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Investigating the Photoyield of Spacecraft Materials

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Photoemission spectra were measured for conducting, semiconducting, and insulating materials used in NASA's James Webb Space Telescope and Solar Probe Mission studies to determine the contribution of photoemissions to overall spacecraft charging.

BACKGROUND: PHOTO-INDUCED SPACECRAFT CHARGING

The photoelectric effect is an important contributor to spacecraft charging.

- When photons of energies greater than the work function or electron affinity (threshold energy) of a material interact with embedded electrons, the photoelectric effect, or photoelectron emission occurs.
- Photoelectron emission leaves a surface positively charged. One of several factors contributing to spacecraft charging.
- Important to understand photoelectron emissions for energy ranges of high solar photon flux. (See Fig.1)

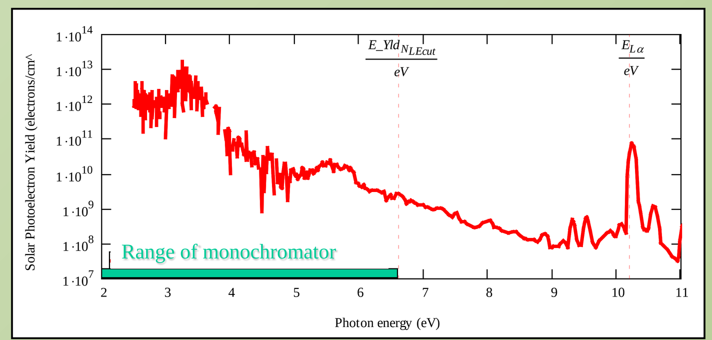

Fig. 1: Logarithmic plot of solar photon yield verses photon energy. Note that the majority of the photons produced by the sun are within the energy range of the monochromator.

- Photoemissions can contribute to charging of conductors, semicondcutors, and insulators used in the James Webb Space Telescope and Solar Probe Mission studies. (See figures 2 and 3)
- Photo-induced currents more difficult to measure in semiconductors and insulators.
  1. Photon energy must be greater than band gap for photoelectric effect to occur.
  2. Low conductivity → Induced charging more difficult to detect.

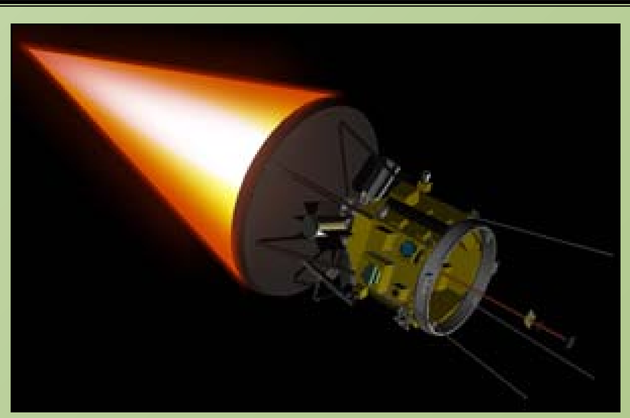

Fig. 2: NASA/JPL Solar Probe model.

Fig. 3: James Webb Space Telescope model.

INSTRUMENTATION FOR PHOTOYIELD MEASUREMENTS

Instrumentation was upgraded to better detect the photoemissions of semiconducting and insulating materials.

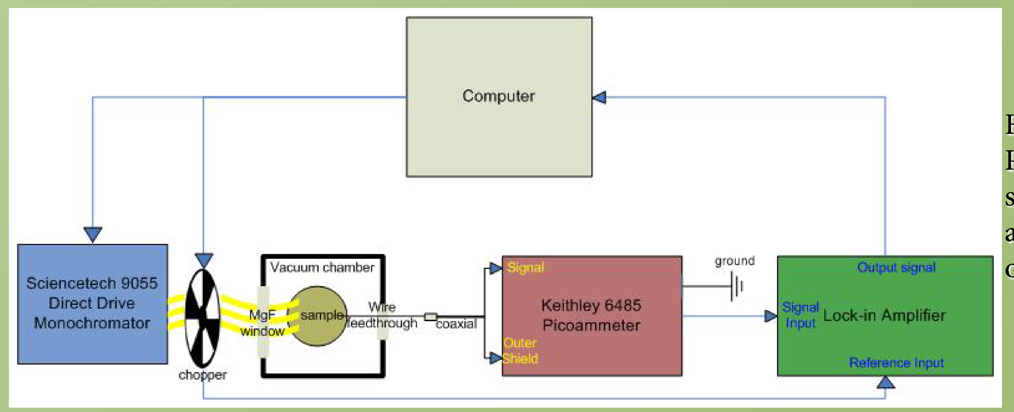

Fig. 4: Photoyield measurement system with lock-in amplifier (to reduce effects of ambient noise on data.)

