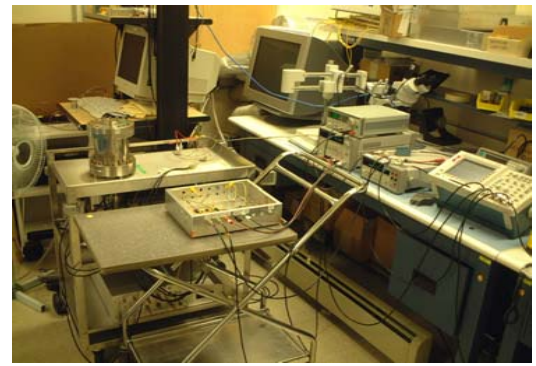
# Using Deep UV LED Light to Mitigate LIGO Test Mass Surface and Bulk Charging




Ke-Xun Sun

Stanford University


LIGO Science Collaboration (LSC) Meeting

Louisiana State University

August 16, 2006

# Acknowledgments


- UV LED charge management experiment team:
  Sei Higuchi, Allex Goh, Brett Allard, Dale Gill
  Sasha Buchman, and Robert Byer
- LIGO test mass and suspension discussion:
  Rai Weiss, Norna Robertson, Roger Route, Brian Lantz,
  and Marty Fejer, Sheila Rowan, Jim Hough

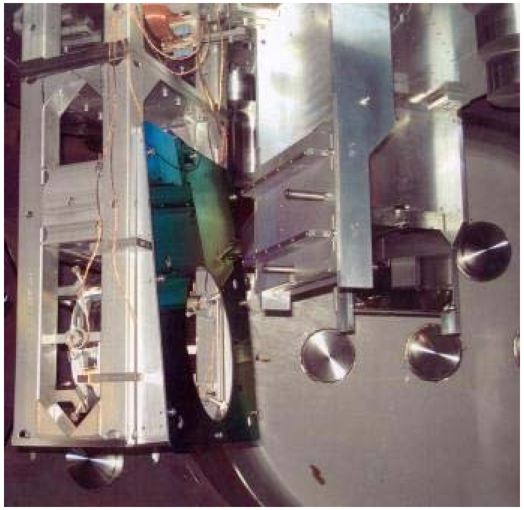

- At LSC March Meeting
  Ke-Xun Sun, Sei Higuchi, Brett Allard, Dale Gill, Saps Buchman, and Robert Byer, "LIGO Test Mass Charging Mitigation Using Modulated LED Deep UV Light, " LIGO Science Collaboration (LSC), OWG & SWG Joint Meeting, Hanford, Washington, March 22, 2006, LIGO Documentation G050143-00-Z

# Outline

- Livingston experimental results after LSC March meeting
  - Vented, touched (discharged), BN range now 14 MPC
  - Charge is the suspect for previous higher noise floor
- Recent Experiment on UV LED charge management system
  - UV LED Spectral stability
  - UV LED power stability
- LIGO test mass UV Charge management
  - UV illumination effects on surfaces
  - UV illumination effects in bulk
  - High frequency AC charge management
  - New dimensions of measurements and calibrations
- Stanford experimental plan
  - LED
  - Charge management system
  - Coating
  - AC charge management for LIGO test mass

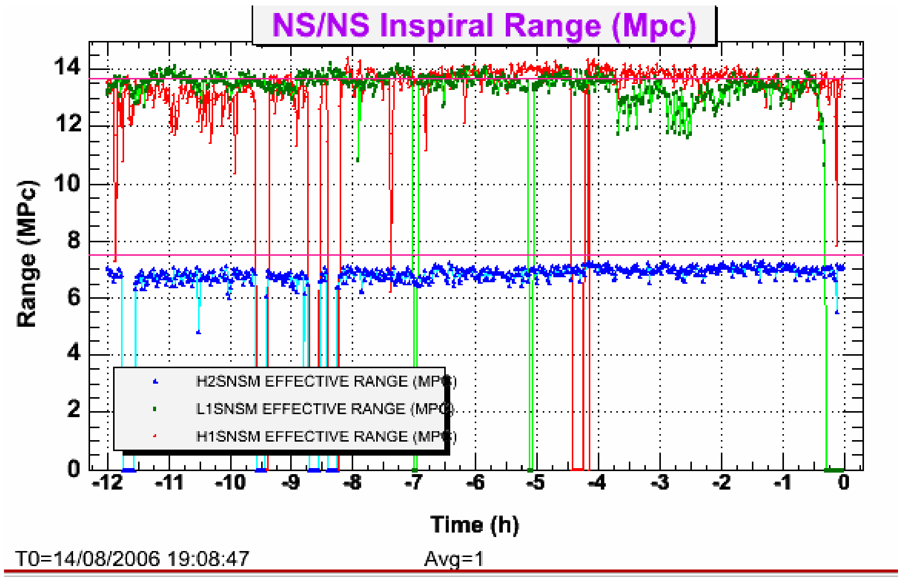
## *L1 Interferometer Sets New Performance Standard*

- May 5 2005, vented chamber, touched ITMY mirror etc
- After pump down, a sharp improvement in sensitivity that corresponded to a drop in the noise floor between 40-100 Hz.
- Electrical charge removal is suspected the reason for the improvement



# LIGO Test Mass Charges Accumulation

Charges can accumulate on LIGO test mass and surrounding structure causing noise increase



