Low-temperature quantum transport in CVD-grown single crystal graphene

Stefano Guiducci

NanoSEA 2016, Giardini Naxos

S. Xiang, V. Miseikis, L. Planat, S. Guiducci, S. Roddaro, C. Coletti, F. Beltram, S. Heun,
Nano research 2016, 9 (6): 1823-1830

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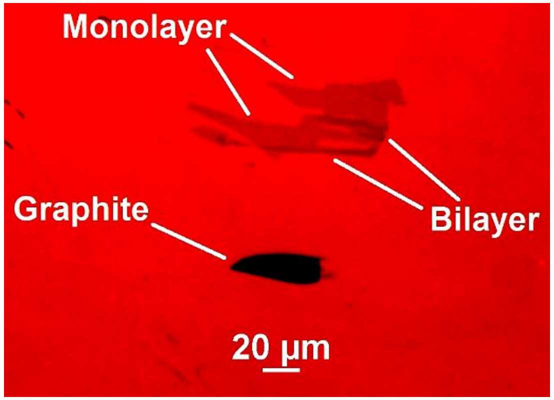
Introduction

Exfoliated graphene

- Excellent quality.
- No need for special equipment.
- Small flakes, random shape.
- Poor scalability.



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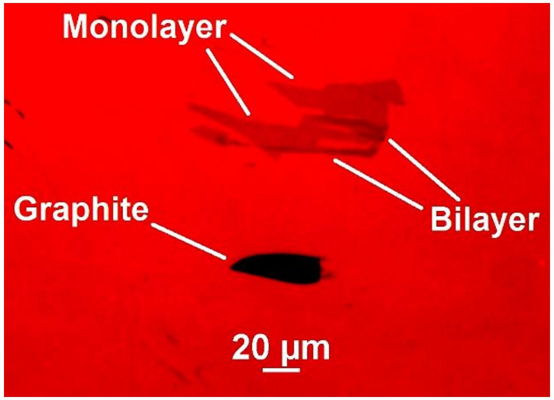
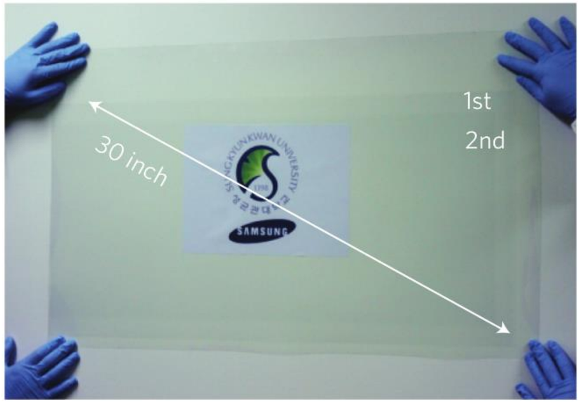


CVD-grown graphene

- Excellent size.
- Fast and reliable growth.
- Excellent scalability.
- Lower graphene quality (polycrystalline, defects and contamination).



Introduction

Exfoliated graphene	CVD-grown graphene	CVD-grown single crystal graphene
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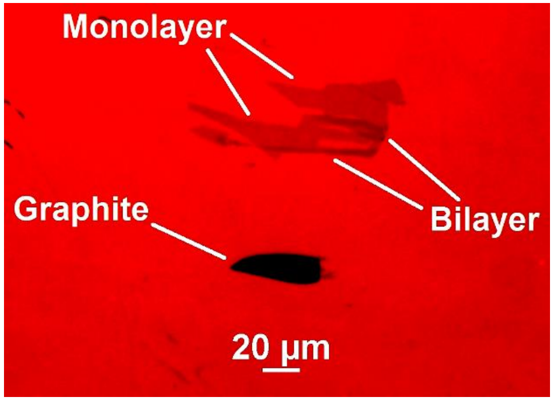
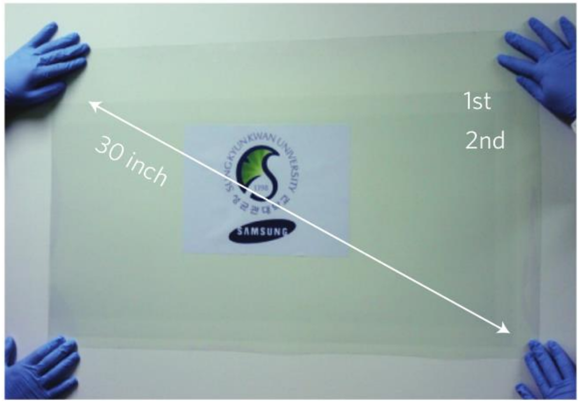
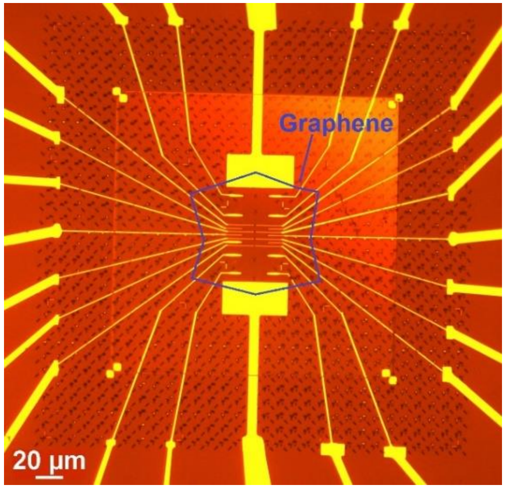






We fabricated several devices that we tested in magneto-transport at low temperature to prove its good electronic quality.

