Variable Temperature Thermochromic Switching Under Varying Illumination

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Introduction

Minnesota is home to some of the greatest temperature ranges in the United States, with lows reaching below -40º Celsius and highs reaching nearly 40ºC. This results in higher than average spending on the heating and cooling of buildings. We have been investigating into responsive building materials to help address this. In particular, we have been studying a thermochromic paint that can capture solar energy and transfer it into the building as heat at low temperatures and reflect the energy at higher temperatures to keep the building cooler. Thermochromic materials are materials that change color in response to their temperature. Leuco dyes in general have a clear phase and a colored phase, ours in particular is black at low temperatures and transparent at higher temperatures. We have paired it with a white paint to improve reflectance at these higher temperatures and are looking into finding a coating that will enhance the absorption at low temperatures without changing the reflectance when the paint

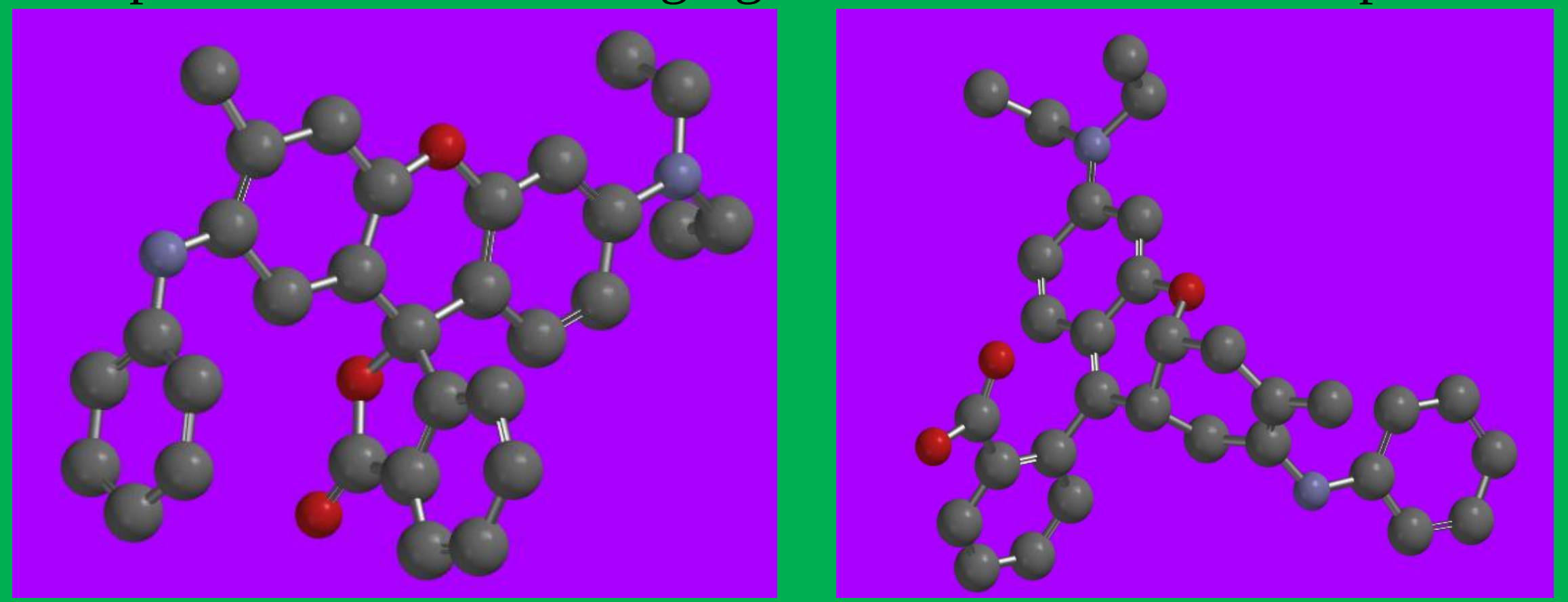


Figure 1: On the left is what our compound looks like when black and is considered the 'closed form' of the molecule. On the right is the transparent 'open form' where one of the bonds connecting an oxygen atom and carbon atom has been broken. In these pictures oxygen atoms are red, carbon atoms are grey, and nitrogen atoms are blue. The hydrogen atoms have been omitted from these images for simplicities sake.

