NDnano
Center for Nano Science and Technology

NDnano Summer Undergraduate Research 2017 Project Summary

1. Student name & university: Alfredo Duarte - University of Notre Dame

2. ND faculty name & department: Hirotaka Sakaue – Aerospace and Mechanical Engineering

3. Project title: Chemical sensor for fluid dynamic and environmental applications

4. Briefly describe new skills you acquired during your summer research:

The exposure to a professional research environment taught me a whole new set of skills. This summer I learned how to use scientific instruments such as a spectrometer, a pressure controller, scientific lasers, and high speed cameras. Practicing science also requires effort and patience, during my time here I learned the meticulousness and care that is required to perform some of the necessary procedures. I learned how to be part of a team in a fast-paced research environment, where active discussion and collaboration are key to getting results. Finally, I learned data acquisition and reduction techniques that can be applied to many areas, even outside of engineering.

5. Briefly share a practical application/end use of your research:
The goal of this research is to produce a uniform two-color pressure sensor that can be used in the study of fluid dynamics. Pressure sensitive paint can be utilized in a variety of aerodynamic objects thanks to the non-invasive, low cost, fast, and quantitative pressure information that it offers. Many industries and institutions are in need of an alternative to the traditional pressure taps or transducers, which can have expensive material and installation costs.

6. 50- to 75-word abstract of your project:

Pressure sensitive paint consists of two luminescent dyes: a reference probe and a pressure sensitive probe, solvent, polymer, and porous material. In this study, I elaborated the individual luminescent powders of the PSP by varying parameters such as the concentration of luminescent dye and porous material, solvent and method of drying. The powders were then characterized by its brightness and uniformity.

7. References for papers, posters, or presentations of your research:

Sakaue, H. et al. (2011), ”Characterization and Optimization of Polymer-Ceramic Pressure-Sensitive Paint by Controlling Polymer Content”, Sensors 2011, 11, 6967-6977; doi:10.3390/s110706967

Sakaue, H. et al. (2013), ”Luminophore Application Study of Polymer-Ceramic Pressure-Sensitive Paint” Sensors 2013, 13, 7053-7064; doi:10.3390/s130607053

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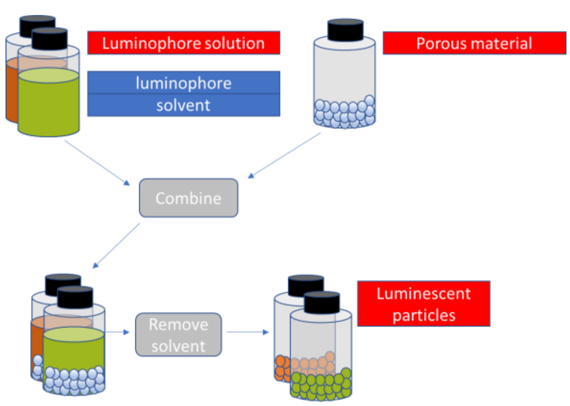
Chemical sensor for fluid dynamics and environmental applications

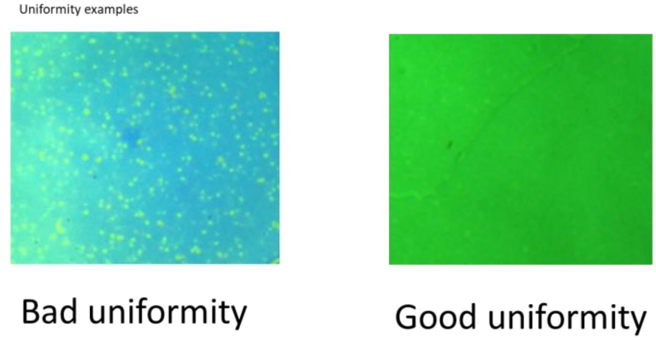
Pressure measurements are essential to the study of fluid dynamics, they can be used to identify flow phenomena, validate computational fluid dynamics codes, and other engineering applications. Pressure sensitive paint (PSP) is an imaging technique that utilizes a luminescent molecule to relate its luminescent output to the pressure. When compared to traditional pressure taps or transducer methods, PSP offers low cost, non-invasive, and flexible pressure information. In PSP research, a two-color PSP has been developed by our team to capture unsteady pressures over a moving/deforming/vibrating fluid dynamic object. It consists of two luminescent dyes: a reference probe and a pressure sensitive probe, porous material, polymer and solvent. Fluorescein was selected as the reference probe, while a Ruthenium was chosen as the pressure sensitive probe. Silica gel (SiO_2) was used as the porous material. To give quantitative pressure measurements, it is required to have a uniform distribution in both luminescent dyes. However, the two-color luminophore solution is sprayed over a base layer, and during this procedure the dyes adsorb onto the layer non-uniformly. To overcome the non-uniformity problem, luminescent particles were developed. These particles will then be mixed to create a uniform two-color PSP. This study explored how the concentration of the porous material and luminescent dye, solvent, and drying method affect the adsorption process in the elaboration of the luminescent powders. Aiming primarily for uniform powders and a maximum luminescent intensity.