Upgraded photoyield measurement system (see Fig. 4)

- PC controls monochromator.
- Light from monochromator is pulsed at constant frequency using light chopper.
- Pulsed light passes through MgF window and contacts sample in vacuum.
- Sample current converted to voltage signal by picoammeter.
- The Lock-in amplifier references chopper frequency and amplifies sample signal of the same frequency.
- Resulting spectra data are read into computer.

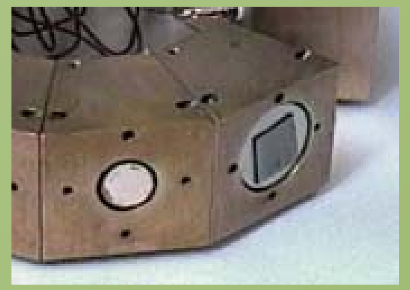

Fig. 5: Dodecahedral sample carousel containing: a) 1cm diameter sample billet and b)photodiode.

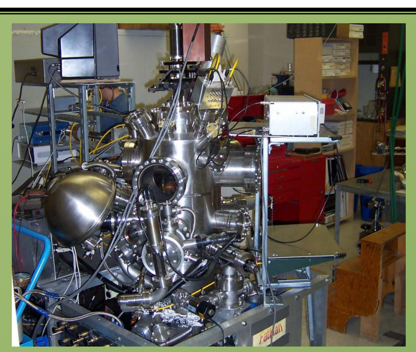

Fig. 6: Ultra-High Vacuum Chamber. Houses samples during photoyield measurements.

EXPERIMENTAL METHODS

1. Validation of Instrumentation Upgrade Before the four spacecraft materials were measured, photoemission spectra were taken on gold (Au). A work function of about 4.65 eV was determined from these data. This corresponds to the accepted value for the work function of gold (~4.8eV), verifying the validity of the upgraded measurement system. (See Fig. 7)

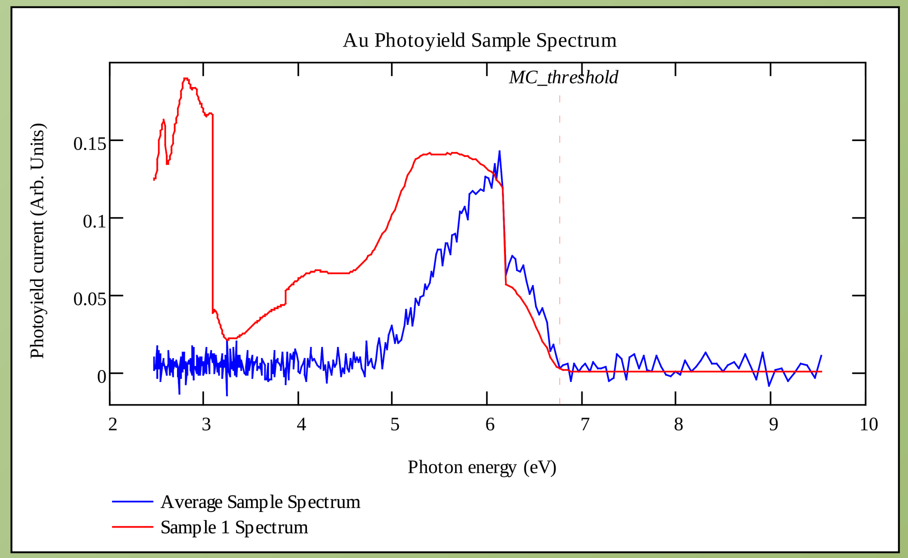

Fig. 7: Photoemission Spectra for Gold (Au) and photodiode.