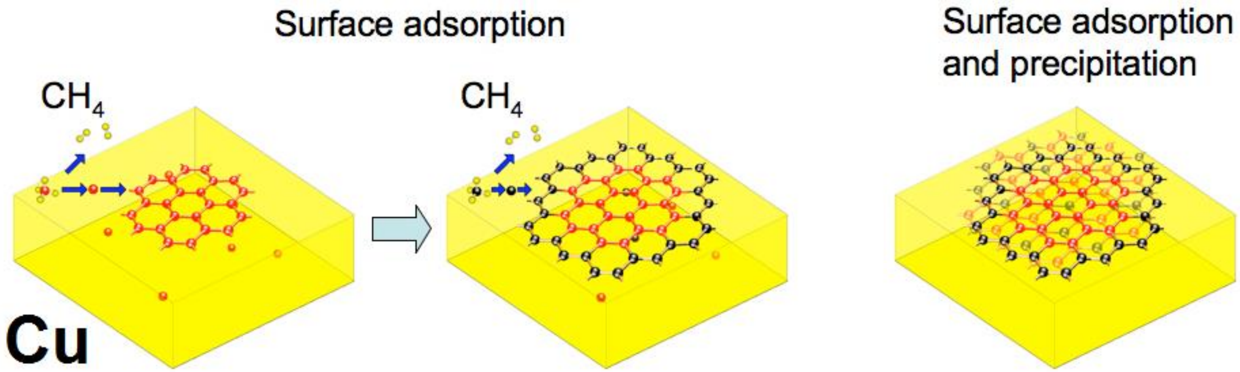
CVD graphene growth

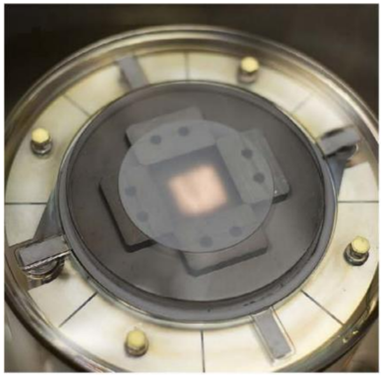
V. Miseikis

- Graphene grown on copper.
- Chemical reaction: $CH_4 \rightarrow 2H_{2(g)} + C_{(s)}$
- Growth in a commercial reactor to increase reproducibility.
- Improvements:

  Number of nucleation sites drastically reduced (oxidized copper).

  Semi-dry technique to detach graphene from copper (electrochemical delamination).





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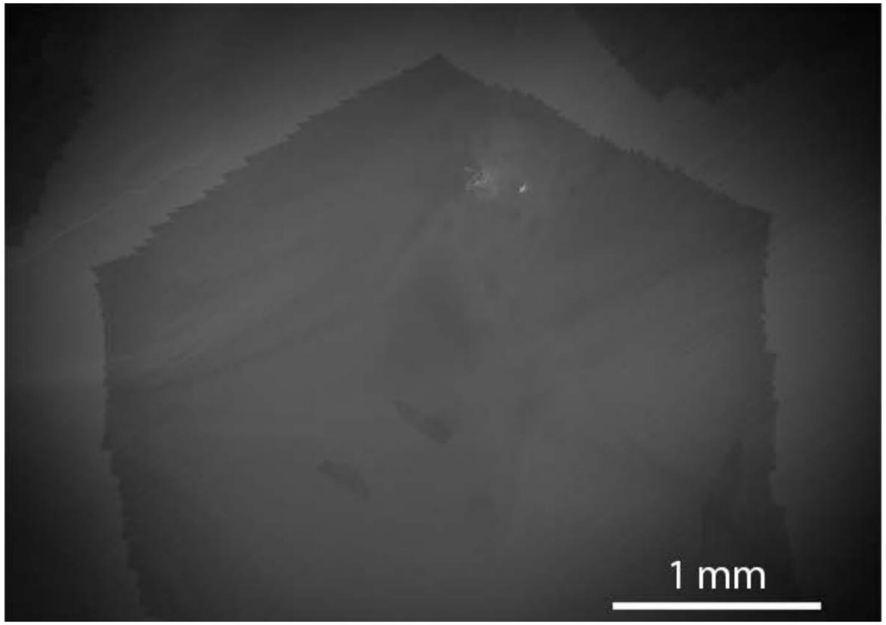
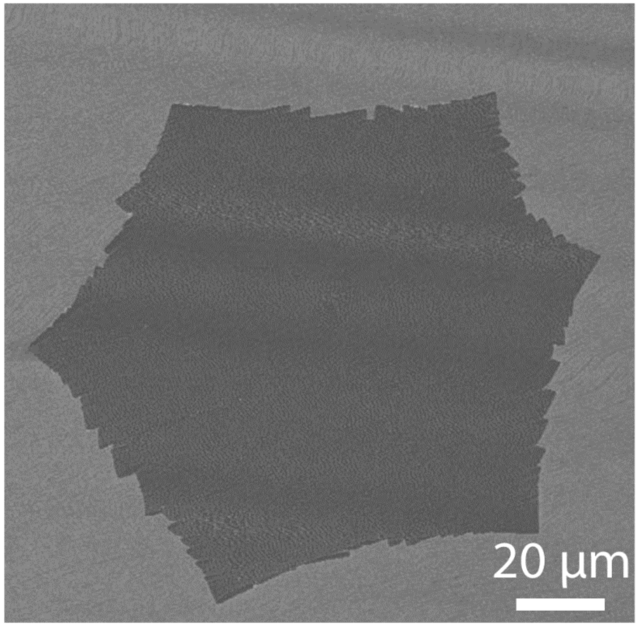
CVD graphene growth