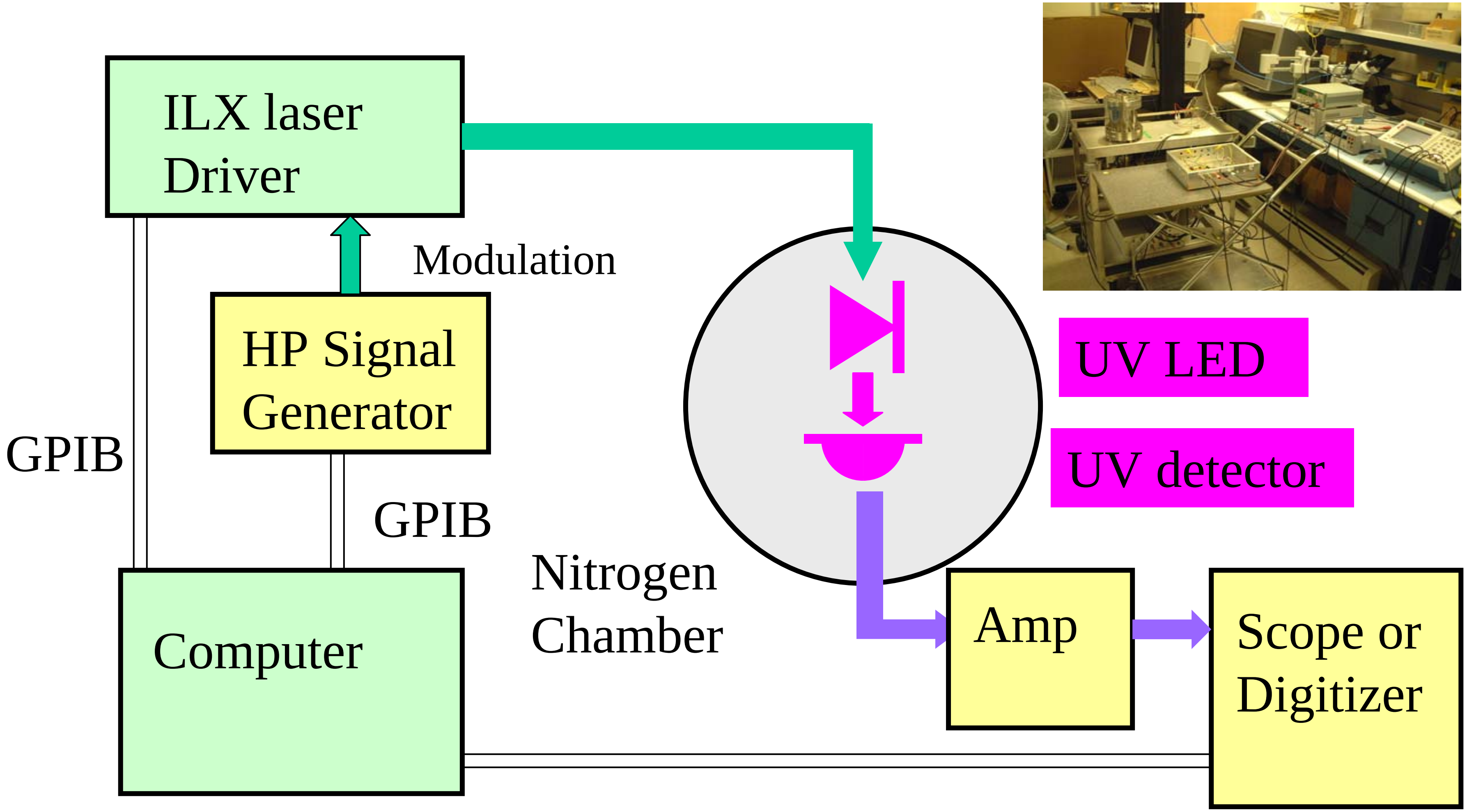

→ **Charge Control Necessary**

*From Braginsky LIGO-G020033

# Charge Management Experiments at Stanford

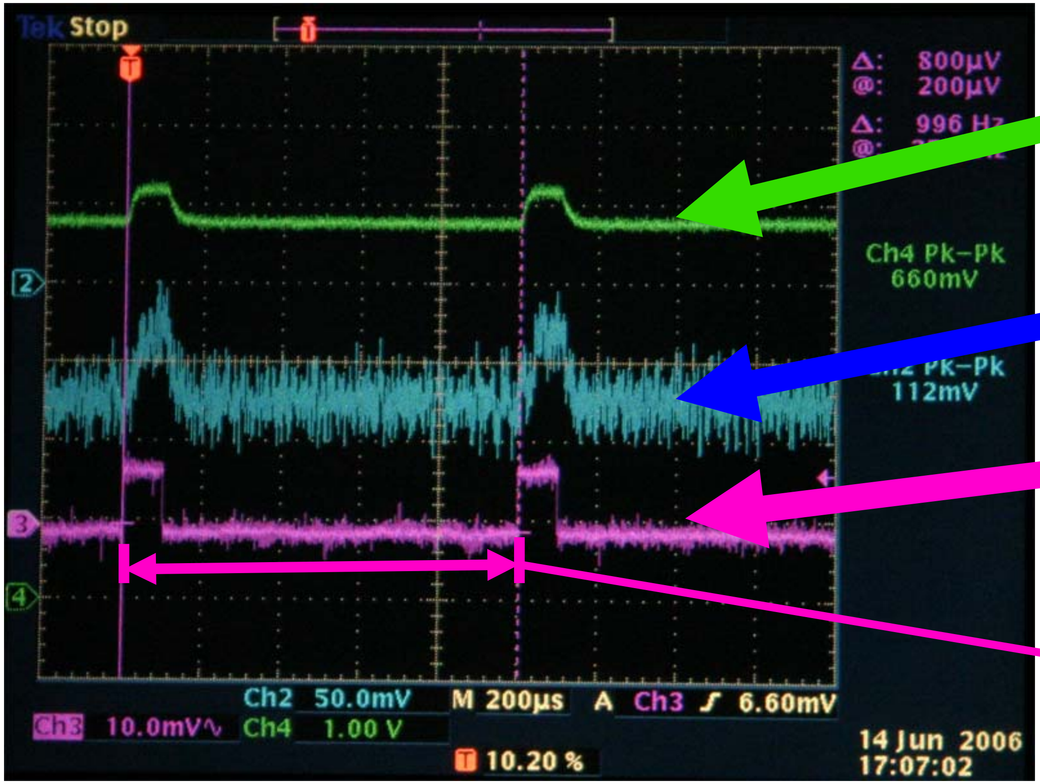
- AC charge management using modulated UV LED light
- UV LED lifetime test
- UV LED based charge management system development
- Metal surface scanning UV photoelectron studies
- Dielectric surface and bulk charge effects