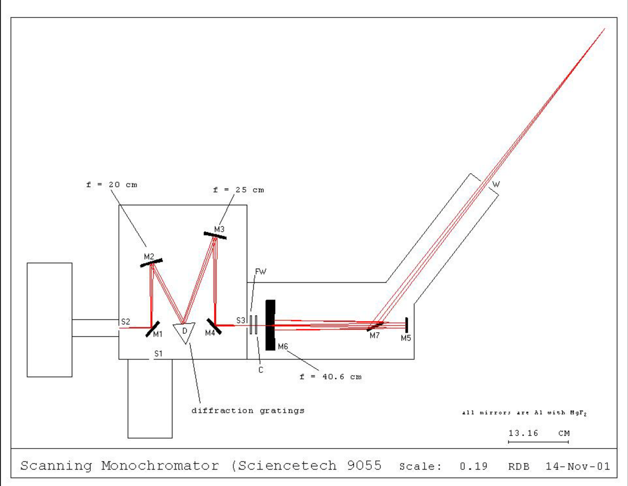

Fig. 8: Ray Diagram of Monochromator Box

2. **Photodiode as Monochromator Intensity Gauge** A photodiode spectrum was taken each day and corrected for the known photodiode detector quantum efficiency. The resulting spectra corresponds to the light intensity from the monochromator at each photon energy. A transmission threshold of ~6.75 eV is observed. (See Fig. 7)
3. **Purging Monochromator Box** Purging monochromator box with nitrogen (N_2) gas reduces UV light absorption by H_2O and O_2 gas. This enhances the transmission spectrum of the monochromator. (See Fig. 8)
4. **Measuring Photoemission Spectra** Spectra were taken for four spacecraft materials with energies ranging form ~2eV to 6.75 eV, the monochromator threshold. Measurements taken in ultra high vacuum, ~10^{-9} torr. (See Fig. 6)

RESULTS

Of the four spacecraft materials studied, only the silicon alloy on Kapton E substrate produced a detectable photo-induced current.

Polyboron Nitride (PBN)

- An insulator used in the Solar Probe Mission study.
  White high temperature, high emmisivity ceramic for use as possible coating on solar probe.
  ~ 3 mm thick.
- No photo-induced current detected (See Fig. 9)
  Current values fluctuated about zero, within the range of ambient noise.

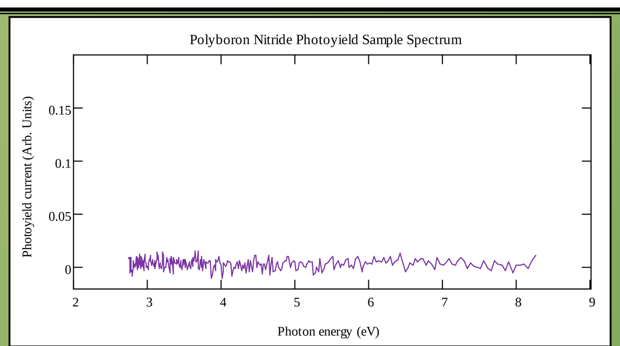

Fig. 9: Photoemission Spectra for PBN.

Alumina (Al_2O_3)

- An insulator used in the Solar Probe Mission study.
  White high temperature, high emmisivity ceramic for use as possible coating on solar probe.
  ~ 1 mm thick.
- No photo-induced current detected (See Fig. 10)
  Current values fluctuated about zero, within the range of ambient noise.

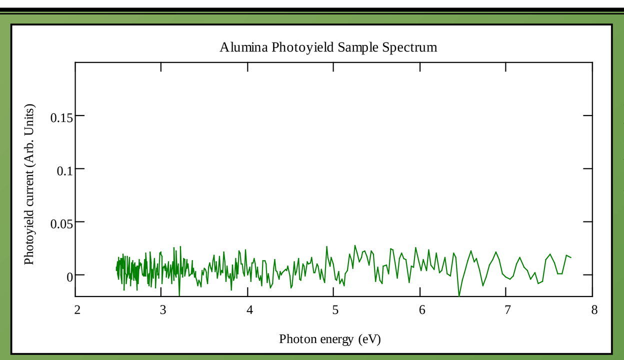

Fig. 10: Photoemission Spectra for Al_2O_3.

Si x PI-E x VDA

- A semiconductor used in James Webb Space Telescope study.
  Top layer: 60 nm layer of silicon alloyed with Iron (Fe), Chromium (Cr), Nickel (Ni).
  Mid layer: 1 mil layer of Kapton E (PI-E), a DuPont™ polymeric Insulator.
  Bottom layer: 100 nm layer of Vapor Deposited Aluminum (VDA).
- Detected photo-induced current. (See Fig. 11)
  Beginning at threshold energy near 5.25 eV. (See Fig. 12)
  Continuing up to transmission threshold of monochromator, ~ 6.75 eV.

