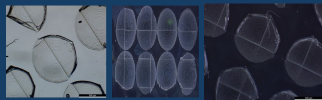
Chattahoochee High School
Energy: Sustainable Materials and Design (EGSD)



Images taken by competitors

Rose Petal Microstructures in Improving Solar Power Efficiency

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Image taken from Dominion Energy Solutions [2].

Introduction

Currently, solar cells contribute to 5% of the world's energy output [1] and are a promising clean energy alternative to fossil fuels. One drawback of these solar cells, however, is their limited efficiency in converting solar energy to usable electrical energy. As of now, solar cells are at maximum 24% efficient [6] and mostly utilize a flat panel surface to capture the sun's energy. Recent studies show that rose petals are highly effective at capturing sunlight due to their unique surface structure which aids in reflecting incoming light [3, 4, 5]. While this phenomenon has been previously studied in energy applications, little research has been done using synthetic rose petal mounds to optimize uniform mound dimensions for energy generation.

By modeling solar panels after modified epidermal structures on rose petals using 3D print technology, this project aims to increase the efficiency of solar power cells and compare the effects of structure shape and size on light-capturing effectiveness.

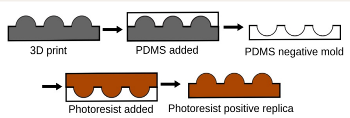


Figure 1: Simplified diagram of the major steps of the experimental procedure. Image created by competitors.

Background

Rose petals are uniquely effective in transmitting light due to their randomly oriented and conical, microscopic mound structures which assist in reducing reflection of incoming light and redirecting photons in multiple directions [3]. This property maximizes light absorption on rose petals and gives roses their bright color. Based on a previous study done by a team of scientists in Germany, we modelled our artificial mounds at a height of around 15 um to resemble real rose petals. The base width and length were scaled up to be visible and to make printing easier. In addition, our artificial mounds were printed uniformly in contrast to the disorganized and random pattern seen on natural rose petals with the goal of making potential manufacturing simpler with a more replicable design.

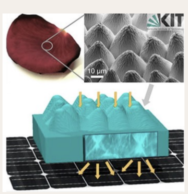


Figure 2: Microscopic image and render of rose petal mounds redirecting light [3]. Image by KIT.

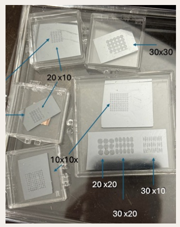
Hypothesis

Solar panel surfaces modeled after modified rose petal microstructures will be able to more effectively redirect sunlight compared to flat, mound-less surfaces, thus increasing the light-capturing effectiveness of solar power cells. Furthermore, panel surfaces with larger epidermal structures will generate a higher voltage due to their shallower angle of incidence, which helps to more effectively redirect light.

Materials and Methods

1. 3D-Printing mounds

- 7 samples resembling rose petal mounds were modelled using SolidWorks CAD software with different base dimensions (10^{-4} m): 10x10, 20x10 (2), 20x20, 30x10, 30x20, 20x30. All mounds were 15 um tall. Each sample consisted of mounds printed on a 1 cm x 1 cm square.
- The CAD designs were printed on silicon wafers using a Nanoscribe 2 photon polymerizer 3D printer at 10x resolution and IP-Q resist.
- After printing, the samples were silanized overnight in a desiccator to make removal of PDMS later easier.



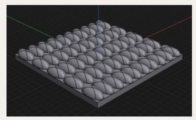


Figure 3 (above): SolidWorks CAD sample of rose petal mounds (30 x20) created by competitors.

Figure 4 (left): 3D printed samples with dimensions.
Picture by Nik Roeske.

2. Creating negative molds with PDMS

- Polydimethylsiloxane (PDMS), an organic, silicon-based polymer, was used to make a negative mold of the 3D printed mounds.
- A liquid solution of PDMS was made by mixing 50 mL of the base and 5 mL of the curing agent in a 140 mL beaker.
- The solution was poured in a glass petri dish and degassed for 10 minutes in a vacuum chamber 4 times (5 minutes between each degassing).
- After degassing, the PDMS solution and silicon wafers were heated in a drying/sterilizing oven at roughly 60°C for 2 hours to cure the solution.
- Once solidified, the PDMS mold was removed from the glass dish and cut into separate pieces, each containing an imprints.

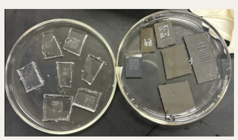


Figure 5: Solidified PDMS molds (left) and corresponding silicon wafers (right). Picture by competitors.

Figure 6 (left): Vacuum chamber setup. Picture by competitors.

3. Creating positive replicas with Photoresist

- SU8-2025 photoresist (provided by Mr. Nikolas Roeske) was used to create positive replicas of the artificial rose petal mounds. SU8 photoresist was chosen for its low viscosity, versatility, and high optical transparency, which allows light to easily pass through it [7].
- SU8-2025 liquid photoresist was poured into a glass dish containing the PDMS molds until all the molds were fully covered.
- The dish, PDMS, and photoresist were then heated over a hot plate in a fume hood at roughly 90°C for 7 minutes to remove impurities, evaporate photoresist solvents, and prepare the photoresist for UV light exposure. After heating, the photoresist was observed to be very fluid and was manually reapplied to the tops of the PDMS molds to fully cover them.
- To cure the photoresist, the dish was placed under a UV lamp for roughly 40 minutes until the photoresist solidified. During this time, the photoresist changed from clear to amber/brown.
- After curing, the photoresist was heated slightly to loosen it and remove it from the glass dish. The photoresist was then cut and trimmed into individual pieces to separate the samples.

Pictures by competitors.