# UV LED Lifetime Experiment



# UV LED Operated for AC Charge Management

## UV LED Direct Readout



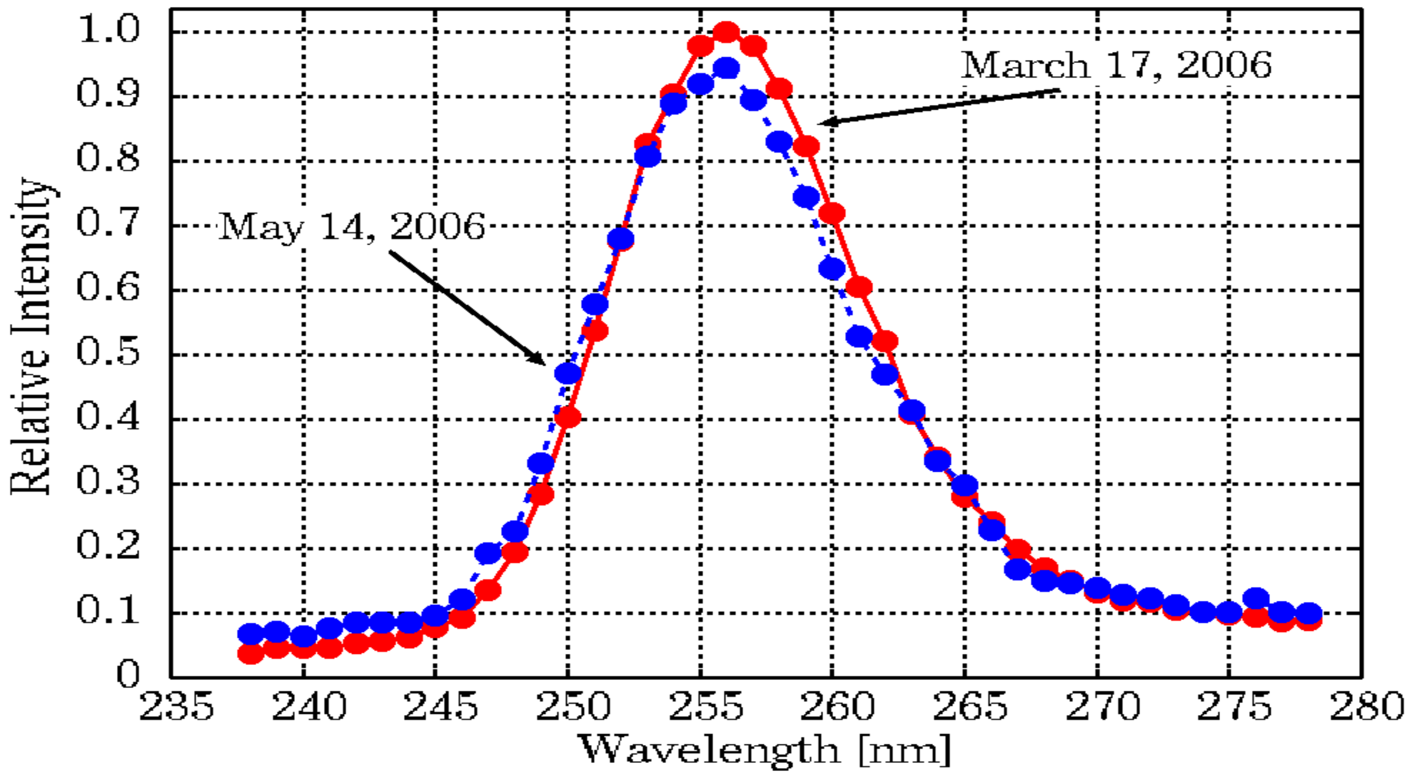

Signal to UV LED

Signal from UV Photodiode

Driving Signal

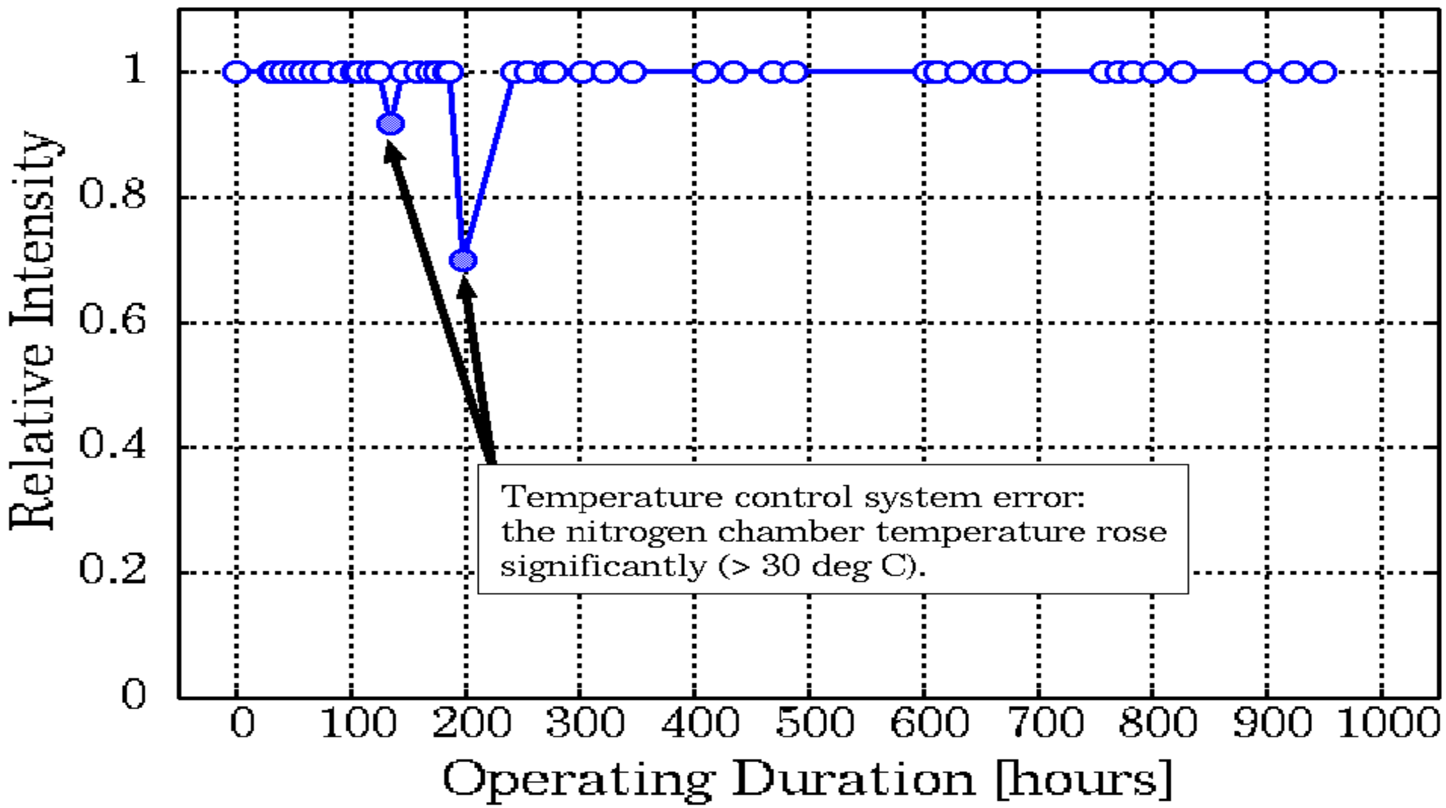
1 msec

# Spectral Stability




- •UV LED emission spectrum before (red), after 250-hour operations (blue).
- •No major spectral shift is observed.
- •UV LED is highly expected to last for significantly longer than 1,000 hours.

# Power Stability




- Power stability of the UV LED is shown over the entire operating duration.
- Power level has stayed relatively constant, as observed using a UV photodiode.