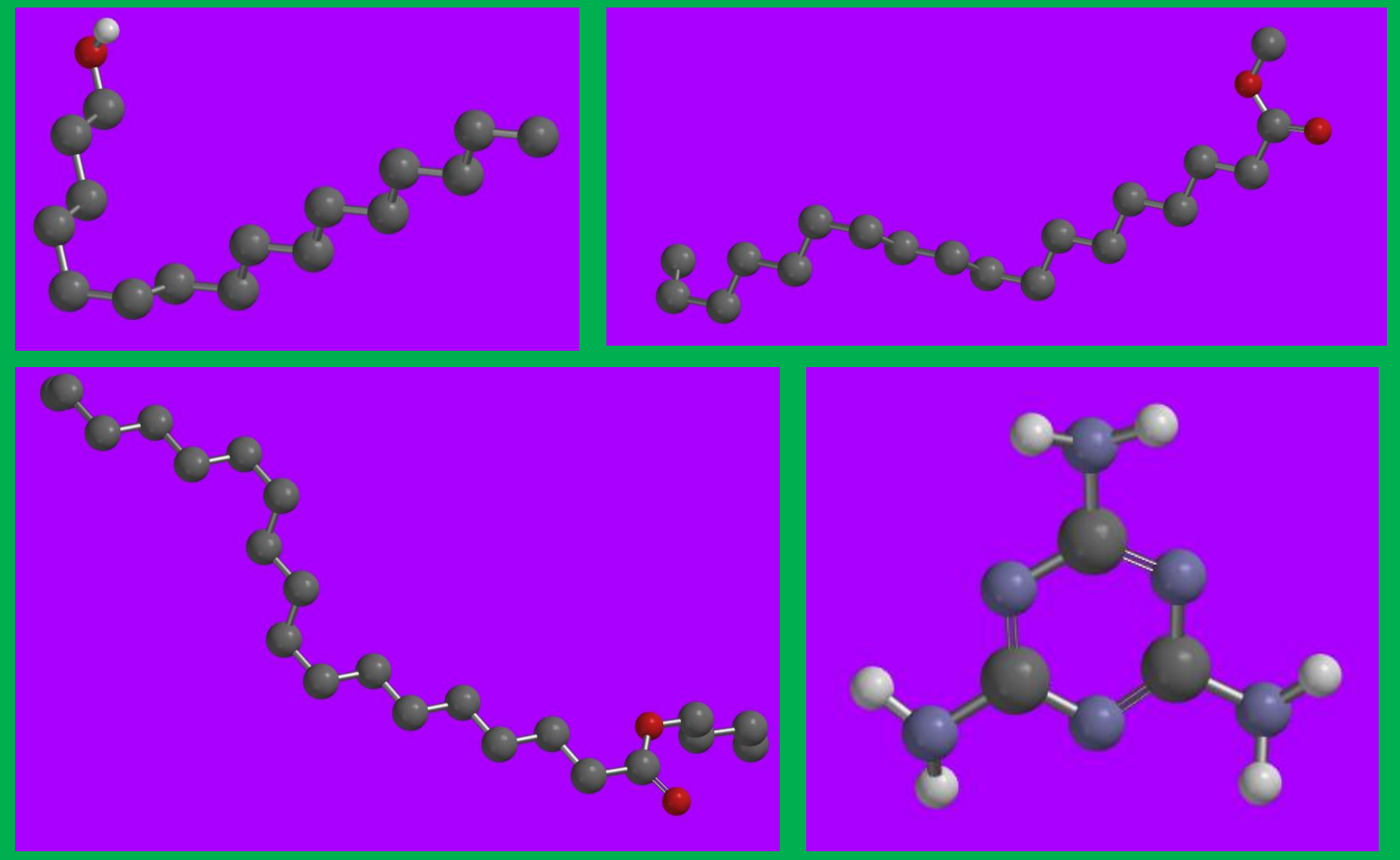


Figure 2: The leuco dye we are using is micro-encapsulated with a 'soup' of other chemicals to facilitate the switch. Bottom right is melamine, which forms the capsules. Top left is hexadecanol, top right is methyl stearate and bottom left is butyl stearate, these three are the 'soup' surrounding the leuco dye molecule.