V. Miseikis

- Monocrystalline graphene flakes extended up to several millimeters.
- Fast growth (1mm per hour).
- High crystalline quality already shown with SEM, TEM, Raman, SAED, LEED, XPS.





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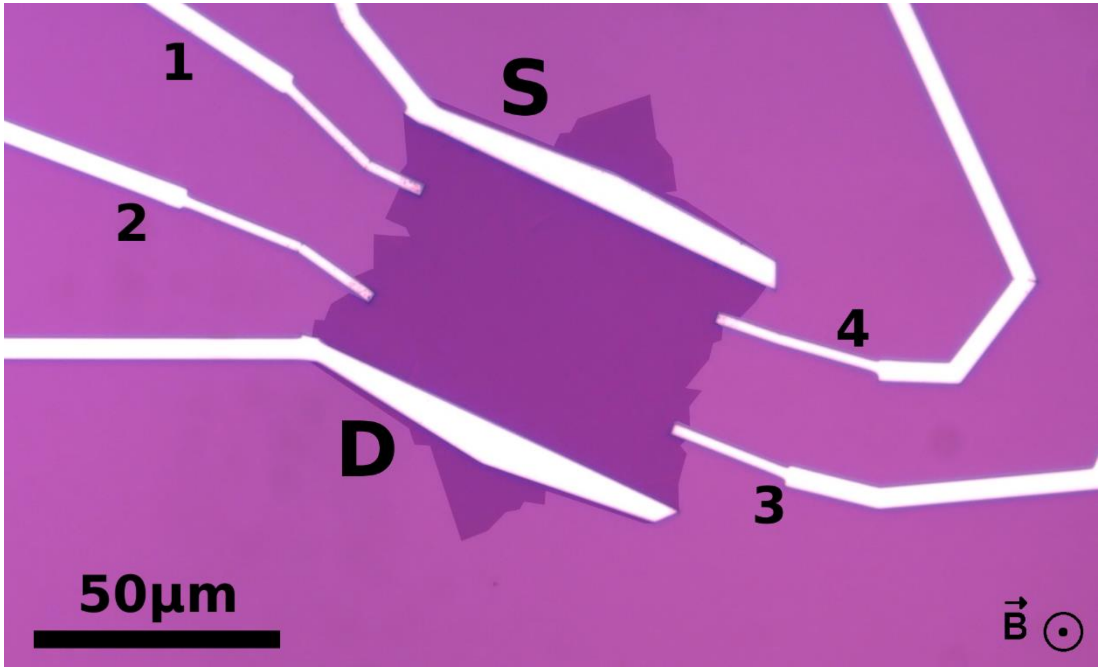
Electron transport characterization

- Graphene transferred on 300nm of SiO_2 (n++ doped Si substrate used as a backgate).
- Hallbar fabricated (approx. 50µm x70µm).



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Electron transport characterization