# LIGO Test Mass Charging

- Test mass charging due to:
  - Cosmic ray ionization ? (Braginsky G020033)
  - Pumping system transportation (Rowan CQG **14** 1537)
  - Dust rubbing transfer (Harry, G040063)
- Test mass charging consequences:
  - Reduction of suspension Q (Rowan, Harry)
  - Non-Gaussian noise due to charge hopping (Weiss)
  - Possible noisy forces due to other charged bodies
  - Charge problem at L1 (Livingston 4k interferometer)
- The consensus reached:
  - LIGO Test mass charges need to be managed

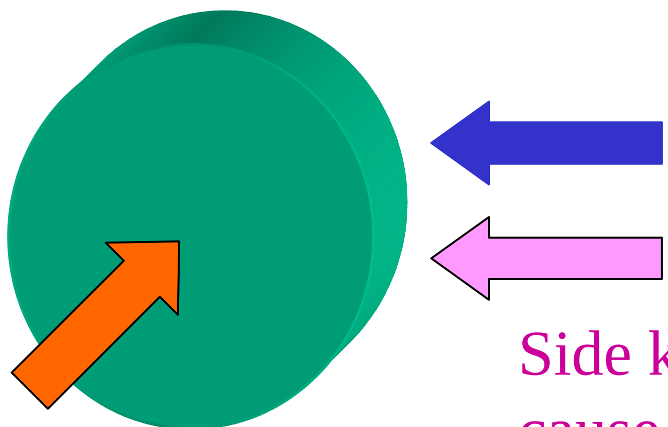
# UV Photon Source Requirements for LIGO Test Mass Charge Management

- $Q_c \sim 10^{-7}$ C/m$^2$ commonly cited
- Charging rate $Q_c \sim 10^{-7}$C/day
- $N_e \sim 10^{12}$ electrons/day (or $N_e \sim 10^{7}$ electrons/second)
- Photoelectric "Q. E.": $\eta \sim 10^{-5} \sim 10^{-7}$
- UV photons required: $N = 10^{14}$/second
- $P_{UV} = Nhc/\lambda T = 10^{-9} - 10^{-6}$ W
- $P_{UV} \sim 1$ nW – 1000 nW (average power over a day)
- Dynamic Range ~ 1000

$P_{UV} \sim 1$ mW (Peak power)

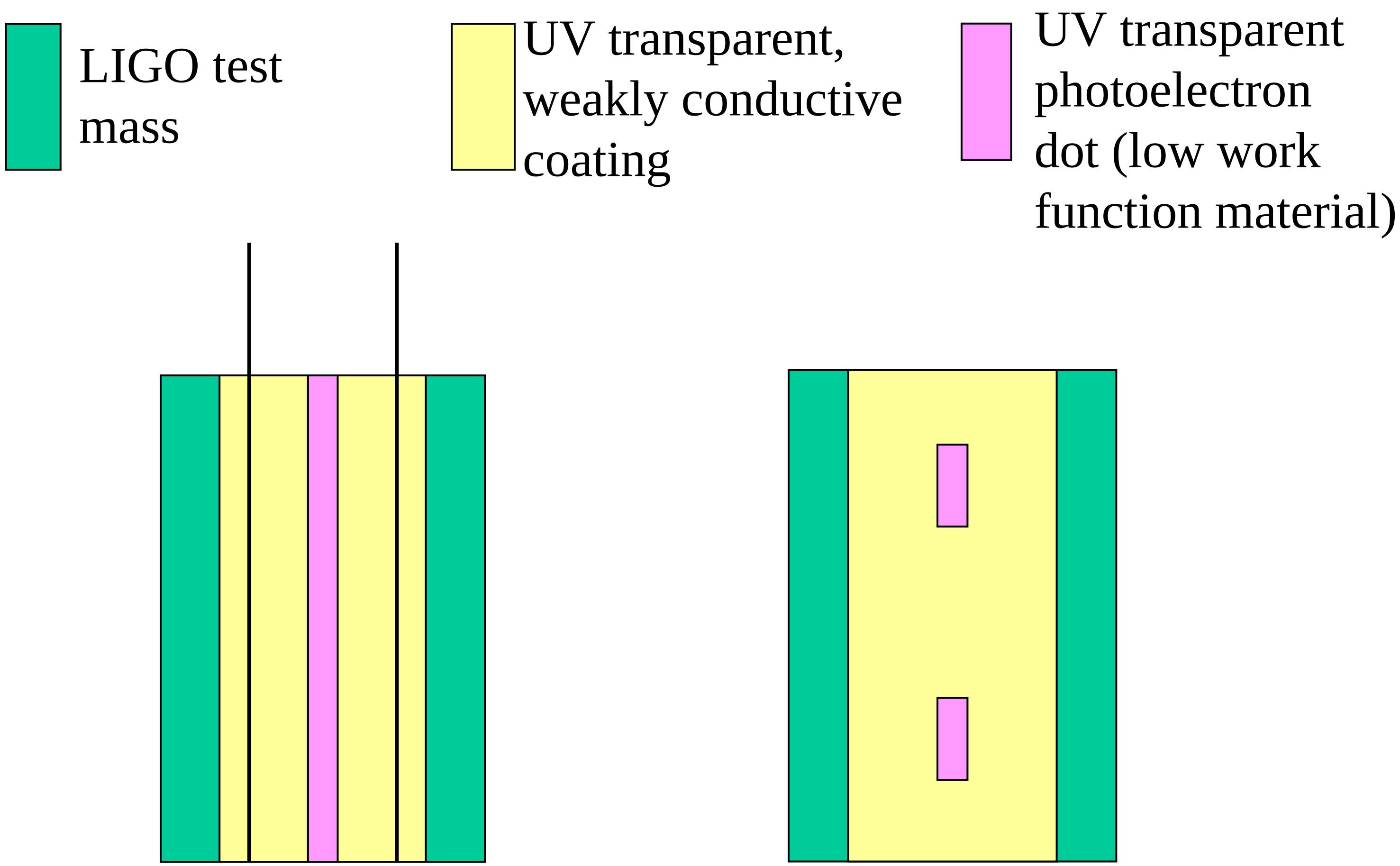
# Conductive Coatings

- Many kinds:
  - Transparent ionic conductor: $MgF_2$, ITO …..
  - Thin metal layer: Au (50 A)
- Coating on the side and back of the test mass



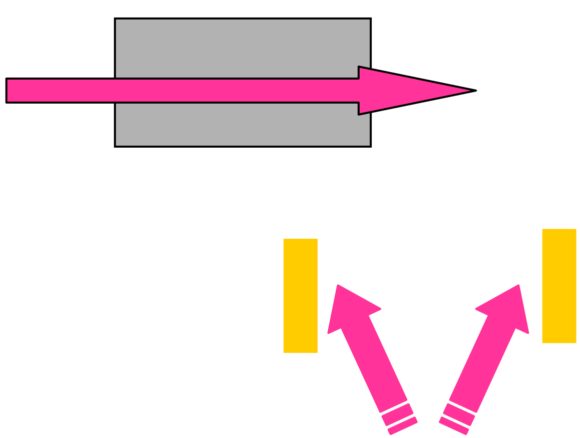

Side kicking UV photons will not cause radiation pressure strong enough to increase noise

