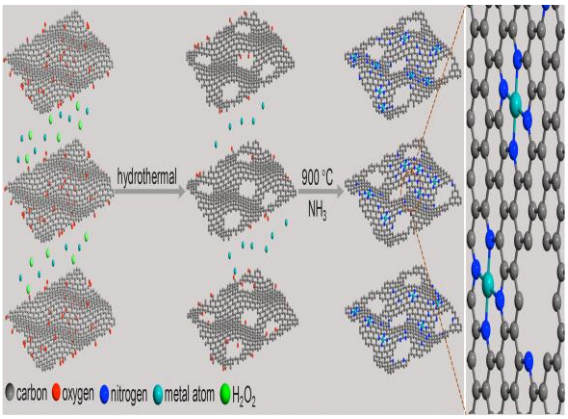
Statement of Research Plans

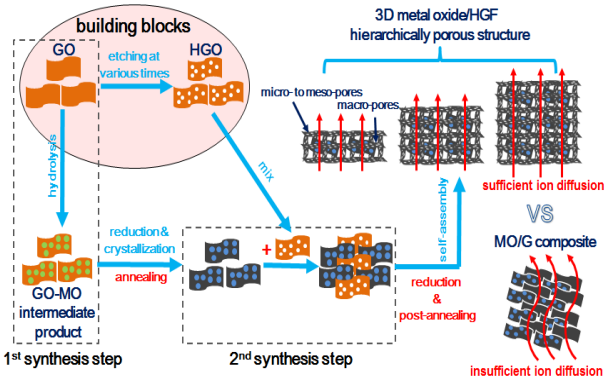
My academic and research interests are inclined to the design of novel functional 2-D materials and architectures, with optimum performance while exploiting high surface area, novel size effects, along with compositional variations for photocatalysis, wastewater treatment, electrochemical energy conversion, and storage devices[1-7]. Thus, I have been engaging in various successful interdisciplinary research collaborations to explore the research areas of my passion. As required by position, I have established multidisciplinary collaborations with the University California Los Angeles (UCLA), Stony Brook University (USA), Sungkyunkwan University (South Korea), and Fudan University (China) within the last four years. Furthermore, I have successfully secured and completed various research projects with my international collaborators in the field of development of novel catalyst at nanoscale and their applications in photocatalysis, fuel cells, wastewater treatment, and electrochemical devices. For instance, my collaborative and research group in UCLA recently developed a reliable and general approach for the synthesis of single metal atoms catalyst (SACs) supported on nitrogen-doped carbons (M-N-Cs) which are distinguished from other metal-oxides supported SACs for their high electrical conductivity and electrochemical stability in harsh electrochemical conditions, representing an attractive class of electrocatalysts [1]. Series of transition metals (e.g., Fe, Co, Ni) with exclusive single atomic dispersion embedded in two-dimensional nitrogen-doped graphene lattices that enhance the definitive and unambiguous identification of the atomistic structure. We believe that developed catalysts are the best reported ever as exhibiting exceptional activity and stability, with low over potential and high turnover frequency. The general synthesis, unambiguous structural identification, and catalytic investigation of a series of nitrogen-doped carbons (M-N-Cs) mark a critical advancement in establishing the structure-property correlation in single atom catalysts. In addition, the generality of our synthetic approach can be used to prepare a broad class of MN_4C_4-based catalysts for diverse electro-catalytic applications, including OER/ORR, hydrogen oxidation/evolution, CO_2 reduction, and N_2 reduction.



In particular, I am interested in the fundamental question of how synthetic route and material architectures affect their fundamental properties Photocatalysis, wastewater treatment [2-7], electrochemical energy conversion, and storage devices. Thus, my focus is to establish a reliable, practical, and valid explanation regarding the observations that the effects at the microscopic level can tell us about the macroscopic nature of these systems. As an example, meticulous design and synthesis of transition metal dichalcogenides such as CuS_2, MoS_2 NiS_2 etc will be carried oust using CVD and ionic liquid assisted wet chemical methods.

Separately, we are undertaking research on how nanostructured electrode materials can be used as energy storage devices. The reason for this is that nanostructured materials have shown considerable promise for electrochemical energy storage [8-15]. Sometimes, it claimed that

orders of magnitude increase in energy or power density in research devices. However, these devices have failed to deliver their promise in practical devices. A critical challenge behind this failure is that the extraordinary performance demonstrated in such nanostructures so far was only achieved in electrodes with rather a low real mass loading, which is approximately 1 mg cm^{-2} or less. The above-mentioned number is far less than the practical levels of mass loading that should be greater than10 mg cm^{-2}. Therefore, it cannot be readily scaled due to the increasing ion diffusion resistance in thicker electrodes. To sustain the same gravimetric capacity and current density in thicker electrodes with 10 times greater mass loading, that is 10 mg cm^{-2} against 1 mg cm^{-2}, it requires the delivery of 10 times more charges, over 10 times longer distance. Such an application is particularly challenging for materials with intrinsically high energy density or power density, and hence it requires a high charge delivery capability, beyond what typical electrode architectures can offer. The requirement represents a fundamental scientific challenge in electrode architecture design, rather than a simple engineering scaling matter. To deliver the promise of the new electrode materials with intrinsically high capacity or high-rate capability in practical devices, it is necessary to develop a new electrode architecture that can efficiently deliver the sufficient electrons or ions to make the full use of these new electrode materials at practical mass loading. To this end, our current research work mainly focuses on the development a general strategy of two-step synthesis method to create a holey graphene framework (HGF) with the hierarchical porous structure as the conductive scaffold for metal oxides and polymers. We believe that this highly interconnected graphene framework will offer excellent electron transport properties while the hierarchical porous architecture ensures excellent ion transport properties. In particular, the in-plane pores in the graphene sheet provide abundant ion transport pathways for facilitating rapid ion transport and mitigating diffusion limitations of electrolyte transport across the entire porous structure[15].