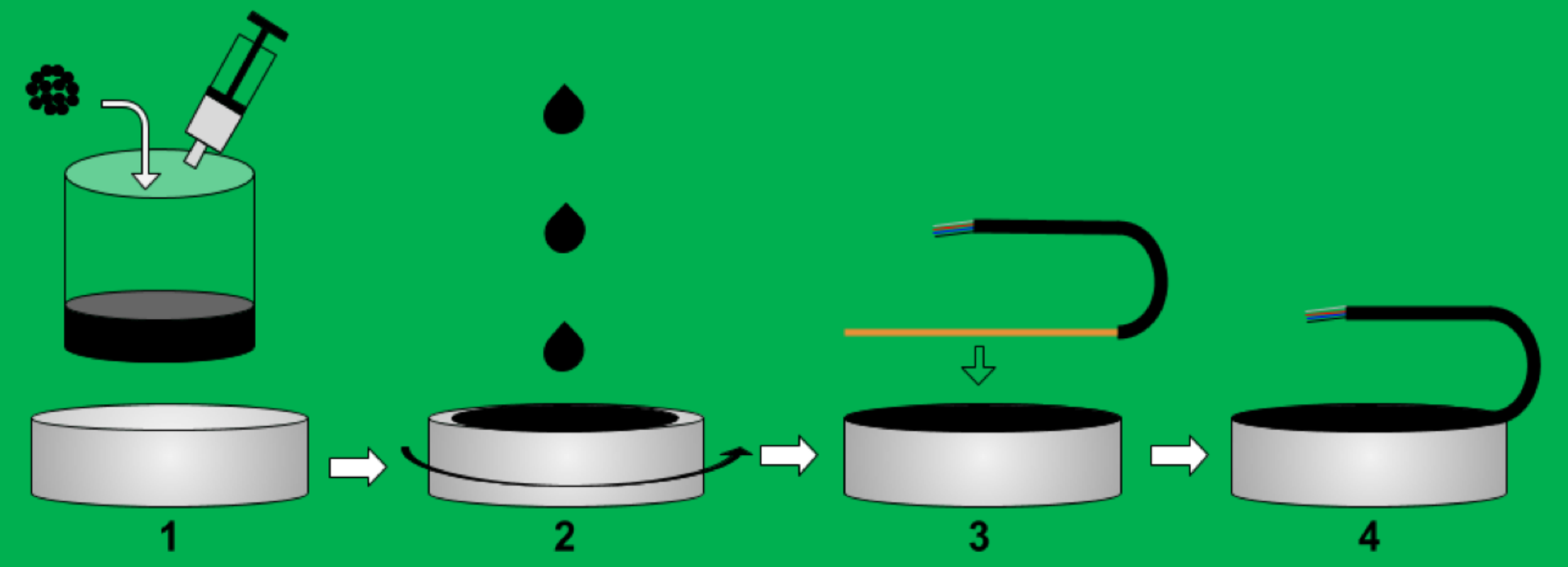


Figure 3: Diagram depicting spin coating process

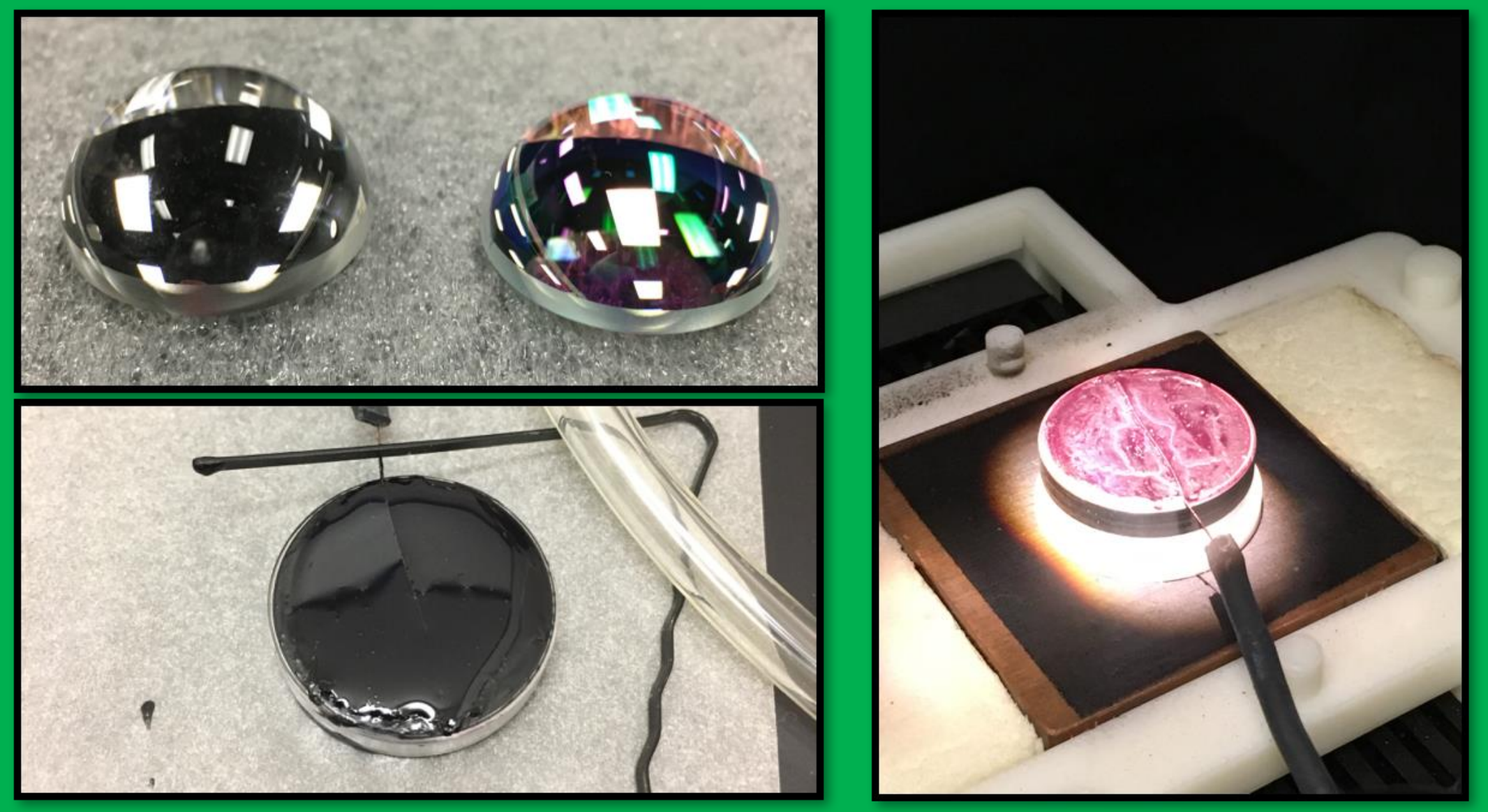
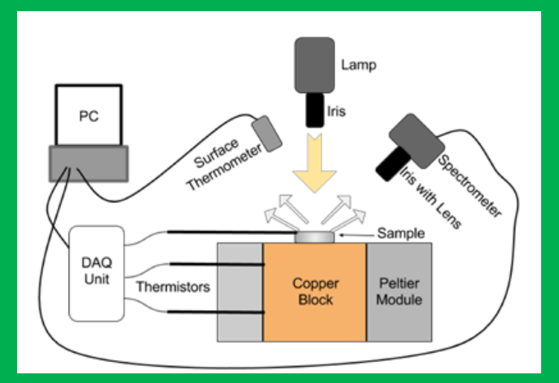