# Conductive Coating Patterns

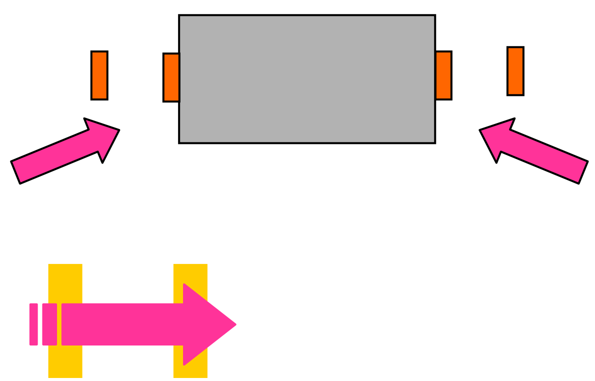


# UV Illumination Schemes

- Direct illumination
  - UV mercury lamp is routinely used for attachment removal
  - UV LED has sufficient power for cw or pulsed direct illumination
  - Need to make sure no solarization (tanning) effect



- Illumination on coatings
  - Thin Au coating on non-critical portions of test mass and suspension structure
  - Photoelectric effect on thin Au coating is common mechanism for photocathode
  - Higher throughput in charge control

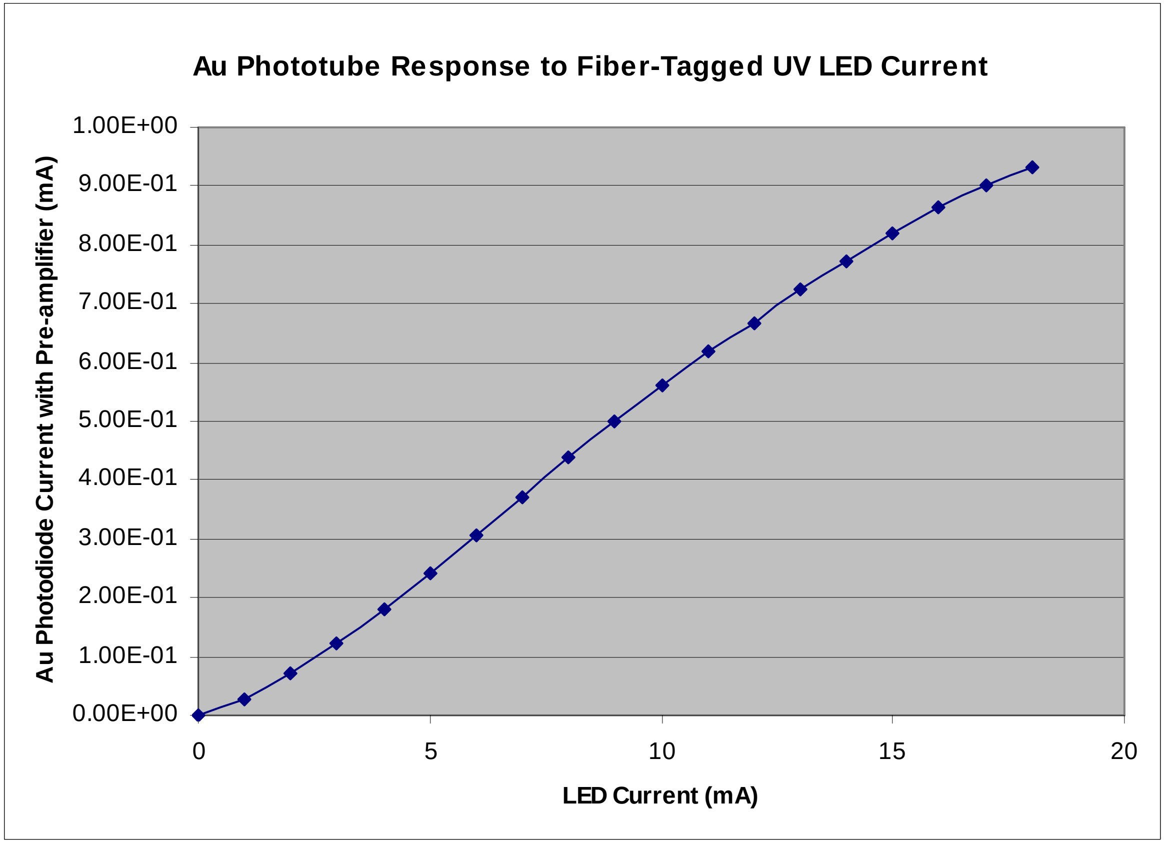


# Au Photodiode Photocurrent Response vs. Fiber-Tagged UV LED Current

## Efficient Photoelectron Emission Observed

Advantages of direct replacement of mercury lamp with UV LED:

- Significant power saving
  - 1 W for UV LED CMS (including all control electronics)
  - 15 W for Hg lamp CMS
- Significant weight reduction
  - 4~5 kg per spacecraft
  - 12~15 kg for launch
- Easy environmental management:
  - Less heat generation near GRS module
  - Much less EMI




*(Au phototube UV power calibration ~16μW/mA)*

# UV-Induced Bulk Conduction in Dielectric Insulator

**Direct Experimental Determination and Modeling of VUV Induced Bulk Conduction in Dielectrics during Plasma Processing**

**Mayur Joshi, James P. McVittie*, Krishna Saraswat**
Center for Integrated Systems, Stanford University, Stanford, CA 94305.
***Email:** jmcvittie@stanford.edu

