Pronounced scale-dependent charge carrier density in graphene quantum Hall devices

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Abstract: The miniaturization of quantum Hall resistance standards (QHRS) using epitaxial graphene on silicon carbide (SiC) necessitates understanding how device dimensions impact performance. This study reveals a pronounced scale-dependent carrier density in graphene Hall devices: under electron doping, carrier density decreases with increasing channel width (Wd), while the opposite occurs under hole doping. This phenomenon, most significant for Wd ≤ 400 μm, directly influences the onset of magnetic field required for quantization. Fermi velocity measurements and angle-resolved photoemission spectroscopy (ARPES) analysis indicate that band structure modifications and electron-electron interactions underlie this size dependence. Utilizing machine learning with limited data, we optimized the device geometry, identifying a channel width of ~360 μm as the optimal balance between resistance uncertainty and on-chip integration density. This work provides key insights for designing high-performance, miniaturized graphene-based QHRS arrays.

References:

[1] L. Chen, H. Wang, Z. Kong, et al., "Gaseous catalyst assisted growth of graphene on silicon carbide for quantum Hall resistance standard device," Adv. Mater. Technol., vol. 8, no. 2, [2023] 2201127.
[2] Z. Kong, Y. Feng, H. Gao, et al., "Pronounced scale-dependent charge carrier density in graphene quantum Hall devices," Mater. Today Phys., vol. 51, [2025] 101928.

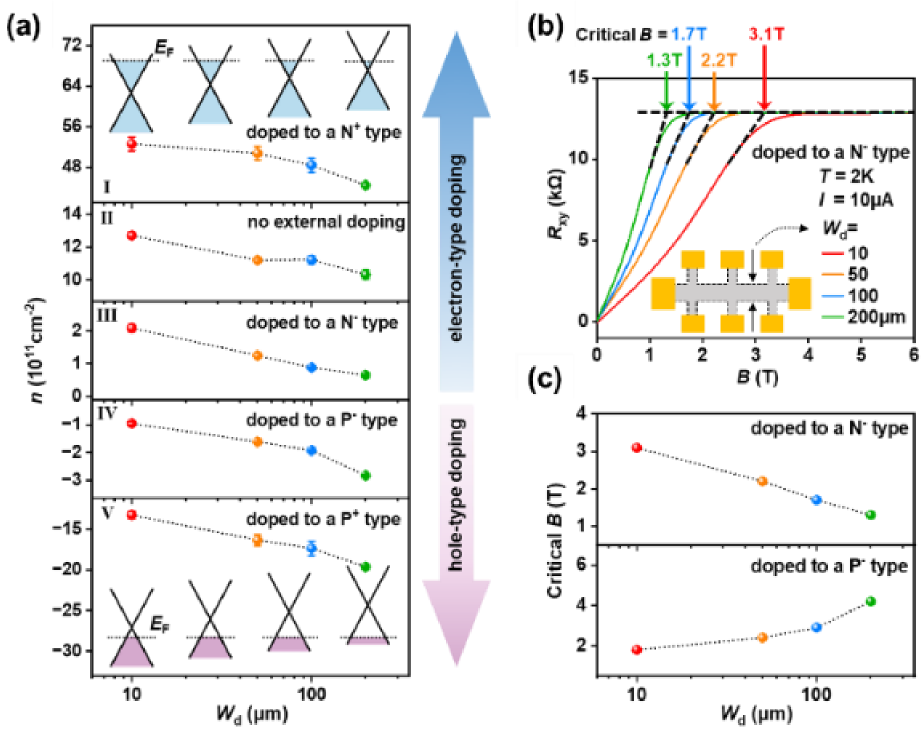

Fig. 1. Scale-Dependent Carrier Density and Device Optimization Scale-dependent carrier density. (a) Carrier density n as a function of channel width Wd under different doping conditions (N^+, undoped, N^-, P^-, P^+). Insets illustrate the shift of Fermi level with Wd. (b) and (c) showing the variation of the onset of magnetic field (*B*) for entering quantized Hall pleteaus as a function of Wd in N^- and P^- type.