Figure 4: Upper Left – Old Lens and New Lens,
Lower Left – Wet TC Sample, Right – Dry TC Sample

Figure 5: Diagram of Experimental Setup



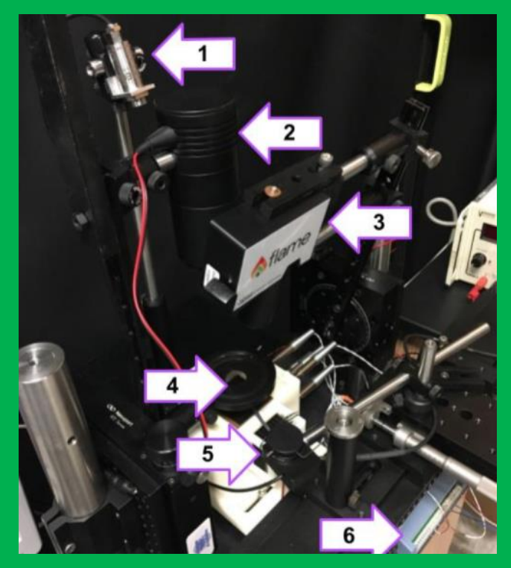
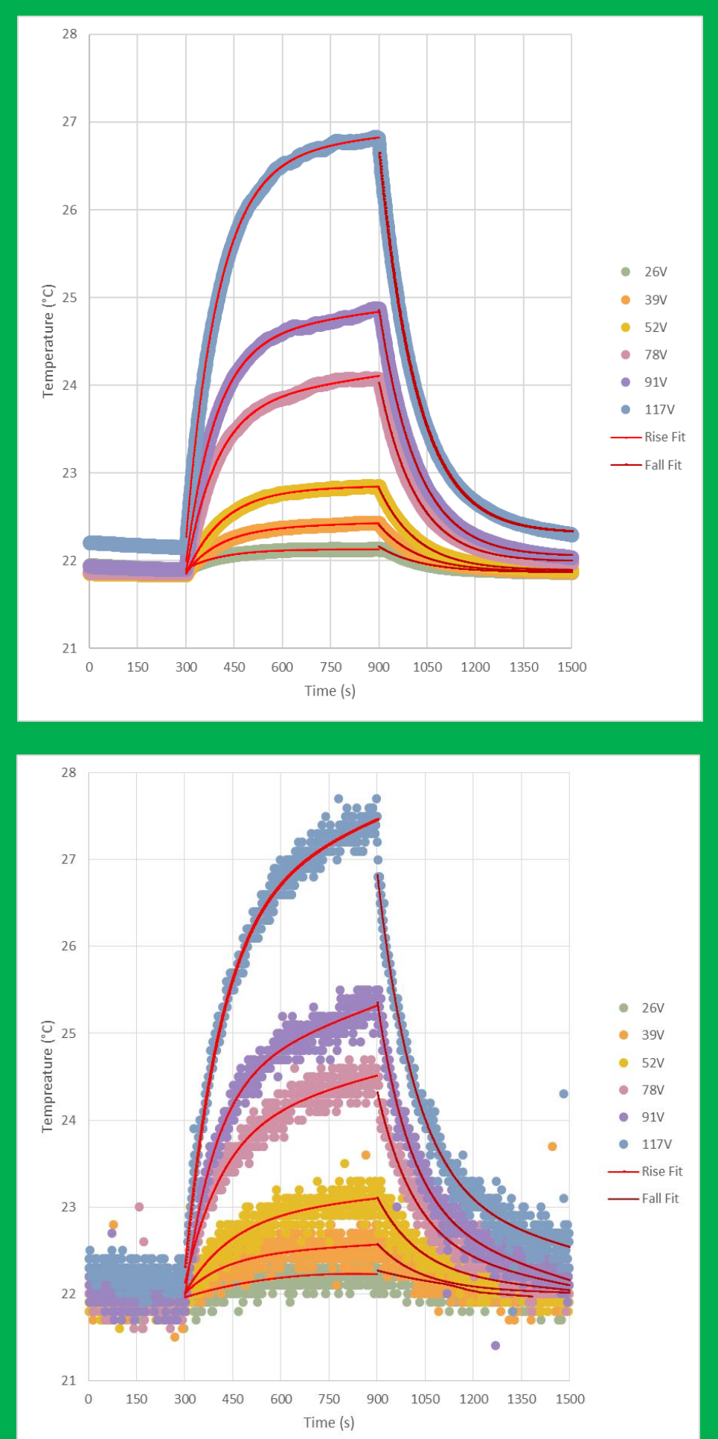