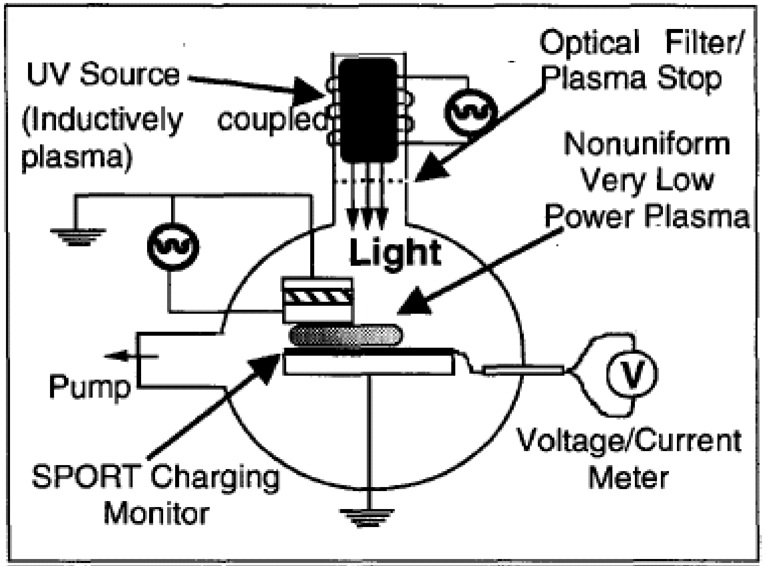



**Figure 2:** Dual Plasma apparatus used to measure VUV induced bulk photoconduction

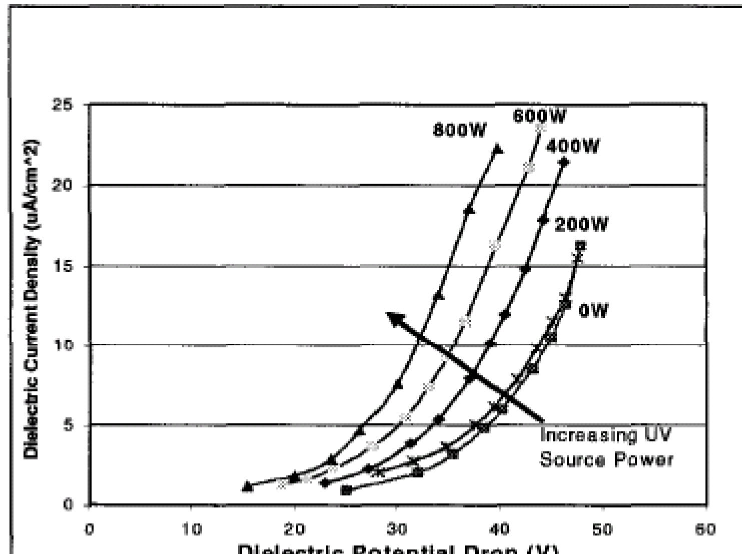
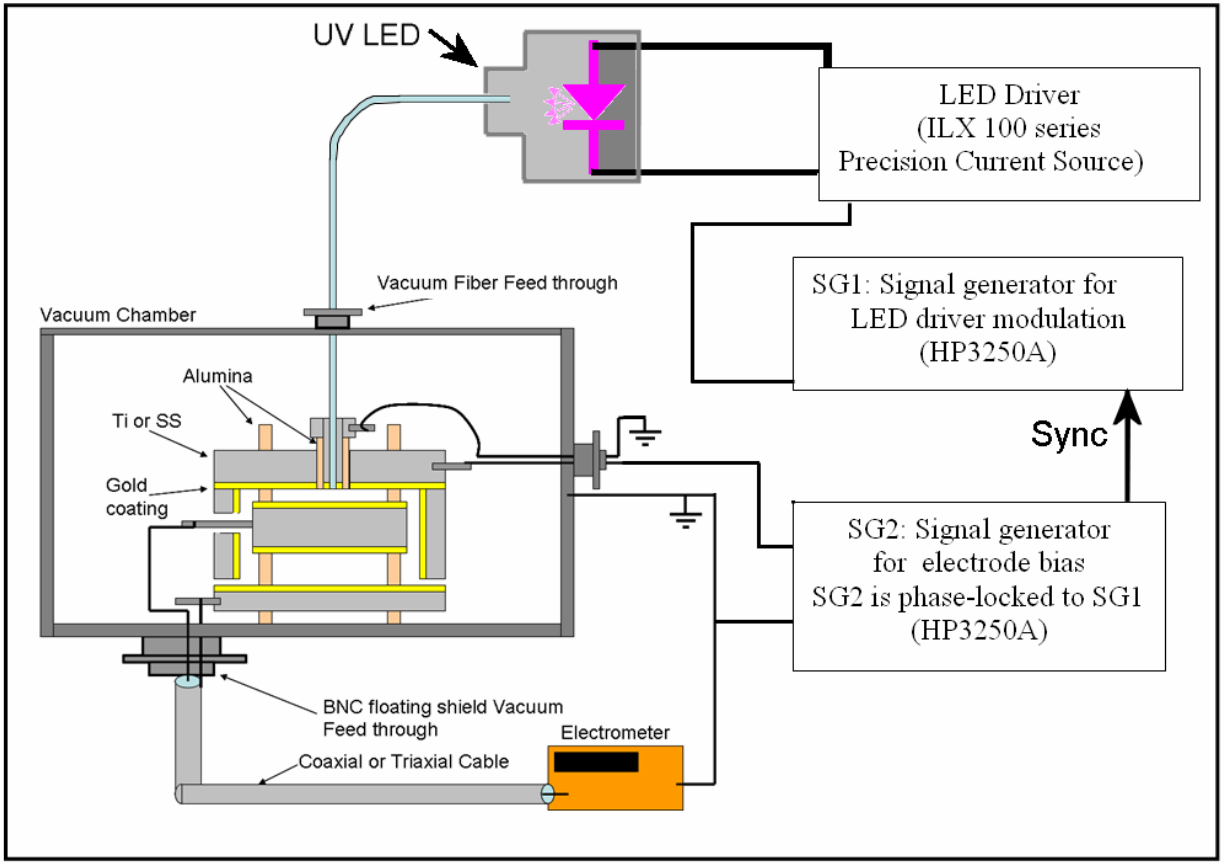



**Figure 4:** Effect of changing UV source power on a 1000Å LTO.

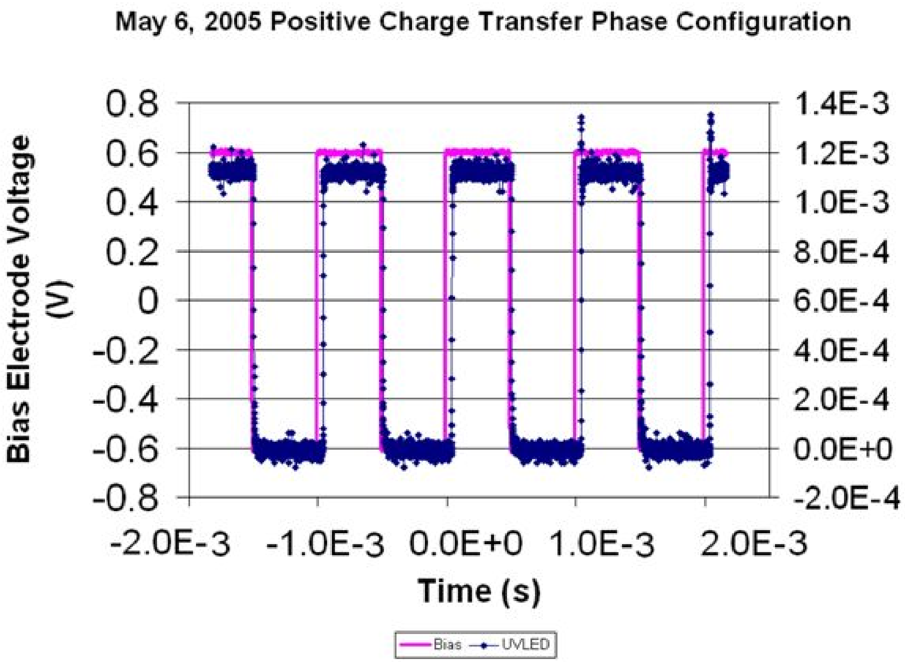
# UV LED Charge Management
## Experimental Setup

