High Temperature Superfluidity in Double Bilayer Graphene

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We show that by employing atomically thin crystals such as a pair of adjacent bilayer graphene sheets, equilibrium superfluidity of electron-hole pairs should be achievable for the first time. The transition temperatures calculated with screening are well above liquid helium temperatures. Because the sample parameters needed for the device have already been attained in similar graphene devices, our work suggests a new route towards realizing high-temperature superfluidity in existing quality graphene samples.

Our proposed system consists of a pair of parallel bilayer graphene sheets (Fig. 1(a)). The lower bilayer sheet is an electron bilayer and the upper bilayer sheet is a hole bilayer. The two bilayer sheets are separated by a hBN insulating barrier of width D_B to prevent tunneling between the sheets and recombination. There are separate electrical contacts to the two bilayers. By tuning a bias V_{BB} between the bilayers, and biases V_{TG} and V_{BG} on top and bottom metal gates, a wide range of carrier densities can be achieved. Because the bilayers have quadratic energy bands, the regions of strong correlations are readily accessible. We discuss bilayer graphene since it has been well characterized but a number of other such crystals are possible.[1]

Figure 1(b) shows $\Delta_{\max}$, the maximum of the $T = 0$ gap calculated with screening included. Densities are restricted to $n > n_{min}$ so that E_F lies in the quadratic energy band range. For each D_B, above a critical density n_c the gap is so small that in realistic disordered systems it is unlikely there would be pairing. However at $n = n_c$ a discontinuous jump in $\Delta_{\max}$ occurs to much higher energies. Reference [2] reported a similar jump for two monolayer Graphene but only at an inaccessible $r_s > 2.35$. For smaller D_B, the superfluidity persists to higher n_c and higher temperatures. For comparison, $\Delta_{\max}$ calculated without screening is shown for $D_B = 0.5$ nm. For $n > n_c$, it is screening that suppresses the superfluidity. At low densities the effect of screening on $\Delta_{\max}$ is progressively reduced because of large Fermi surface smearing.

[1] K.S. Novoselov,*et al.*, P.N.A.S. **1**02, 10451 (2005).
[2] Yu.E. Lozovik, S.L Ogarkov, and A.A. Sokolik, Phys. Rev. B **8**6, 045429 (2012).

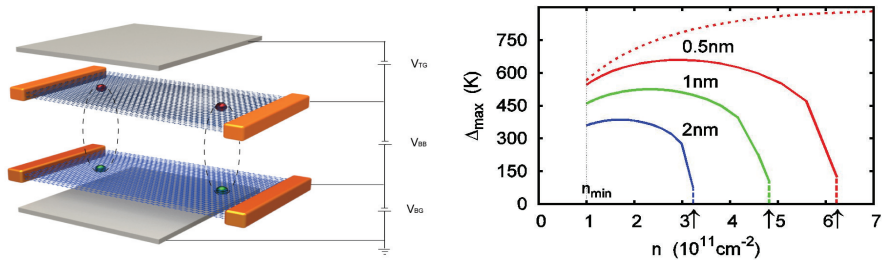

Figure 1: (a) Spatially separated electron-hole system with electrons in one graphene bilayer sheet separated by a hBN dielectric barrier of thickness D_B from holes in a second graphene bilayer sheet. Top and bottom metal gates control the densities. (b) $\Delta_{\max}$ calculated with screening for barrier thicknesses D_B as labeled. At density n_c (arrows), $\Delta_{\max}$ drops discontinuously to sub-mK energies. Dotted red line is $\Delta_{\max}$ for $D_B = 0.5$ nm calculated without screening.