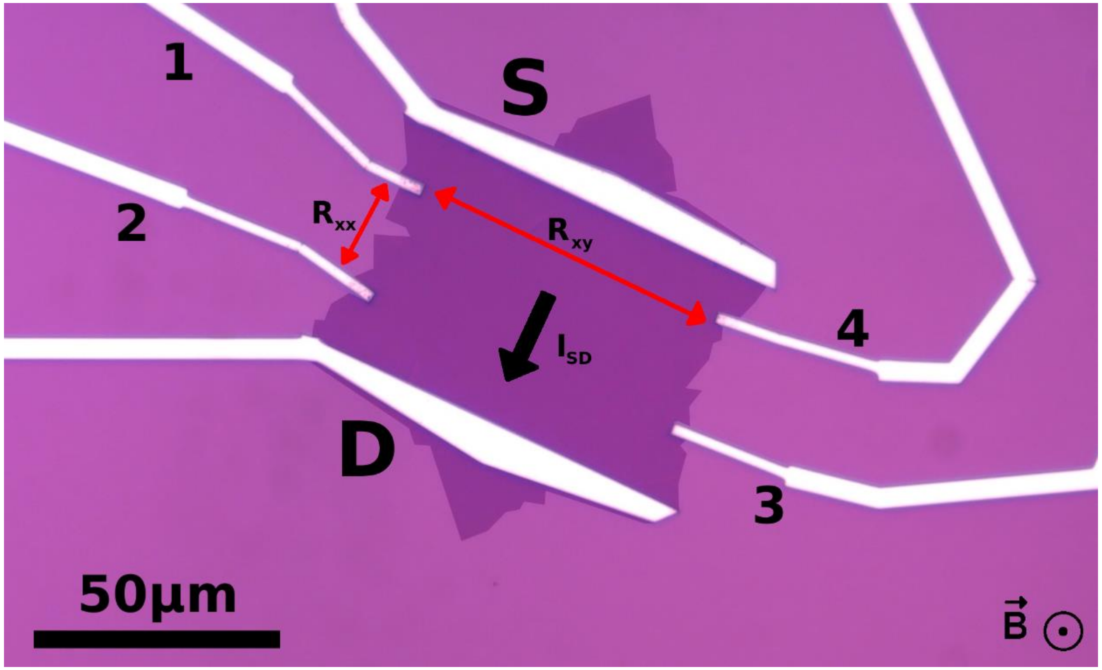
- Graphene transferred on 300nm of SiO_2 (n++ doped Si substrate used as a backgate).
- Hallbar fabricated (approx. 50µm x70µm).
- Four voltage probes used to measure longitudinal and transversal (Hall) resistance, respectively:

  $R_{xx}=V_{12}/I_{SD}$

  $R_{xy}=V_{14}/I_{SD}$
- No sample annealing in order to measure the graphene «as is».
- He-3 cryostat, temperature range:

  0.25K - 20K
- Out of plane magnetic field, range:

  0 - 10 Tesla



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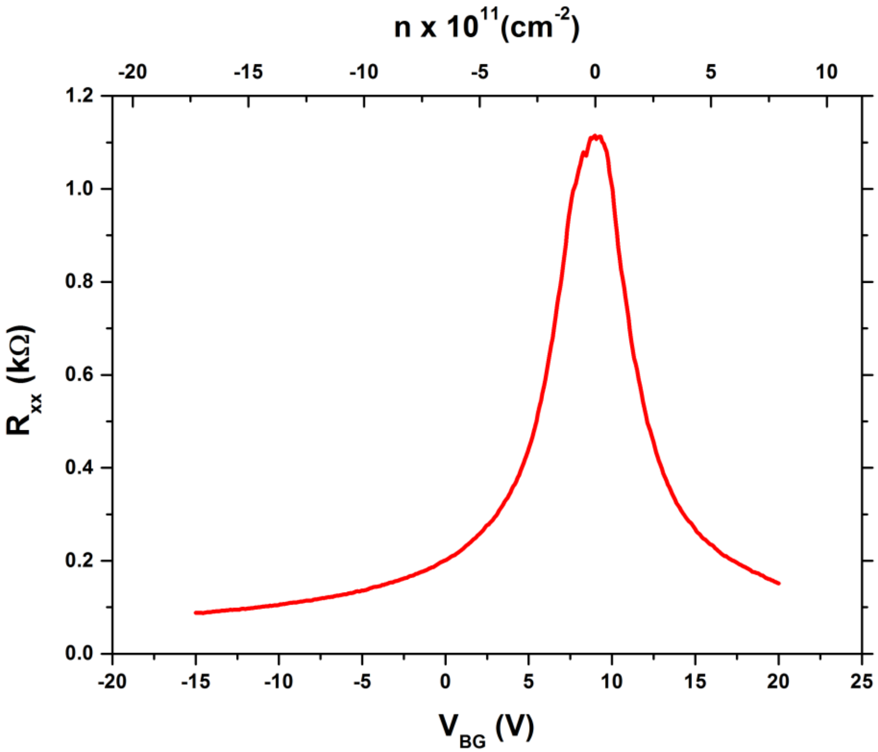
Electron transport characterization

- $\mu = 1.13 \times 10^4 cm^2/Vs$ (mobility at 250mK).
- $V_{Dirac} = +9V$
- $n(V_{BG}=0) = -6.5 \times 10^{11} cm^{-2}$ (p-doped) →

→ Low intrinsic carrier concentration

(in fact values in the 10^{12} cm^{-2} range are reported for CVD polycrystalline graphene and with the substrate removed by wet etching).