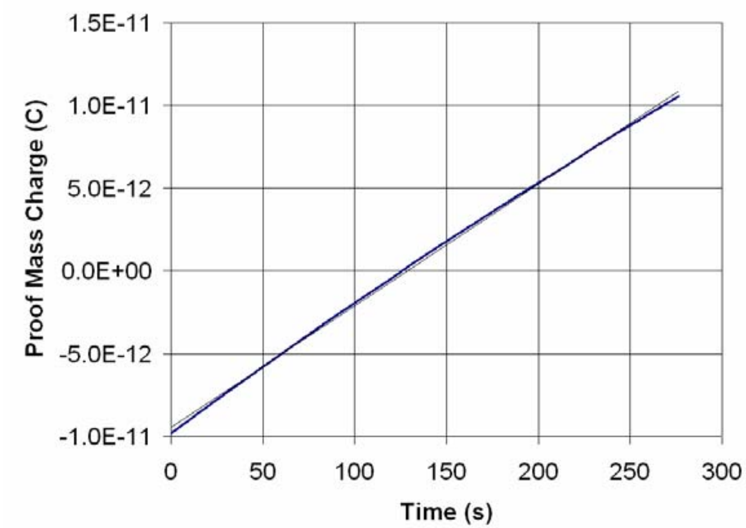



- GP-B heritage
- Au coating on proof mass and housing to simulate LISA GRS
- Fiber connected UV LED driven by modulated current source
- Housing electrode modulation phase-locked to UV modulation
- UV light shining on proof mass and reflected onto housing electrode
- Sensitive electrometer to measure the proof mass potential

