Organic Monolayers on p-Doped Silicon Affect Photocurrents of Photosystem I Films

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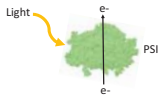
INTRODUCTION

A New Type of Solar Cell

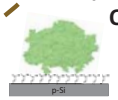
Biohybrid solar cells convert light energy to electricity through the use of Photosystem I (PSI), a protein complex that drives photosynthesis in green plants.

Advantages of Photosystem I



- Transports electrons at near-100% quantum efficiency
- Vast abundance in nature

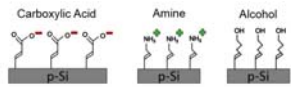
Improving Current Using Organic Monolayers on p-Doped Silicon



- Prior research[1] has shown that PSI films on **p-doped silicon** (p-Si) yield photocurrents far exceeding those on gold or n-doped Si.
- **Organic monolayers** on gold surfaces have been shown to improve photocurrent of PSI[2], but the effects of monolayers on p-Si for PSI films have not yet been studied- hence the motivation for this project.

OBJECTIVES

1. Successfully deposit three ω-terminated alkynes of **varying charge** to a hydrogen (H)-terminated Si surface:

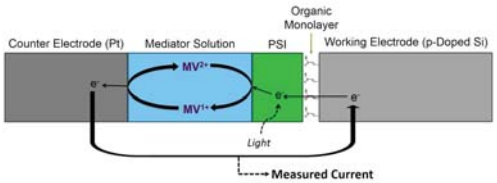


2. Determine which of the above **functional groups** best enhances the photocurrent of a PSI film
3. For the most effective functional group(s), determine the effect of carbon **chain length** of the monolayer on the **magnitude** as well as the **stability** of the **photocurrent**

EXPERIMENTAL METHOD

Method for Processing of p-Si Wafers:

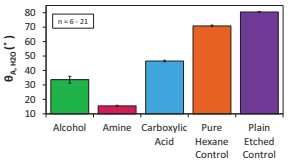
- **Etching with HF** — Creates H-terminated Si surface
- **Immersion in 0.1M Organic Monolayer-Hexane Solution** — Deposits organic monolayer on Si (Control sample was immersed in pure hexane solvent only)
- **Contact Angle Measurement** — Confirms bonding of monolayer to Si surface
- **Vacuum Deposition of PSI** — Deposits PSI on silicon surface
- **Photochronoamperometry** — Measures photocurrent passing through the PSI film:



- **Profilometry** — Measures thickness of the PSI film

RESULTS & DISCUSSION

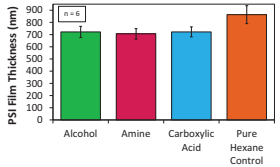
Confirmation of Monolayer Deposition



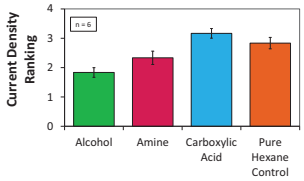
The contact angle for a water droplet on Si indicates the wettability of the surface, confirming the presence of organic monolayers.

Consistency of PSI Film

The average thickness of the PSI film on each wafer did not vary enough to make a noticeable difference in the photocurrent later on.



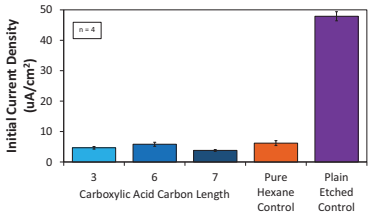
Photocurrent Comparison of Three Different Functional Groups



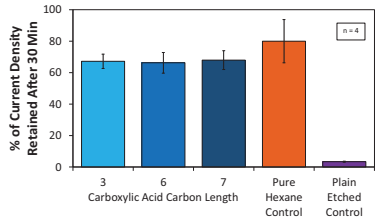
Photochronoamperometry was used to measure the current through the PSI film under red light. The highest current density, at 50 μA/cm², was achieved using the carboxylic acid monolayer.

This result is likely due to electrostatic attraction between the negative surface of the acid monolayer and the positive ends on PSI.

Effect of Carboxylic Acid Chain Length on Photocurrent & Stability



Though the 6-carbon functioned best of the acids, it did not outperform the hexane control. Overall, all of the monolayer-treated samples greatly underperformed plain etched Si; possibly an adverse effect of the monolayer deposition process.



Over time, however, it appears that the organic monolayers provide a significant increase in stability: likely due to protection from Si surface oxidation. Chain length, on the other hand, does not seem to make a difference in the first 30 minutes.

*Note: All error bars represent standard error

CONCLUSIONS & FUTURE WORK

- The **carboxylic acid** monolayer most consistently achieved the highest photocurrents out of the three functional groups tested
- **No correlation** between carboxylic acid chain length and photocurrent over time (for the **first 30 minutes**) was found
- **All monolayer-modified Si** wafers retained current density at much higher percentages than the plain etched Si

Future Directions

- Experiment with organic monolayers capable of covalently bonding with PSI
- Test photocurrent stability over longer periods of time (≥ 24 hr)
- Refine monolayer deposition method to achieve greater consistency in coverage & limit oxidation
- Investigate why the hexane solvent is enhancing Si surface stability
- Develop a nanowire/Si surface to deliver electrons to PSI with greater efficiency

REFERENCES & ACKNOWLEDGEMENTS

[1] LeBlanc, G. et al. *Adv. Mater.* **2012**, *24*, 5959-5962.
[2] Ciesielski, P. et al. *ACS Nano*. **2008**, *2*, 2465-2472.

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