UC San Diego
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NanoEngineering

UCSD NANO & CHEMICAL ENGINEERING

SPECIAL SEMINAR

February 9th 2023

Seminar Presentation: 9:30am – 10:30am

SME Room 248

"Engineering subnanometer pores in single-layer graphene for high-performance gas separations"

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Abstract: High-performance molecular-selective membranes are needed to improve the energy efficiency of separation processes and reduce industrial carbon emissions. In this context, nanoporous single-layer graphene membranes, prepared by incorporating subnanometer vacancy defects (i.e., pores) in the graphene lattice, are highly promising. They can sieve molecules and do so at high rates because the resistance to diffuse is controlled by a single transition state at the atom-thick nanopore. The main challenge for their realization is incorporating a high density of nanopores with the needed subangstrom resolution for relevant gas separations (e.g., 0.3-0.5 Å for separating CO2 from N2 and CH4) and doing so homogeneously over a large area. Nanopores can be incorporated into the graphene lattice via post-synthetic etching strategies or during its crystallization (intrinsic defects). In this presentation, I will i) critically compare these two routes, ii) discuss the fundamentals behind ozone etching, iii) discuss the origin of the intrinsic defects, and iv) share our recent success in boosting the density of gas-selective intrinsic defects to record densities, and hence performance.

I will start by introducing a post-synthetic ozone etching chemistry that allows controlled nucleation and expansion of vacancy defects with a sub angstrom resolution, and finish with a bottom-up strategy for the controlled synthesis of nanocrystalline graphene where incomplete growth of nanometer-sized, misoriented grains generates molecular-sized pores in the lattice. Generally, post-synthetic strategies are believed to allow more control over vacancy defects, and bottom-up approaches are considered more scalable. However, the answer might not be so definitive. I will share our recent results showing the scale-up potential of post-synthetic approaches; and how by understanding the origin of the intrinsic defects, we can engineer them to produce high-performance gas-sieving membranes (e.g., a high density of gas-sieving pores that result in membranes with CO2 permeance of 18,500 GPU and a CO2/N2 selectivity of 28).

Educational Development and Training: Diversity and teamwork for the win. Drilling billions of nanopores in graphene to make atom-thick molecular filters is a challenging endeavor. This presentation will illustrate how the different perspectives, backgrounds, and skills of my colleagues and I worked synergistically to achieve this feat. Our combined expertise in advanced characterization techniques allowed us to unravel the fundamental science behind the oxidation of graphene and our engineering background to leverage this knowledge to control the etching of nanopores in graphene over a large scale. Efforts to increase equity and inclusion are crucial because scientific research thrives in diversity.

Biosketch: Luis Francisco (Paco) Villalobos is a Swiss National Science Foundation postdoctoral fellow at Yale University in Prof. Elimelech's group. His research interests focus on understanding the mechanisms behind the selective transport of molecules and on developing novel membrane technologies for the sustainable production of critical materials and energy. Currently, he is engineering ion selective membranes by developing an improved understanding of the key structure-property relationships and transport mechanisms involved in the permeation of ions.
Paco received his PhD in Chemical Engineering from King Abdullah University of Science and Technology (KAUST) and his BSc in Chemical Engineering from Universidad Nacional Autónoma de Mexico (UNAM). Before joining Yale, he worked as a postdoctoral researcher at the École polytechnique fédérale de Lausanne (EPFL). He is the recipient of the North American Membrane Society Young Membrane Scientist Award (2022).