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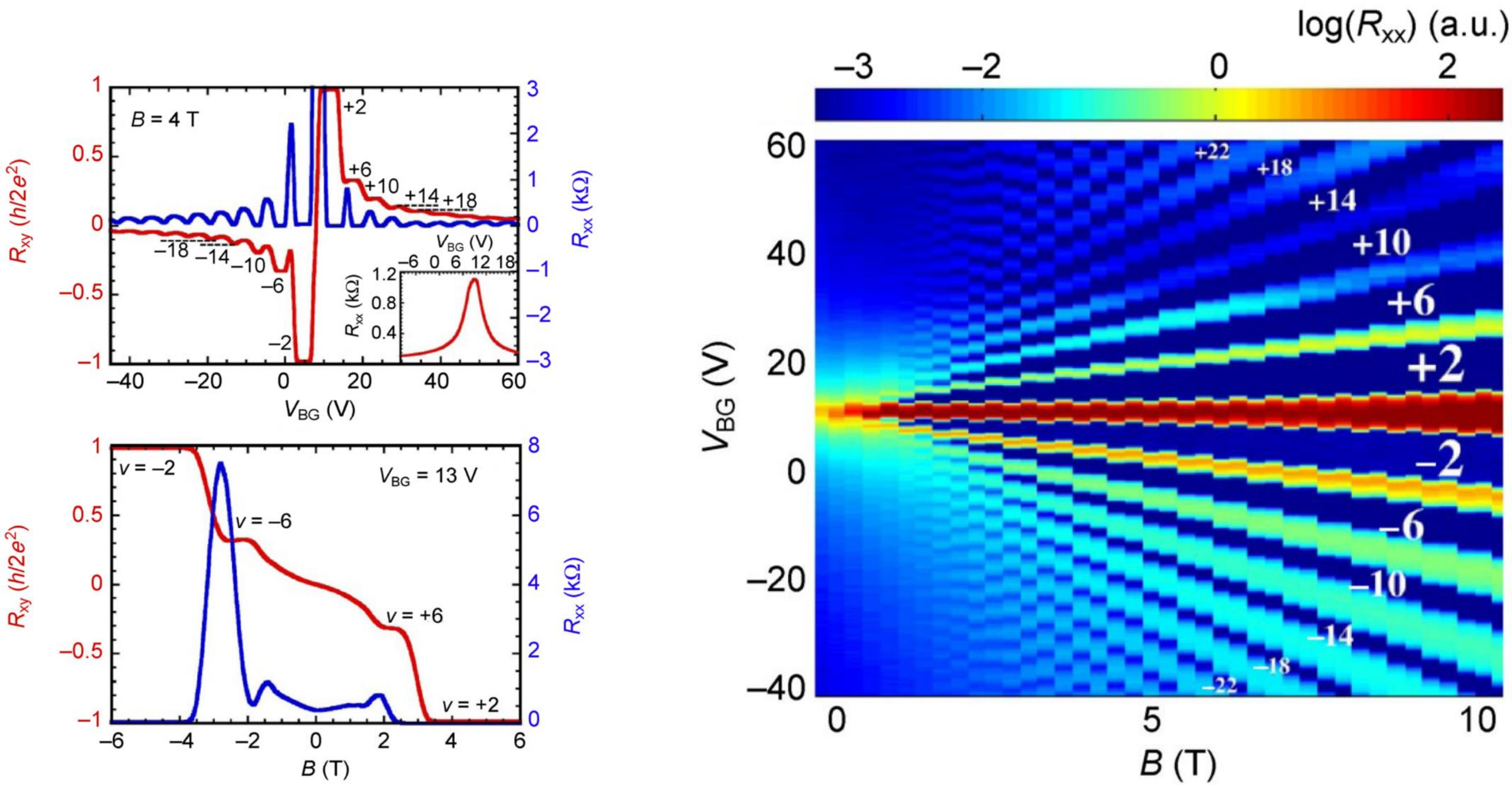
Quantum Hall