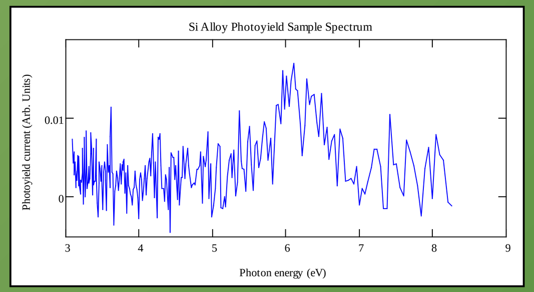

Fig. 11: Photoemission Spectra for Si x PI-E x VDA

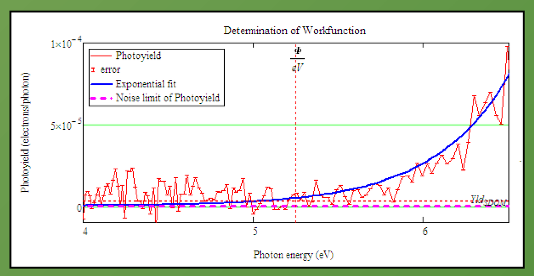

Fig. 12: Photoemission Spectra for Si x PI-E x VDA with exponential fit. Threshold energy ~ 5.25 eV

RESULTS (continued)

VDA x PI-E x Si

- A vapor-deposited conductor used in James Webb Space Telescope study.
  Top layer: 100 nm layer of Vapor Deposited Aluminum (VDA).
  Mid layer: 1 mil layer of Kapton E (PI-E), a DuPont™ polymeric insulator.
  Bottom layer: 60 nm layer of silicon alloyed with Iron (Fe), Chromium (Cr), Nickel (Ni).
- No photo-induced current detected. (See Fig. 13)
  Current values fluctuated about zero, within the range of ambient noise.
- High reflectivity in monochromator range (2eV to 6.75 eV). (See Fig. 14)

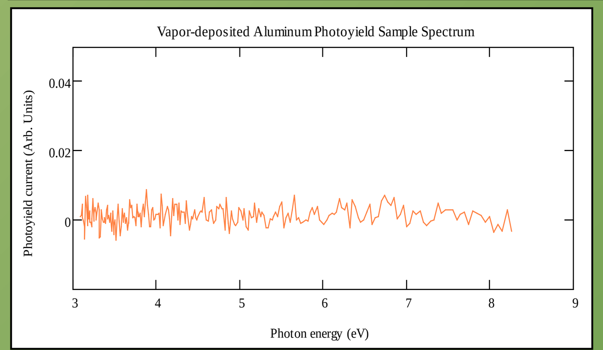

Fig. 13: Photoemission Spectra for VDA x PI-E x Si

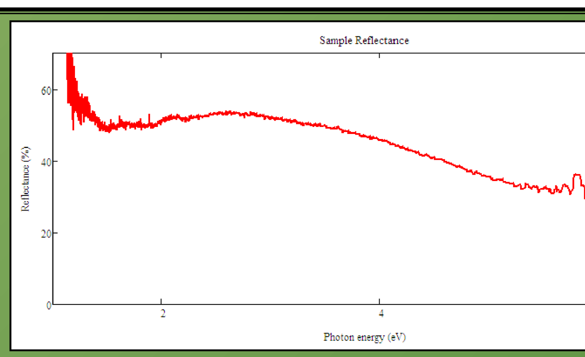

Fig. 14: Graph of Percent Reflectivity vs. Energy for VDA.

CONCLUSIONS

Photoemission spectra correlate with conductivity and reflectivity of materials.

Metals

Gold (Au)
- Measured work function value (4.65 eV) agrees with accepted value for gold (~4.8eV).
- Used as standard to verify that upgraded instrumentation is accurate.

Vapor Deposited Aluminum (VDA)
- Work function of aluminum (~4 eV) is within the monochromator's range, but no photo-induced current was observed.
- Absence of photoyield likely due to high reflectivity of Vapor Deposited Aluminum (see Fig. 14)

Semiconductors

Si x PI-E x VDA
- Observed photo-induced current beginning at 5.25 eV correlates with band gap of Si alloy.
- Photoemission current intensity much lower than gold (relative to the noise level). This is expected, since gold (a metal) is more conductive than the Si alloy (a semiconductor.)

Insulators

Polyboron Nitride (PBN)
- No photo-induced current was observed, likely because the band gap of PBN exceeds the monochromator transmission threshold.
- Higher energy light source needed to determine photoyield threshold energy.

Alumina (Al_2O_3)
- No photo-induced current was observed, likely because the band gap of PBN exceeds the monochromator transmission threshold.
- Higher energy light source needed to determine photoyield threshold energy.

Continuing Research
1. Take photoyield measurements for semi-transparent insulators, such as Kapton.
2. Refine lock-in amplifier technique to improve detection of subtle photo-induced currents.
3. Use higher energy monochromated light source to determine threshold photoemission energies of insulators.

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- Solar Probe picture from NASA's Solar Probe website, http://solarprobe.gsfc.nasa.gov/solarprobe_spacecraft.htm