DHIRANI GROUP

Systems with Quantum Electronic Behaviour Nanoengineered from the bottom-up – Dhirani group

When we get to the very, very small world---say circuits of seven atoms---we have a lot of new things that would happen that represent completely new opportunities for design. … We can use, not just circuits, but some system involving the quantized energy levels, or the interactions of quantized spins, etc….
R. Feynman, APS 1959, "There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics."

A theme of the Dhirani group's research is to use nanostructures as building blocks to make quantum systems, study their behaviour and potentially their "designer" nature. A strong structure-behaviour link may shed light on previously observed but not well understood quantum phenomena; in addition, new combinations of nanobuilding blocks can lead to observation of new phenomena (See Fig. 1). Such a bottom-up approach for fabricating quantum materials is possible because in recent decades, there have significant advances in the discovery and synthesis of a wide variety of nanostructures. Also, nanostructures exhibit strong quantum effects. A well-known example is "quantum dots" which exhibit strongly size-dependent optical properties; their discovery and development garnered a 2023 Nobel prize.

Fig 1 shows an example of a quantum nanostructured material developed by the Dhirani group following this bottom-up approach. These materials are a new class of nanosheets comprising gold metal particles electrically connected via semiconducting "molecular wires" with quantum particle-in-a-box-type energy levels. (See Fig 1). These nanosheets are highly ordered, one nanoparticle thick and macroscopic (cm) in size. Classical wires exhibit increasing resistance with increasing wire length (longer wires have more scattering and higher resistance); however, these materials exhibit exponentially decreasing material resistance with increasing molecular wire length yield due to quantum charge transport through the material's energy levels (longer molecule wires have more closely spaced energy levels and lower transport barriers: see Fig. 2). Studies of these and other new materials and devices are ongoing.

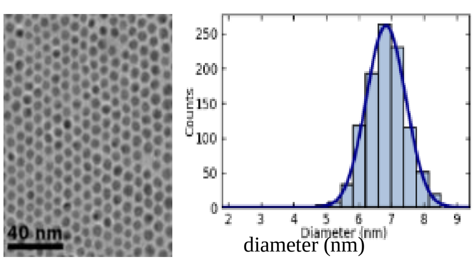

Fig. 1 Metal-semiconducting Nanosheets fabricated by the Dhirani group Ref [3]

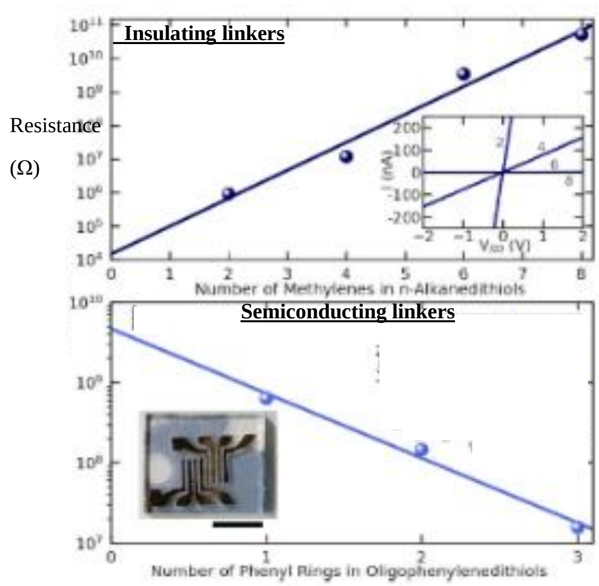

Fig. 2 Quantum Resistance exhibited by nanosheets: tunneling vs quantum delocalization Ref [3].

Building on these results, the goals of this research opportunity are to:

- design, fabricate, characterize and explore the range of behaviours of quantum nanostructured materials, and
- develop their potential device applications.

DESCRIPTION OF STUDENT PARTICIPATION:

Students will begin by performing a literature review. In the first phase of an experiment, they will fabricate and characterize nanostructured materials. In the second phase of the experiment, students will help take measurements of and/or apply material properties (electrical, magnetic, optical).

[1] Zabet-Khosousi, A. and **Dhirani, A.A.**, 2008. Charge transport in nanoparticle assemblies. *Chemical reviews*, *108*(10), pp.4072-4124.
[2] M. Tie and **A.-A. Dhirani.** "Coulomb effects and exotic charge transport in nanostructured materials." *21st Century Nanoscience – A Handbook.* Ed. K. Sattler. Milton Park: Taylor and Francis (CRC Press), 2018.
[3] Gravelsins, S., Park, M.J., Niewczas, M., Hyeong, S.K., Lee, S.K., Ahmed, A. and **Dhirani, A.A.**, 2022. Large emergent optoelectronic enhancement in molecularly cross-linked gold nanoparticle nanosheets. *Communications Chemistry*, *5*(1), p.103.