Delocalization by Disorder in Layered Systems

Dmitrii L. Maslov\textsuperscript{a}, Vladimir I. Yudson\textsuperscript{b}, Andres M. Somoza\textsuperscript{c}, and Miguel Ortuño\textsuperscript{c}

\textsuperscript{a}Department of Physics, University of Florida, P. O. Box 118440, Gainesville, FL 32611-8440
\textsuperscript{b}Institute for Spectroscopy, Russian Academy of Sciences, Troitsk, Moscow region, 142190, Russia
\textsuperscript{c}Departamento de Física-CIOyN, Universidad de Murcia, Murcia 30.071, Spain

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**Disordered Conductors**

more disorder, more resistance
• incoherent: more scattering, more resistance
• coherent: enhances localization, more resistance

common belief: localization destroyed only by inelastic scattering

This Letter: that’s wrong, i.e.
more disorder, **less resistance** (in some cases)
(simple model with two types of disorder)
System considered

Model: two types of disorder
a) layers (1D)
b) bulk disorder (3D)

Graphene
NaCo$_2$O$_4$
cuprates
etc

naively $\frac{\sigma_{||}}{\sigma_{\perp}} \sim \left( \frac{m^*_{||}}{m^*_{\perp}} \right)^{-1}$
in absence of bulk disorder, $V(x, y, z) = 0$

in- and out-of-plane degrees of freedom **separate**

$$\varepsilon(\vec{k}_||, k_z) = \varepsilon_||(\vec{k}_||) + \varepsilon_z(k_z)$$

in a 1D (disorder) potential $U(z)$

$$\Psi(\vec{r}_||, z) = \varphi(\vec{r}_||) \chi(z)$$

with eff. 1D Schroedinger eq. for $\chi$

$$[\varepsilon_z(-i\partial_z) + U(z)] \chi(z) = \left( E - \varepsilon_||(\vec{k}_||) \right) \chi(z)$$

• infinitesimally weak disorder $U(z)$ **localizes all states**, i.e. $\sigma_{zz} = 0$
  1D localization in z-direction

• $U(z)$ does not affect motion $||$, $\sigma_{||}$ infinite (no bulk disorder)
Add bulk disorder $V(x, y, z)$

- Mixes in- and out-of-plane degrees of freedom, no separation of variables
- 1D localization z-direction destroyed
- $\sigma_{zz}$ increases with bulk disorder (while weaker than planar disorder)
  $\sigma_{zz}$ peaks when disorders similar
  $\sigma_{zz}$ decreases upon further increase of bulk disorder
- $\sigma_{||}$ decreases monotonously with bulk disorder

Rest of paper: confirm this prediction with
a) Anderson model (numerical)
b) analytical, using Berezinskii solution 1D localization
Anderson Model

\[ H = - \sum_{i,j} a_j^\dagger a_i + \sum_i \epsilon_i a_i^\dagger a_i + \text{H.c.} \]

hopping on site

on-site energy \( \epsilon_i = \phi_i + \eta_{i_z} \) and \( i = (i_x, i_y, i_z) \)

\( \phi_i \) bulk disorder, random in interval \( (-W_B/2, W_B/2) \)

\( \eta_{i_z} \) planar disorder, W or \(-W\) with probability 0.5
FIG. 2: (Color online) Out-of-plane conductance versus the bandwidth of bulk disorder $W_B$ for a range of values of planar disorder $W$, as shown in the figure, and $L = 30$. 
FIG. 3: (Color online) Out-of-plane conductivity versus the bandwidth of bulk disorder $W_B$ on a double logarithmic scale for a range of system sizes, as shown in the figure, and three values of planar disorder: $W = 1.5$ (upper set), $W = 2$ (middle set), and $W = 2.5$ (lower set).
Analytical Solution

\[
\sigma_{zz}(\omega) = \frac{e^2}{2\pi} \frac{1}{A^3} \sum_{\vec{k}_{||}, \vec{k}'_{||}} \int d\vec{z}'
\times \langle \langle v_z G_+^R(\vec{k}_{||}, z; \vec{k}'_{||}, z') v'_z G_-^A(\vec{k}'_{||}, z'; \vec{k}_{||}, z) \rangle_p \rangle_b ,
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\end{align*}
\]
Summary

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