Figure 6: Picture of Experimental Setup
[1] Surface Thermometer
[2] Lamp
[3] Spectrometer
[4] Sample
[5] Power Meter
[6] DAQ Unit

Model for thermal rise of a one-dimensional coating

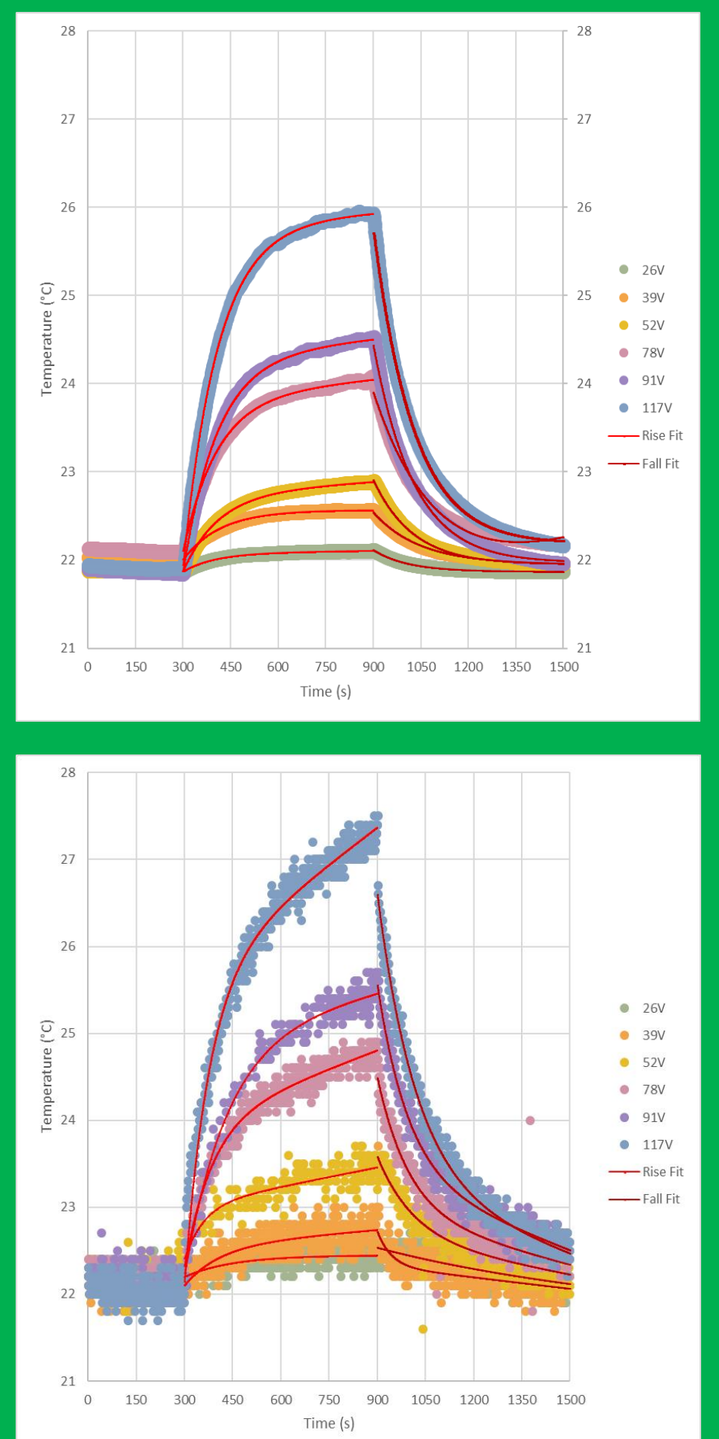
The temperature difference between the illuminated coating only differs from the temperature of the environment by a few degrees Celsius. We expect conduction (and linear convection) to dominate heat losses. Proceeding with these assumptions, the heat flow balance in the material is given by:

$$\frac{dQ}{dt} = \frac{mc_s dT}{dt} = I(1-R)A - \frac{\kappa_s A}{L_s}(T - T_{ss}) - \frac{\kappa_a A}{L_a}(T - T_a)$$



