

Tuning Magnetism with Patterned Defect Engineering in Graphene Nanoribbons

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Atomically thin quasi-one- and two-dimensional materials host a wide range of quantum phenomena. In graphene nanostructures, defects can induce emergent magnetic behavior by generating low-energy zero modes (ZMs), often of topological origin. Interactions among patterned ZMs shape frontier bands and enable magnetically ordered phases. Here, we present two recent studies that exploit patterned defect motifs to control quantum magnetism in graphene nanoribbons (GNRs). First, combining topological classification with defect engineering, we identify a new class of zigzag-edged magnetic Janus GNRs (JGNRs). These JGNRs host diverse quantum magnetic phases – ranging from antiferromagnetism to ferrimagnetism to ferromagnetism – which can be tuned by controlling their defective edge structures, decorated with benzene-like motifs. Second, we study another noncentrosymmetric GNR in which all ZMs reside on the majority sublattice; strong electron–electron correlations drive a Stoner instability, producing a ferromagnetic insulating ground state with a sizable band gap. At elevated temperatures, a chemically induced transformation triggers an insulator-to-metal transition and suppresses ferromagnetism. Both studies represent joint theory–experiment efforts, in which theoretical predictions are validated through bottom-up synthesis and scanning probe microscopy measurements.