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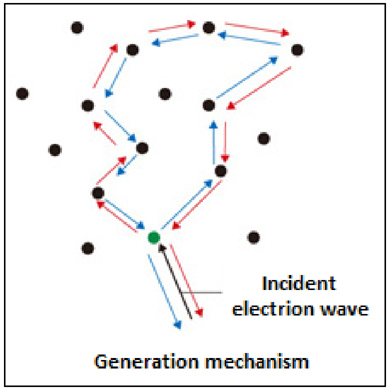
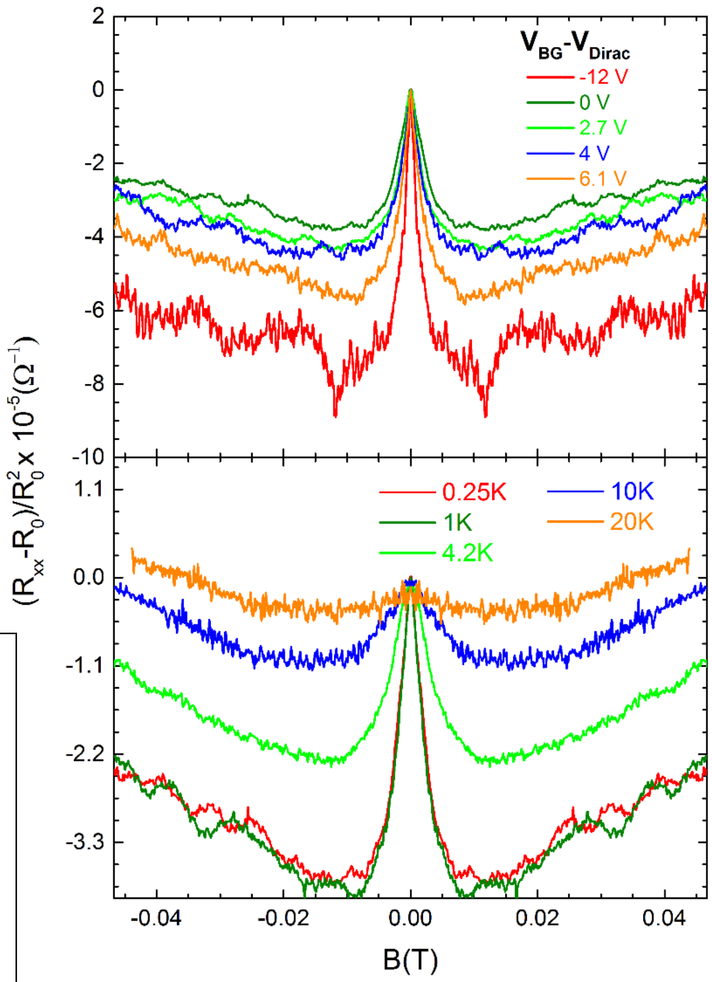
Weak localization

- Well estabilished phenomenon due to quantum interference.
- Requires that $L_e < L_\varphi$.
- A non-zero magnetic field breaks time reversal symmetry suppressing quantum interference.
- High temperature suppresses quantum interference.





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- E. McCann et al., Phys. Rev. Lett. **97**, 146805 (2006) :

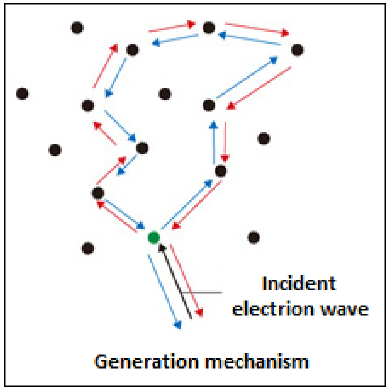
$$\frac{\Delta R_{xx}}{R_0^2} = -\frac{e^2}{\pi h}\left[F\left(\frac{\tau_B^{-1}}{\tau_\varphi^{-1}}\right) - F\left(\frac{\tau_B^{-1}}{\tau_\varphi^{-1}+\tau_{iv}^{-1}}\right) - 2F\left(\frac{\tau_B^{-1}}{\tau_\varphi^{-1}+\tau_*^{-1}}\right)\right]$$

