IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Investigating morphology-controlled hybrid metal plasmonic materials in catalysis**	
Project Number	**IMURA1033**	
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Research Clusters: Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST **one.** For more information, see www.iitbmonash.org)*		**Highlight which of the Academy's Theme(s) this project will address?** *(Feel free to nominate more than one. For more information, see www.iitbmonash.org)*	
1	*Material Science/Engineering (including Nano, Metallurgy)*	***1***	*Artificial Intelligence and Advanced Computational Modelling*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*	2	*Circular Economy*
3	*Math, CFD, Modelling, Manufacturing*	3	*Clean Energy*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*	4	*Health Sciences*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*	5	*Smart Materials*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*	6	*Sustainable Societies*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*	7	*Infrastructure*
8	*HSS, Design, Management*		

The research problem

Define the problem

Anthropogenic CO_2 emission into the atmosphere is recognised as a major cause for global warming and climate change. Development of scalable technologies that address the challenges of CO_2 capture and sequestration are of paramount importance to arrest global warming. Contemporaneously, there is a need to develop technologies and processes for the conversion of CO_2 to value added fuels and chemicals.

In recent years, there has been an explosion of interest in plasmonic materials both from a fundamental perspective [1] as well as in their application to global challenges such as CO_2 conversion [2]. Exciting research in the utilisation of plasmonic metal nanoparticles in catalysis have shown that catalytic activity can be significantly enhanced during light exposure and plasmon excitation [2,3]. Recently, it has also been shown that intra-particle reactivity under light excitation can be controlled [4] and this shows promise for the generation of a new class of plasmonic catalysts.

This project seeks to develop a range of shape-controlled multi-component plasmonic nanoparticles and investigate their application in the catalytic conversion of CO_2 to value added chemicals. The project will entail identification of suitable multi-component plasmonic systems, development of scalable synthesis protocols, testing and optimising the materials for catalytic CO_2 conversion and development of a fundamental understanding of the role of plasmonic materials in enhancing catalytic activity. If possible, a pilot scale prototype reactor will also be designed.

More recently, developing on the Sabatier Principle of Catalytic Resonance Theory, researchers have shown that perturbation on catalyst surface can be used to modulate the apparent activation energy of the reaction to increase the dynamic steady state rate of reaction. Periodic oscillations in the field can be used for increasing the apparent rate of reaction and selectivity, including pulsed illumination in photocatalysis [5]. Here, we will investigate wavelength, intensity and pulse oscillation to enhance the rate of plasmonic reaction.

[1] N. Rivera and I. Kaminer, *Nature Reviews Physics* **2**(10), 538–561 (2020).
[2] Z. Zhang, C. Zhang, H. Zheng, and H. Xu, *Accounts of Chemical Research* **52**(9), 2506–2515 (2019).
[3] R. Verma, R. Belgamwar, and V. Polshettiwar, *ACS Materials Letters* **3**(5), 574–598 (2021).
[4] S. Bhanushali, S. Mahasivam, R. Ramanathan, M. Singh, E. L. Harrop Mayes, B. J. Murdoch, V. Bansal, and M. Sastry, *ACS Nano* **14**(9), 11100–11109 (2020).
[5] Ji Qi, Joaquin Resasco, Hossein Robatjazi, Isabel Barraza Alvarez, Omar Abdelrahman, Paul Dauenhauer, Phillip Christopher, ACS Energy Letters, 2020, 5, 3518

Project aims

Define the aims of the project

1. Identification of suitable plasmonic supports and catalytically active metals that can be synthesised as single, multi-component nanoparticle structures.
2. Development of synthetic processes for the generation of promising multi-component plasmonic materials and optimisation of the production process.
3. Identify synthesis processes that are scalable and demonstrate production for a pilot level demo reactor.
4. Test promising plasmonic multi-component systems in CO_2 conversion to value-added chemicals. The choice of products and reactions to be investigated will constitute an important part of this activity and a techno-commercial approach will be employed.
5. Optimise the catalytic reaction and develop a pilot scale reactor for the product identified.

What is expected of the student when at IITB and when at Monash?

Highlight how the project will gain from the students stay at IITB and at Monash

IITB:

1) Student will conduct a literature search and identify suitable plasmonic materials to investigate for CO_2 catalytic conversion. This will include optimal metals, morphologies and techno-commercial considerations. This can include 3-4 potential systems to investigate further.
2) Development of scalable synthesis processes for 2 of the 4 multicomponent candidate catalyst systems.
3) In-depth characterisation of the 2 multi-component systems.
4) Identification of possible CO_2 conversion reactions and products and choice of 2 target products for investigation at Monash.

Monash University:

1) Development of scalable synthesis processes for the remaining 2 multicomponent catalyst systems and their in-depth characterisation.
2) Testing the 4 plasmonic catalysts in CO_2 conversion reactions identified in 4 at IITB and identification of best candidate material.
3) Optimisation of catalytic conversion reaction for the best multi-component catalyst.
4) Development of design for pilot scale reactor.

Expected outcomes

Highlight the expected outcomes of the project

1. Development of a tool-kit for the production of plasmonic catalysts for CO_2 conversion.
2. Design of a pilot level process for plasmonic CO_2 conversion.
3. The results will be published in peer reviewed journals and patented, where appropriate.

How will the project address the Goals of the above Themes?

Describe how the project will address the goals of one or more of the 6 Themes listed above.

The outcomes from this project will directly contribute to the Circular Economy and Sustainable Economies themes by adding value to CO_2, that is currently considered a waste-product. This also addresses the Smart Materials theme by utilising research in this area to address the goals of Circular Economy and Sustainable Societies.

Capabilities and Degrees Required

List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.

Students with the following background are encouraged to apply :

1. Postgraduate degrees in Materials Science and Engineering/Chemical Engineering/ Chemistry/Physics. In exceptional cases, students with bachelors degree in these disciplines may be considered.
2. Students that have carried out research intensive projects as part of their UG/PG programmes in nanomaterials synthesis, characterisation and application will be preferred.
3. Familiarity with analytical techniques such as XRD, FTIR, SEM/TEM, UV-vis spectroscopy will be an added advantage.
4. We are looking for highly motivated students who are excited about working on a global challenge in a highly interdisciplinary environment.

Necessary Courses

Name three tentative courses relevant to the project that the student should complete during his/her coursework at IITB (the student will require to secure 8 point in these courses)

Any three of:
CL656: Colloid & Interfacial Engineering
CL611: Electrochemical Reaction Engg
CL618: Catalysis and Surface Chemistry
MM 732: Structural Characterisation of Materials
MM 750: Vibrational Spectroscopy for Materials Scientists
MM 718: Laser Processing and Nanostructures
CL665: Sustainable Engineering Principles

Select up to **(4)** keywords from the Academy's approved keyword list **(available at http://www.iitbmonash.org/becoming-a-research-supervisor/)** relating to this project to make it easier for the students to apply.

1. Novel functional materials
2. Nanotechnology/nanoscience
3. Optics, photonics
4. Water, Climate Change (Carbon capture, sequestration and utilisation)