Multiband effects in the BEC-BCS crossover of double bilayer graphene

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Abstract

We investigate the effect of the two energy bands, the conduction band and valence band, in bilayer graphene on the properties of BEC-BCS crossover in electron-hole double bilayer graphene. We characterize the crossover by the momentum dependent superfluid gap, the condensate fraction and the evolution of the chemical potential as functions of the density and of the energy gap between the conduction and valence bands.

Introduction

- Two graphene bilayers separated by a hBN insulating layer.
- There are electrons in one bilayer and holes in the other one.
- An electric field applied perpendicular to the bilayer sheets opens up a tunable energy gap between the bands in each bilayer.

Theory

We use multiband Mean-field theory with intra-band pairing.

\[ \xi_{\pm} = \frac{\hbar^2 k^2}{2m^*} - \mu \]

Conduction band

\[ \xi_{-} = -\frac{\hbar^2 k^2}{2m^*} - E_g - \mu \]

Valence band

We solve the two coupled Gap equations.

\[ \Delta_{k'} = -\frac{1}{2} \sum_{k'} F_{k'k}^{\pm} V_{kk'} \Delta_{k'}^{\pm} \]

Form Factor

\[ F_{k'k}^{\pm} = -\frac{1}{2} \left[ \frac{1}{\epsilon_{k'}} - \epsilon_{k} \right] \epsilon_{k'} \epsilon_{k} \]

Coulomb Potential

\[ V_{kk'} = -\frac{2\pi e^2}{\epsilon |k - k'|} \]

Density equation

\[ n = g_+ g_\uparrow \sum_{k,\gamma} (\xi_{\uparrow}^{k})^2 = g_+ g_\uparrow \sum_{k,\gamma} \frac{1}{2} \frac{E_g + \Delta_{k'}}{E_g} \]

Our density control parameter is:

\[ n_+ = g_+ g_\uparrow \sum_k \left[ \left( \xi_{\uparrow}^{k} \right)^2 - \left( \xi_{\downarrow}^{k} \right)^2 \right] \]

Results

Condensate fractions

\[ c^+ = \frac{\sum_{k} (u_{\uparrow}^{k})^2 (v_{\uparrow}^{k})^2}{\sum_{k} (v_{\uparrow}^{k})^2} \]

\[ c^- = \frac{\sum_{k} (u_{\downarrow}^{k})^2 (v_{\downarrow}^{k})^2}{\sum_{k} (v_{\downarrow}^{k})^2} \]

References