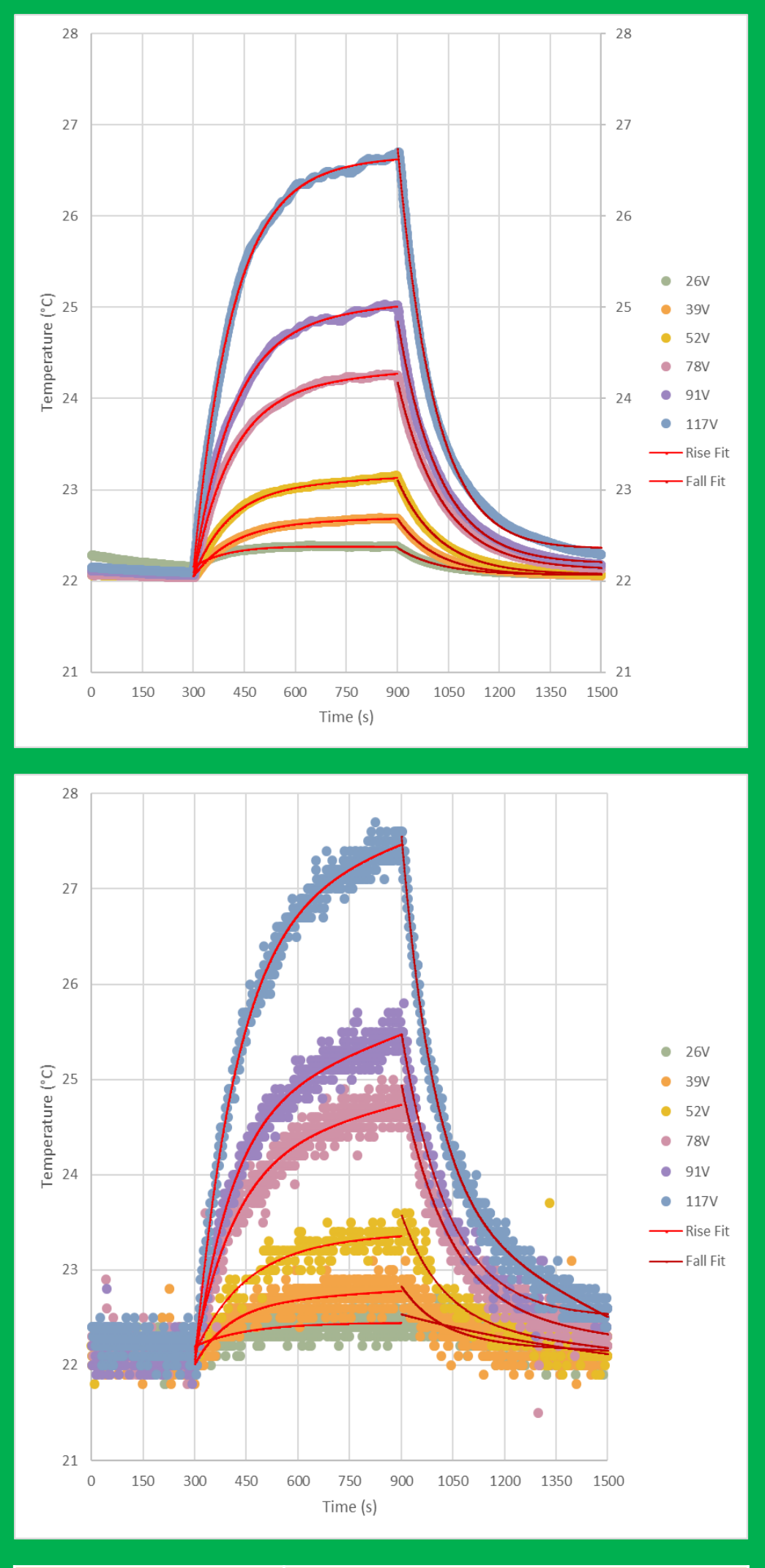
Voltages	ΔT_{bottom} / $\Delta T_{surface}$
26 V	0.23 °C / 0.25 °C
39 V	0.51 °C / 0.45 °C
52 V	0.98 °C / 0.92 °C
78 V	1.94 °C / 1.87 °C
91 V	2.59 °C / 2.57 °C
117 V	4.39 °C / 4.33 °C

Figure 7:(Above) 30°C Transition Temperature Coating



Voltages	ΔT_{bottom} / $\Delta T_{surface}$
26 V	0.21 °C / 0.24 °C
39 V	0.56 °C / 0.45 °C
52 V	0.88 °C / 0.62 °C
78 V	1.74 °C / 1.66 °C
91 V	2.44 °C / 2.69 °C
117 V	3.90 °C / 3.59 °C

Figure 8:(Above) 25°C Transition Temperature Coating



Voltages	ΔT_{bottom} / $\Delta T_{surface}$
26 V	0.24 °C / 0.25 °C
39 V	0.59 °C / 0.65 °C
52 V	0.97 °C / 1.17 °C
78 V	2.10 °C / 2.13 °C
91 V	2.79 °C / 2.69 °C
117 V	4.45 °C / 4.78 °C

Figure 9: (Above) 20°C Transition Temperature Coating

Figures 7-9: Top-bottom layer. Middle – surface. Bottom – change in temperature.