# Positive Charge Transfer

UV LED and bias voltage modulated at 1 kHz

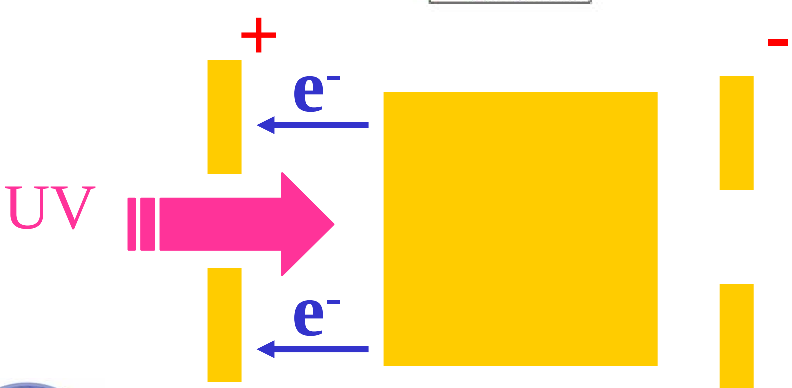


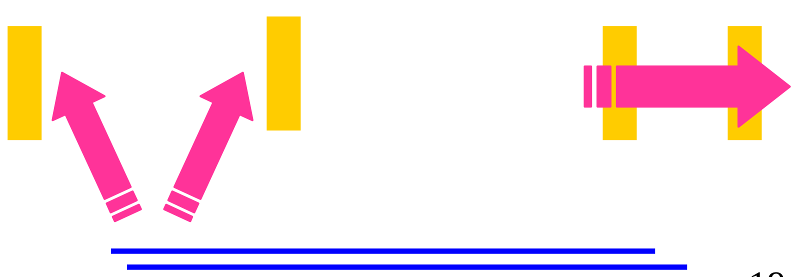




UV phased to positive AC ½ cycle

Electrons fly to housing electrode

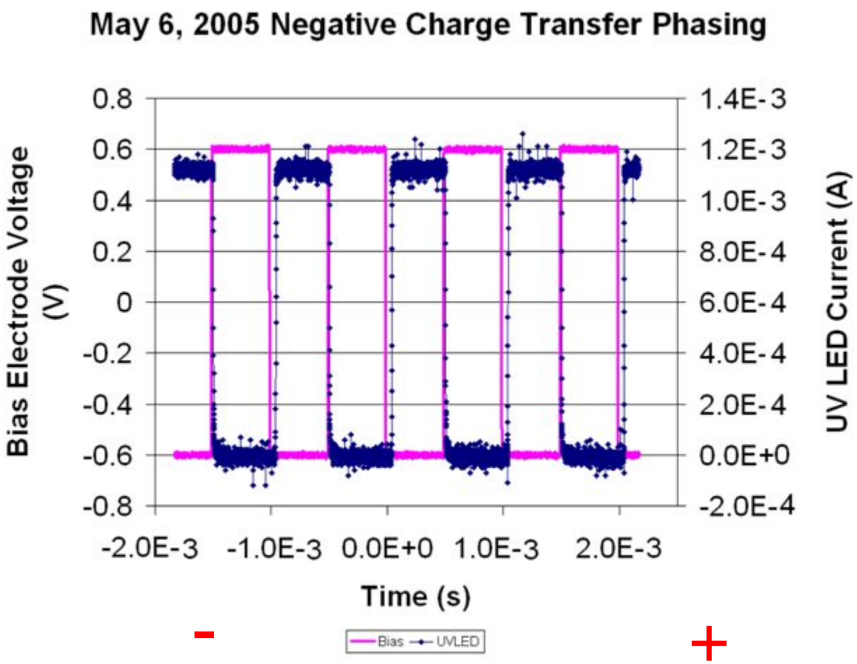
Proof mass potential increase

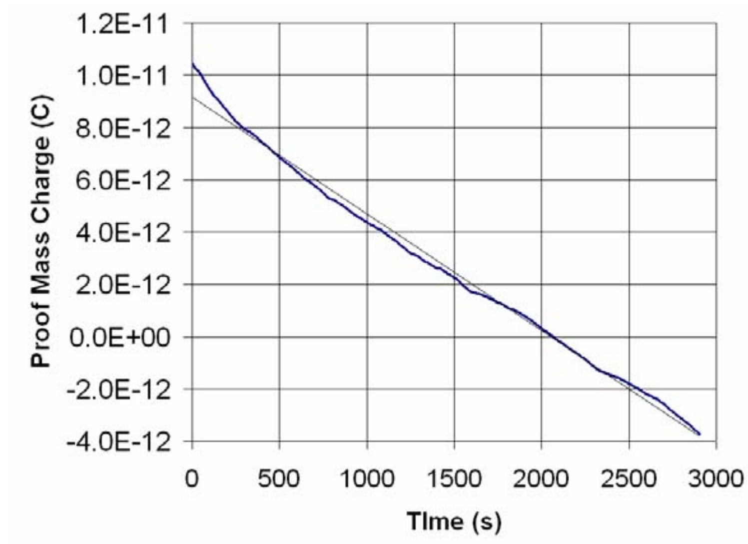


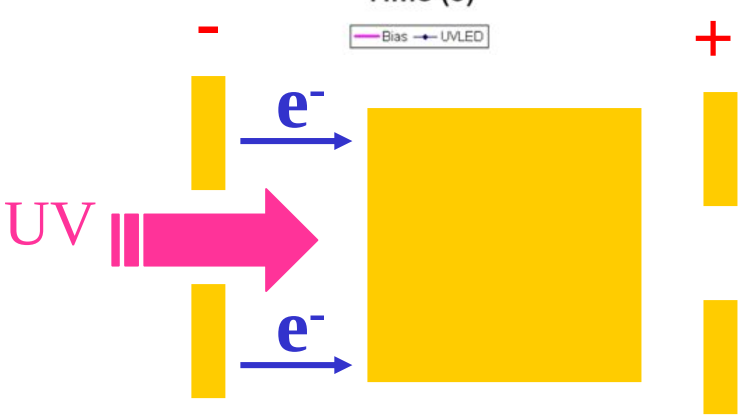



# Negative Charge Transfer

## UV LED and bias voltage modulated at 1 kHz



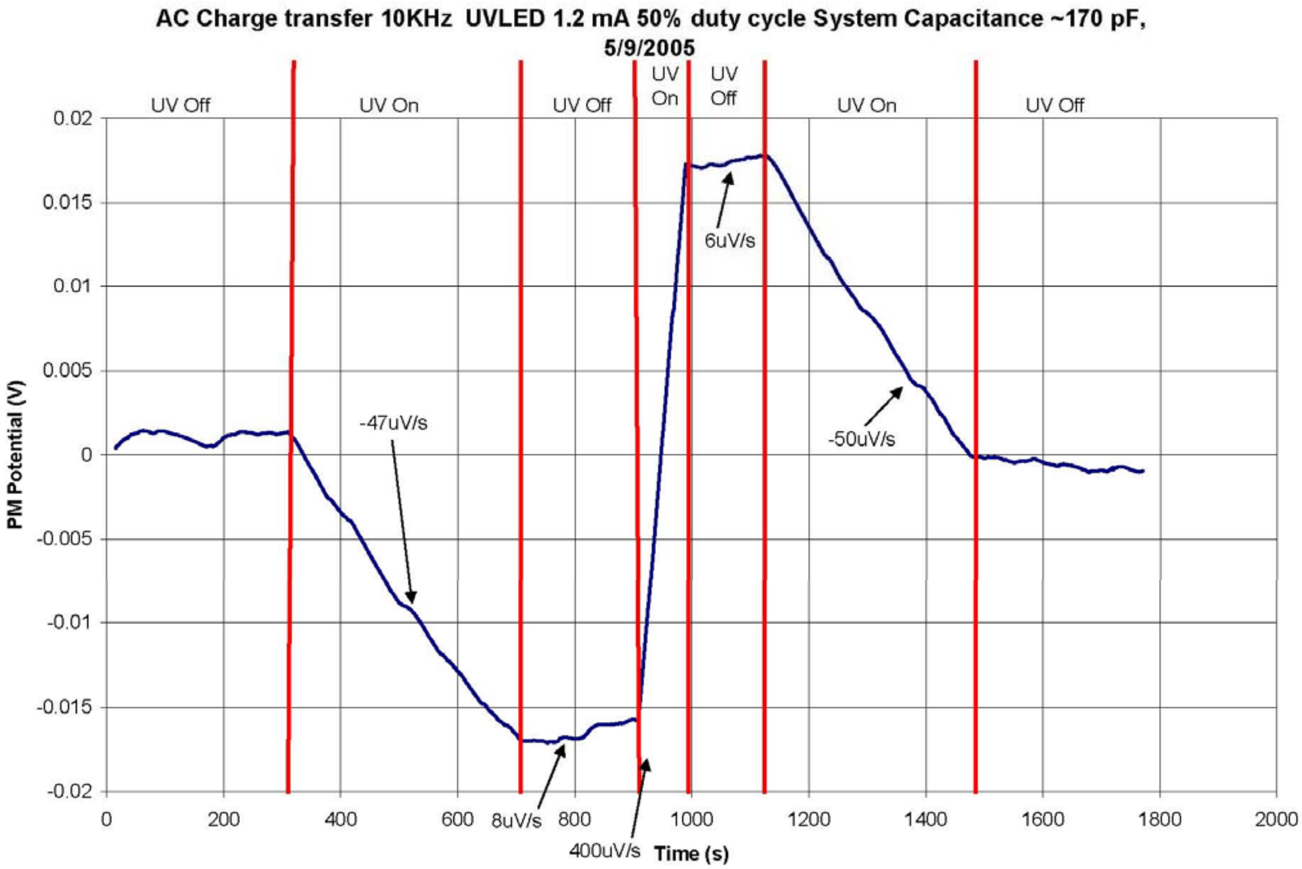




UV phased to negative AC ½ cycle

Electrons fly to proof mass

Proof mass potential decreases

# UV LED Based AC Charge Management




Results for AC charge transfer studies using a UV LED with observed power or ~11 μW at a center wavelength of 257.2 nm. The image on the left shows the UV test facility. The figure shows both charging and discharging over a proof mass potential of +/- 20 mV.

# Charge Management Experiments at Stanford

1. AC charge management using fast modulated UV LED
2. UV LED lifetime test (running 2440 hours so far)
3. UV LED based charge management system development (in design process, with the success of the UV LED lifetime tests)
4. Metal surface scanning UV photoelectron studies (on going experiments: Nb and Au)
5. Modeling efforts
   - Electrostatics
   - Material effects
6. UV charge and transport effects in dielectric surface and bulk (experiment designed, chamber and vacuum system located) --- will be mostly focused on LIGO
7. Kelvin probe
   - Metal surface data (GSFC, Norna, Jordan)
   - UV correlated experiments