## *NE 455/461L – Engineering Design Improvements*

Rajesh Swaminathan (20194189)
Peter Lee (20201956)

---

### *2.4 Engineering Design Improvements (15 marks, done in lab partner pairs)*

The current vapour sensing system employed is basic and has room for improvement.

1. *Propose a change to the laboratory to improve the sensing efficiency and further distinguish the signals produced for each vapour. Focus on the material chosen and how it is applied to the QCM substrate since this will likely yield the greatest improvements. Keep the QCM and gas delivery system and solvents chosen as constant.*

   One simple improvement is to repeat the experiment with a second QCM with a different cross-linker like 11-mercaptoundecanoic acid on the Au-MPC layer which would result in a polar substrate. Furthermore, the exploration of hydrophobic vapours such as toluene and hexane can be done to determine which has better absorption.

   Another method is to change the shape and concentration of the nanoparticles to gain packing saturation. We could also use multiple layers of Au-MPC to increase film thickness and volume.

2. *The proposal change should follow engineering design methodology. Justify why it would affect sensing over the current system.*

   By exploiting the fact that different solvents have different polar affinities, one can selectively use the appropriate substrate for better absorption due to the different levels of hydrophilic and hydrophobic attraction. This will allow more mass to be absorbed in the same amount of sensing time which corresponds to a greater frequency shift. A greater frequency shift would then improve sensitivity by improving Cs (amount absorbed).

   In addition, we could also change the concentration of Au NPs drop casted or change their shape/size to explore further sensing improvements. For example, nanoparticle gold platelets might have the ability to stack on top of each other which would lead to multiple layers and larger volume for the QCM to absorb vapour. An increase in the volume will translate to an increase in mass that can be absorbed.

If the drop cast method isn't optimal enough or there are problems with the Au NPs adhering to the QCM surface due to a change in the cross-linker, we could explore other deposition techniques such sputtering or PECVD.

3. *Specifically justify the laboratory time required to execute the idea, the monetary costs and how the proposed idea can be incorporated into the laboratory. The idea should realistic and be able to be implemented into the laboratory you just performed. Use the constraints of a six hour laboratory period that includes 3 hours of vapour testing that uses common reagents. Do not propose using exotic and expensive materials or procedures requiring expensive equipment or long periods of time.*

   The first change of using two QCMs with different cross-linkers can be separated among the different groups. Two groups could do the polar substrate and two groups could do a non-polar substrate. The data would then be complied and shared. Toluene and hexane is available at Chem Stores and can be purchased easily for a relatively low cost. MUA-11 was done in the first lab from NE454L and can be used for this lab but more stock would be required. Refer to the old CAS number to find the cost of MUA-11 bought for NE454.

   The gold nanoparticles can either be prepared in-lab as a colloidal suspension to obtain different shapes. Depending on the surfactant used, different shapes such as stars, rods, spheres, and platelets can be made. Silver platelets are capable of being created by Prof. Dale Henneke, and the same method could be adapted to form Au particles. The sample shapes and sizes can be verified by TEM, but this is an expensive step.

   Alternatively, we could buy Au nanowires and nanorods directly from Sigma-Aldrich. We were able to find 25 mL of 25 nm nanorods suspended in colloidal suspension stabilized by CTAB, but this solution was extremely expensive at around $462.50 CAD for just 25 mL.

### 3.6 Engineering Design Improvements (13 marks, done in lab partner pairs)

The Grätzel cell design is basic and has room for improvement.

1. *Propose a change to the laboratory to improve the performance of the cell for any parameter determined ($J_{SC}$, $V_{OC}$, FF and power) or to increase reliability or improve the fabrication process.*

   One way to improve the dye loading is to use mesoporous $TiO_2$ NPs instead of an annealed $TiO_2$ + anatase combination. An improved dye loading will improve $J_{SC}$ and $V_{OC}$ by allowing more light to be captured thereby producing more excitons [1].

2. *The proposal change should follow engineering design methodology. Justify how the change would improve the system.*

   The mesoporous nature of the $TiO_2$ NPs will allow better loading of the Eosin-Y dye because of the larger surface area available. It will also improve diffusion of the dye through the film due to the channels formed by the continuous pore structure. A better loading will increase Jsc and $V_{OC}$ by allowing for more excitons to be created. Once these excitons have been created, they will also be able to easy to separate since each dye molecule has a better contact with the $TiO_2$ particles to transfer the charge.

   Furthermore, the thickness of the film wouldn't pose such a large barrier to charge transport since mesoporous $TiO_2$ has an interconnected pore structure that improves diffusion.

3. *The idea should realistic and be able to be implemented into the laboratory you just performed. Specifically justify the time required to execute the idea, the monetary costs and how the proposed idea can be incorporated. Use the constraints of a six hour laboratory. Do not propose using exotic and expensive materials or procedures requiring expensive equipment or long periods of time.*

   Making the mesoporous $TiO_2$ is again a simple matter of colloidal suspension. It can be made using $TiO_2$ precursors in a oil/water micro-emulsion with the usage of a surfactant such as P123. Eric Prouzet, the instructor who provided us with the $TiO_2$ nanoparticles used currently, can also make the same mesoporous $TiO_2$ with not all that much extra effort and for virtually zero extra cost.

   The monetary and time effect of this change is thus insignificant. This change is also quite realistic and easy to make.

   However, if the consistency of the film is an issue in term of thickness, distribution, etc., then we can also deposit a porous $TiO_2$ film through plasma-enhanced CVD (PECVD). This would obviously make the process much more expensive, and would require the use the $4^{th}$ year clean rooms.

## References

[1] Mingdeng Wei et al, "Highly efficient dye-sensitized solar cells composed of mesoporous titanium dioxide," *J. Materials Chemistry* **16** (2006) pp. 1287-1293.