The overall temperature model employed in this study is then:

$$T(t) = \begin{cases} T_{ss}(0) & t \le 0 \\ T_0 + \alpha t + \Delta T\left(1 - e^{-\beta t}\right) & \text{for } 0 < t < t_f \\ T_\infty + \alpha t + \Delta T e^{-\beta t} & t > t_f \end{cases}$$

So far, this model lacks time-dependent temperature reflectance switching; its inclusion would appear in the form R(T) in the above model; this will be the next step in evolving the model.

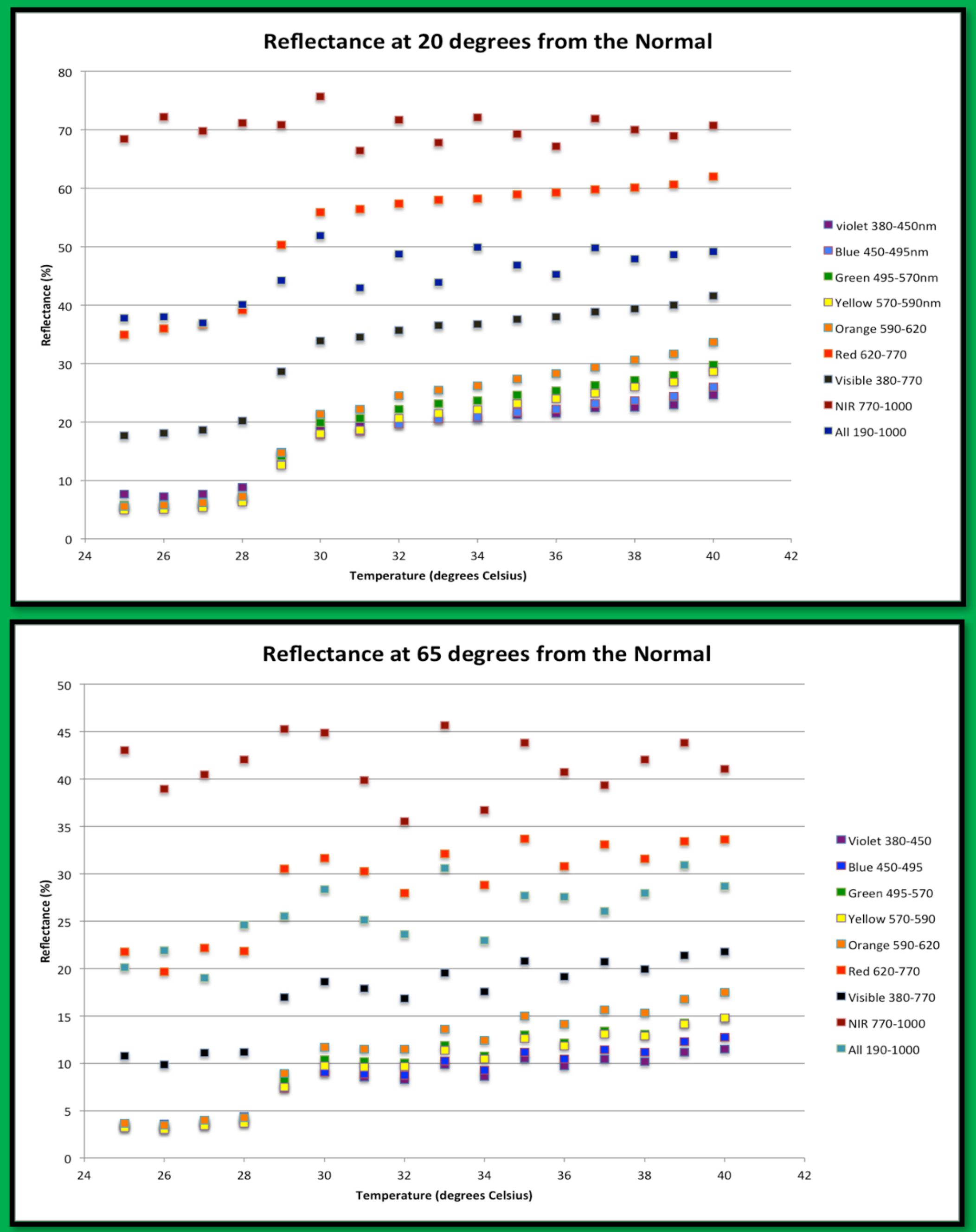


Figure 10: Reflectance and angle data obtained Fall 2016

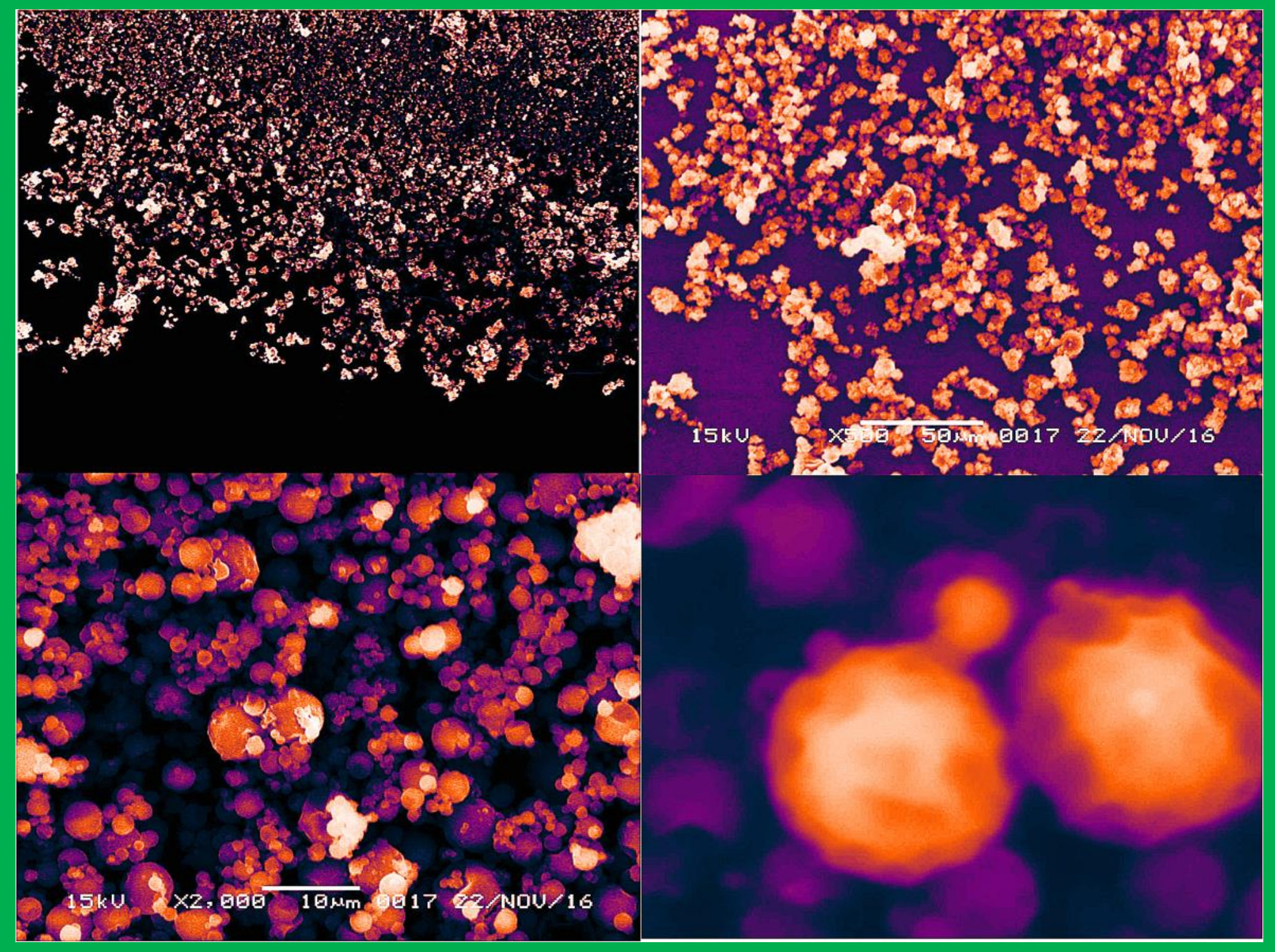


Figure 11: SEM imaging of the surface deposition of the fluoran with a scale for each image. The top left image is at 200x resolution, top right is at 500x, bottom left is at 2000x, and the bottom right image is at 18000x resolution.

Future work

Right now there are two students working on this project, Alexis Corbett and Danielle Hall. Alexis is working on determining the durability of our material by looking at how many color change cycles it will take before the material loses 50% of its initial efficiency and by testing the extreme temperature tolerances to ensure that this is viable and efficient for our (Minnesota's) temperature range. Danielle is working on determining how much light energy is successfully converted into thermal energy. The title of the project currently comes from her portion of the research as this is her graduating semester.

Acknowledgements

We would like to thank the following for use of equipment: St. Cloud State University, Dr. Sivaprakasam, Dr. Sinko, the ETS Department, the Mechanical Engineering Department, and the Physics and Astronomy Department. We would also like to thank William Julius, Meredith Rupp, Kevin, Tobi, and Nancy for work on this project. And, of course, we would like to extend an enormous thank you to our research advisor Dr. John Sinko.

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