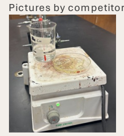


Figure 7: Heating photoresist on a hot plate (outside fume hood).

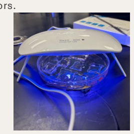


Figure 8: photoresist curing under UV lamp.

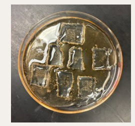


Figure 9: Cured photoresist with PDMS molds underneath.

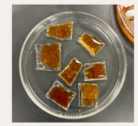


Figure 10: Individual photoresist samples attached to PDMS molds.

4. Microscopic imaging of samples

- Acquired microscopic images of photoresist and PDMS samples and verify success of molding-replicating process. Images taken on Lecia light microscope and Scanning Electron Microscope.

Pictures by competitors.

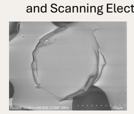


Figure 11: SEM image of sample 20x20.

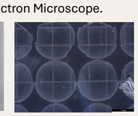


Figure 12: Lecia image of 30x30 PDMS.

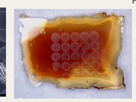


Figure 13: Lecia image of 30x30 photoresist (1).

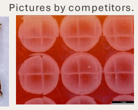
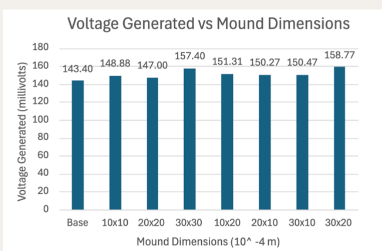


Figure 14: Lecia image of 30x30 photoresist (2).

5. Light testing photoresist samples with multimeter

- A Q-TECH digital multimeter set at DCV 2000 m was used to measure the voltage generated by a 2cm x 2cm solar cell attached to different photoresist surfaces.
- Black electrical tape was put on the parts of the solar cell that weren't covered by photoresist to improve data collection accuracy.
- The samples were placed in a dark box with a viewing hole for the multimeter and a flashlight attached at the top.
- Each photoresist sample was placed on top of the solar cell with the mounds facing up. 3 minutes after each sample was placed, the voltage was recorded. 30 trials of each sample were run.

Data and Analysis



The column labeled "base" represents a flat photoresist structure, serving as a control. There were 30 collections of data points conducted across constant conditions.

The bar chart shows a correlation between mound area and voltage generation. Data from the table below was split into two groups- one for circular mounds and one for ovals with mound area being the x-axis (10^-8 meters squared), and average voltaic output (mv) being the y-axis for both. The circle graph had a correlation coefficient of 0.904 with a coefficient of determination of 0.817, producing the least squares regression line: $y = 0.0169x + 144.52$. The oval graph yielded a correlation coefficient of 0.967 and a coefficient of determination of 0.936, producing the equation $y = 0.0306x + 144.5853$. A linear model was used to compare voltaic output versus the area of the mounds as it reasonably fit the data.

To determine statistical significance, a 2-sample t-test was conducted comparing each group of data to the base (control). A 2-SampTInt function under a confidence interval of 95% with a significance level of 0.05 was used, producing a range of values for each mounded photoresist structure's data set. Each range of values produced by the 2-SampTInt function was then checked to see if it included 0. If the range didn't include 0, this demonstrated that the Null Hypothesis, stating that there is no statistically significant difference between the 2 sets of data, was false, and that our hypothesis was correct.

Dimensions (10^-4 m)	Base	10x10	20x20	30x30	10x20	20x10	30x10	30x20
Average	143.4	148.88	147	157.4	151.31	150.27	150.47	158.77
% Increase	0	3.8215	2.5105	9.7629	5.5160.	4.7908	4.9303	10.718

Figure 15 (top left) and Figure 16 (left): Displays mean voltage output (mv) vs. the dimensions of the squares (10^{-4} m). Table and chart created by participants on Excel.

Conclusion

Conclusion

- Only the data of the 10x10 and 20x20 mounded photoresist structures included a 0 in the range of values produced by the 2-sample t-test, indicating that 5 out of the 7 microstructures resulted in a significant difference. This is evidence that the uniform pattern of photoresist mound microstructures properly reflects light back into the solar panel, allowing it to absorb more sunlight.
- Overall, testing showed that having a uniform pattern of photoresist mounds on the panel surface improved light absorption and energy generation compared to the flat control sample.
- The average efficiency increase across all samples was 6.36%, using the rounded percentages in the table. The 30 x 20 oval-shaped sample performed the best out of all the samples followed by the 30 x 30. Larger microstructures generally resulted in higher voltage outputs, corroborating the hypothesis.

Applications

By implementing rose petal-like mounds onto solar panels, solar cell manufacturing companies can produce solar panel surfaces which will capture light more efficiently. This can increase worldwide solar energy output and reduce the global need for fossil fuels without drastically changing current solar cell design. Furthermore, because our design only alters the solar panels themselves, solar cell users do not need to completely replace their already existing solar cells. Instead, they can install the microstructures on the solar panel itself to increase energy output to meet demand.

Future Recommendations

- Use a 25x resolution printer with IPS material, which results in slower but higher resolution printing instead of a 10x resolution printer with IPQ material for future projects.
- Test with greater mound density so that no flat space is exposed on the panel
- Test variations in mound height

References

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Acknowledgments

- Georgia Tech SENIC Catalyst Grant Program
- Mr. Nikolas Roeske and Georgia Tech IEN nanotech facilities
- Dr. Tina Salguero, Mr. Casey Rowe, and Dr. Eric Formo at UGA's microscopy and imaging facility
- Mr. Matthew Mihordea at Chattahoochee High School for guidance on the science fair process, lab space, and vacuum chamber
- Sahil Hemrajani and Om Patel for advice and multimeter