The individual luminescent particles were created by what we will outline as the standard procedure. Initially, a solution of luminescent dye was created, then on a separate container a given amount of silica gel was measured with a scale. The solution of luminescent dye was then added to the container with the silica gel, which was then placed in a sonicator for 10 minutes to enable proper mixing. Finally, the solvent was removed to leave the remaining luminescent particles. The success of each sample was characterized by two main properties: brightness and uniformity. The uniformity was classified qualitatively from observations as exemplified below. The brightness of the samples was evaluated with the help of the spectrometer and a plate that allowed the samples to be tested under the same conditions, which yielded quantitative values.



Basic procedure to elaborate powders

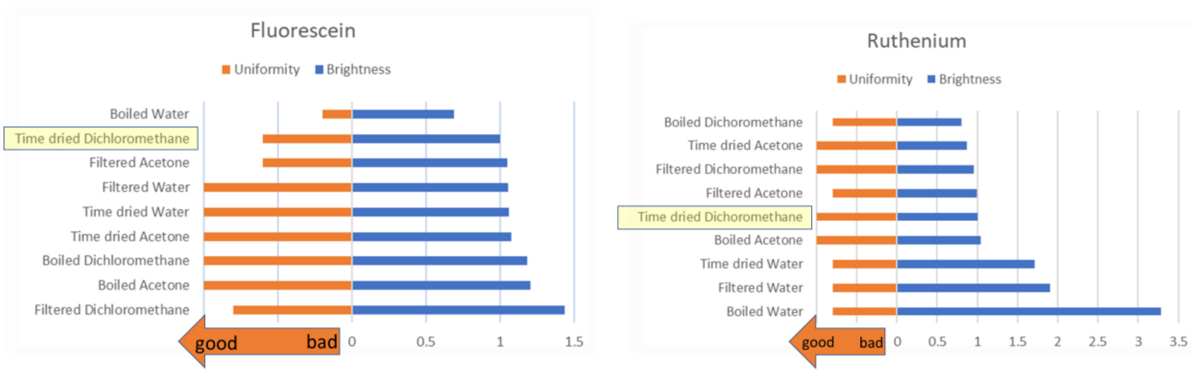
Uniformity examples



The first experiment established a good porous material proportion that could be worked with, which was determined to be 0.05g/mL, any higher proportion resulted in messy non-uniform samples.

The subsequent experiments dealt with the solvent and drying method of the process. Dichloromethane, Acetone, and Water were utilized as the solvents, while filtering, time drying, and boiling were the methods used to get rid of the respective solvent. Fluorescein had many positive combinations, with the filtration of dichloromethane being the most successful technique in both brightness and uniformity. The best results for Ruthenium were achieved by boiling water, however the brightness and decay of this luminescent powder is still a challenge.

Additional experiments were carried out for the concentration of porous material and luminescent dye. In the next attempt, the concentration of porous material was varied while keeping the ratio of porous material to luminescent dye concentration constant. The results for these variations were mostly constant, with dips in brightness as the lower values were approached for both luminescent dyes. Finally, experiments were made by varying the concentration of luminescent dye only. The results of these experiments suggested that higher concentrations were favorable for both brightness and uniformity. The higher concentrations enabled a saturation of the porous material which greatly improved uniformity, while the lower concentrations seemed to have insufficient dye for the porous material which resulted in lower brightness and a noticeable non-uniform distribution.



Uniformity was evaluated on a scale from 0 (bad) – 5 (good). The brightness was normalized in terms of the dichloromethane-time dried sample(highlighted) , which was chosen as the standard.

The best samples were then characterized to find if they could be used in applications. The filtered fluorescein with 0.3 mM concentration was selected to be tested with the help of a spectrometer and a Linkam chamber, a device that enables us to vary the pressure. The pressure was varied from 50 kPa to 150 kPa in intervals of of 10kpa. The test was satisfactory, with the fluorescein displaying no change in brightness for all the different pressure points. The same test was conducted for the boiled Ruthenium 0.3 mM sample. The sample varied its brightness for the different pressures as expected. The relationship between the luminescent output of the sample and the pressure can be modeled as a linear function, which yielded a slope of 0.2042. While this value is still lower than what we are aiming for, all the information gathered from the study represents significant progress in the development of a two-color pressure sensor.