The research will also focus on low temperature ionic liquid assisted synthesis of metal sulphides and their composites. The reason for this is that two-dimensional (2D) atomic crystals of transition metal sulphides such as NiS, CoS_2, MoS_2, and VS_2, among others have attracted intense interest for various industrial applications. However, reliable synthesis of their heterostructures and their composites with graphene with precisely defined spatial modulation of chemical compositions and electronic structures remains a significant challenge. My current group is working to develop a general and reliable strategy for the growth of a wide range of diverse heterostructures, multi heterostructures from two-dimensional (2D) atomic crystals and their composites, using ionic liquid as electrolyte media at low temperature with controlled morphology and structure for energy conversion and storage devices.

I believe my current and future research will be valuable to the institution, as it will make significant contributions to the departments overall interdisciplinary objectives by strengthening academic offerings and the research mission of the faculty. The reason for this is that the research topics are consistent with the requirements of the department requirements. For instance, my research is directly related to rational design and synthesis of 2-D materials for energy application, hence it can enhance the faculty's strengths in 2-D Material design, Synthesis

& Properties. Therefore, my research will equip students with necessary skills and practical experience in finding reliable and researched information pertaining to physics, chemistry, material science, and environmental engineering. It will also be useful to the faculty and the industry with valid and applicable information for future use as students will be able to apply research findings in a real-world situation, even after their graduation. Therefore, I believe that my expertise in the field of experimental 2-D materials, current and future research plans as mentioned along with my strong international collaboration link, will be very helpful for the department to achieve its overall interdisciplinary objectives.

Reference:

1. Holby, E. F.; Zelenay, P., *Nano Energy* **2016,** *29*, 54-64.
2. Shakir, I.; Shahid, M.; Kang, D. J., *Chemical Communications* **2010,** *46* (24), 4324-4326;
3. Shakir, I.; Choi, J. H.; Shahid, M.; Ali, Z.; Kang, D. J., *Journal of Materials Chemistry* **2012,** *22* (38), 20549-20553.
4. Shakir, I.; Ali, Z.; Kang, D. J., *Journal of Alloys and Compounds* **2014,** *617*, 707-712.
5. Shakir, I.; Sarfraz, M.; Ali, Z.; Aboud, M. F.; Agboola, P. O., *Journal of Alloys and Compounds* **2016,** *660*, 450-455.
6. Ghaffar, I.; Warsi, M. F.; Shahid, M.; Shakir, I., *Physica E: Low-dimensional Systems and Nanostructures* **2016,** *79*, 1-7.
7. Ali, Z.; Shakir, I.; Kang, D. J., *Journal of Materials Chemistry A* **2014,** *2* (18), 6474-6479.
8. Shaheen, W.; Warsi, M. F.; Shahid, M.; Khan, M. A.; Asghar, M.; Ali, Z.; Sarfraz, M.; Anwar, H.; Nadeem, M.; Shakir, I., *Electrochimica Acta* **2016,** *219*, 330-338.
9. Zhang, Y.; Huang, Y.; Yang, G.; Bu, F.; Li, K.; Shakir, I.; Xu, Y., *ACS Applied Materials & Interfaces* **2017,** *9* (18), 15549-15556.
10. Shakir, I., H., *Electrochimica Acta* **2014,** *129*, 396-400.
11. Zhu, J.; Shan, Y.; Wang, T.; Sun, H.; Zhao, Z.; Mei, L.; Fan, Z.; Xu, Z.; Shakir, I.; Huang, Y., *Nature communications* **2016,** *7*, 13432.
12. Jiang, T.; Bu, F.; Feng, X.; Shakir, I.; Hao, G.; Xu, Y., *ACS nano* **2017,** *11* (5), 5140-5147.
13. Xu, Y.; Chen, C.-Y.; Zhao, Z.; Lin, Z.; Lee, C.; Xu, X.; Wang, C.; Huang, Y.; Shakir, M. I.; Duan, X., *Nano letters* **2015,** *15* (7), 4605-4610.
14. Huang, Y.; Li, K.; Liu, J.; Zhong, X.; Duan, X.; Shakir, I.; Xu, Y., *Journal of Materials Chemistry A* **2017,** *5* (6), 2710-2716.
15. Sun, H.; Mei, L.; Liang, J.; Zhao, Z.; Lee, C.; Fei, H.; Ding, M.; Lau, J.; Li, M.; Wang, C., *Science* **2017,** *356* (6338), 599-604.