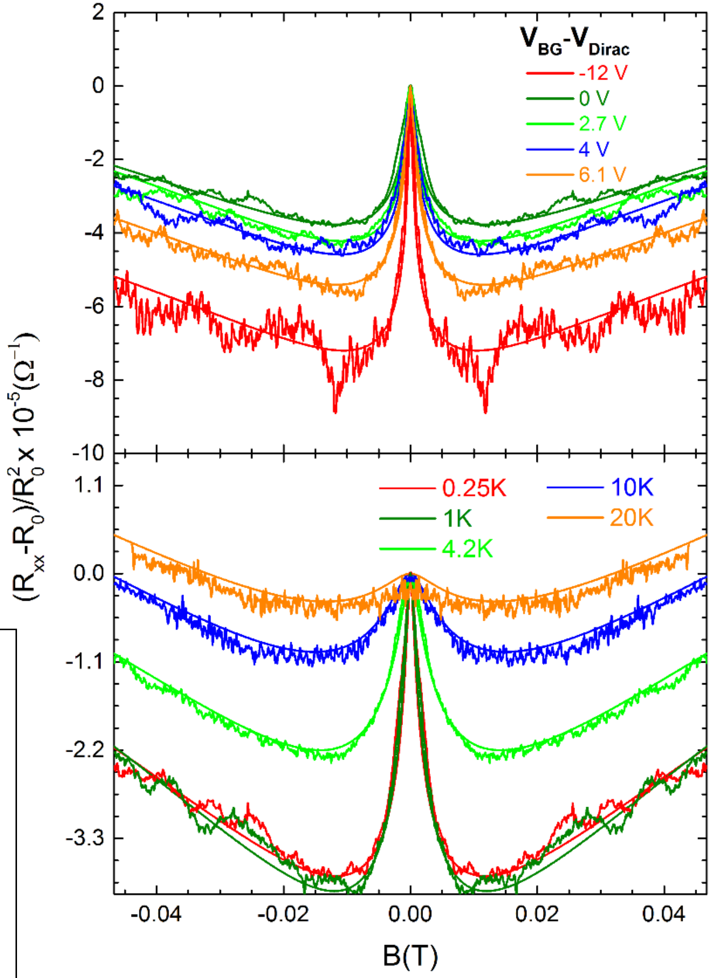
$$\Delta R_{xx} = R_{xx} - R_0$$

$$\tau_B = 4DeB/\hbar$$

$$F(z) = \ln(z) + \psi(0.5 + z^{-1})$$

τ_φ= dephasing time (inelastic)
τ_{iv}=intervalley scattering time (elastic)
τ_*=intravalley scattering time (elastic)





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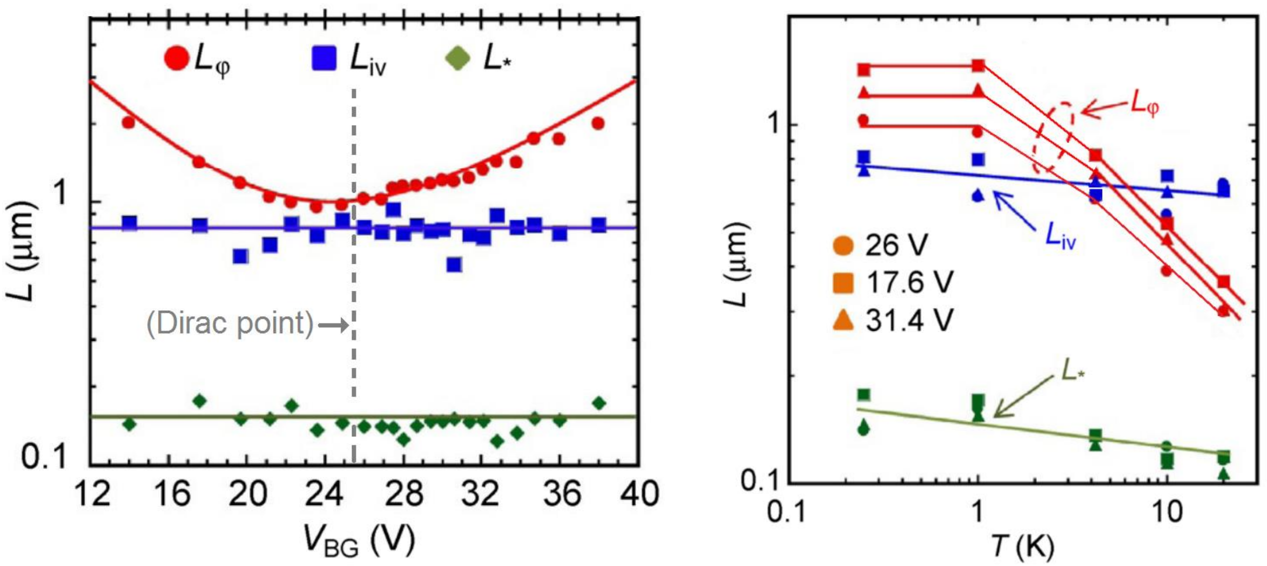
Weak localization

- Both L_* and L_{iv} only weakly depend on V_{BG} and temperature.
- Stronger dependence of L_φ from V_{BG} and temperature.
- $L_\varphi > 1\mu m$ (at T = 0.25K).



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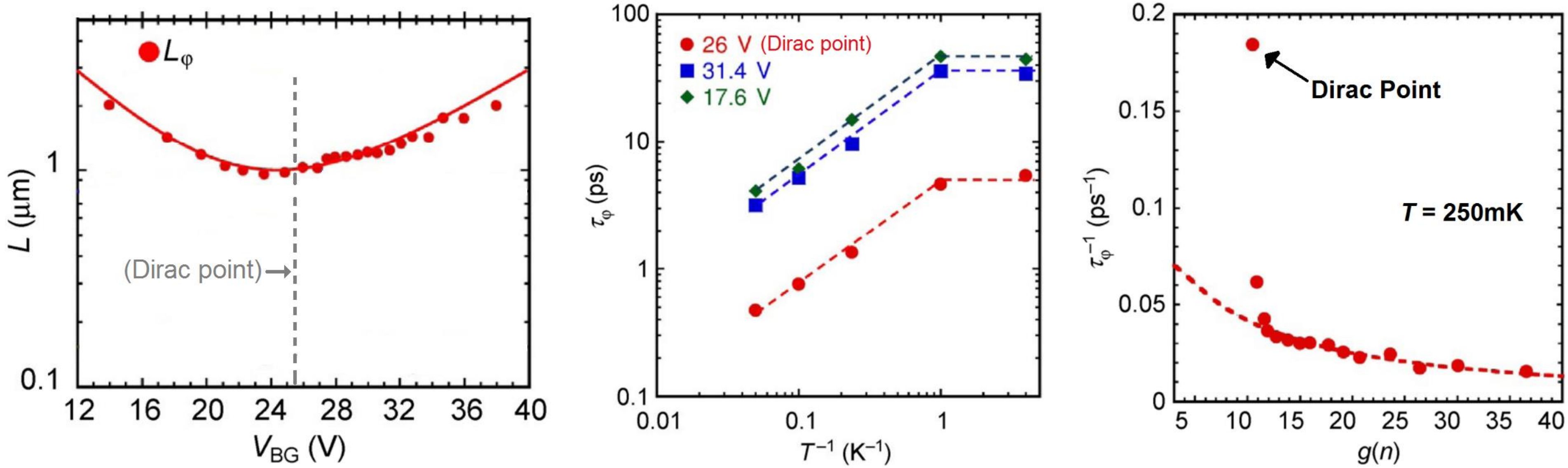

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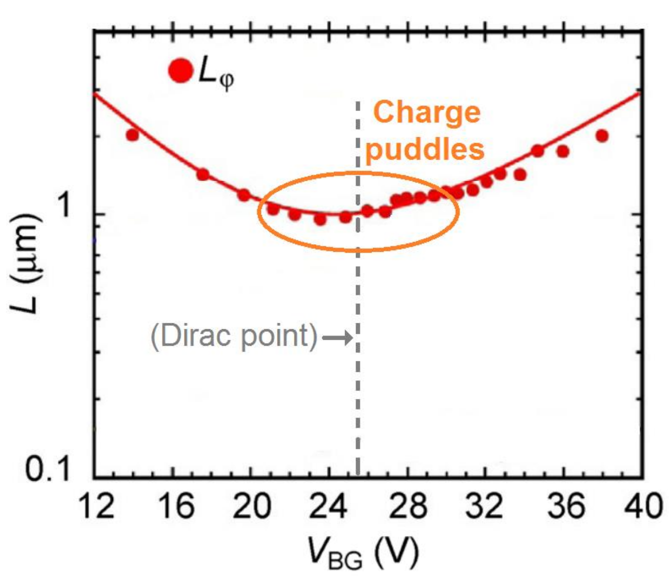
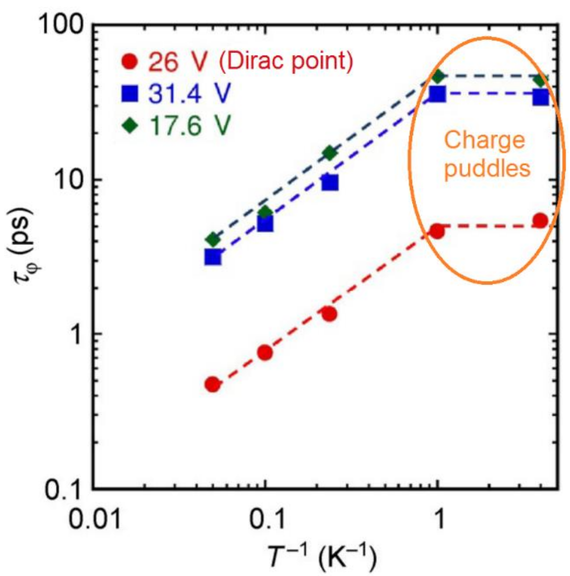
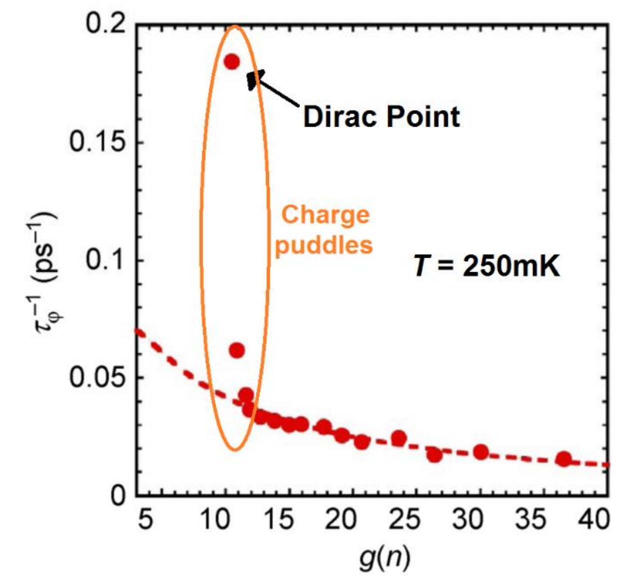
Weak localization

- L_φ minimum at the Dirac point (limited by the size of charge puddles).
- Where $\tau_\varphi(T^{-1})$ is flat the dephasing time is limited by the charge puddles.
- L_φ and τ_φ saturate at different values when changing V_{BG} (the size of the charge puddles changes with V_{BG}).
- $\tau^{-1}_\varphi(g(n))$ fit with Nyquist formula: where the fit agrees with data e-e is the main inelastic scattering mechanism.







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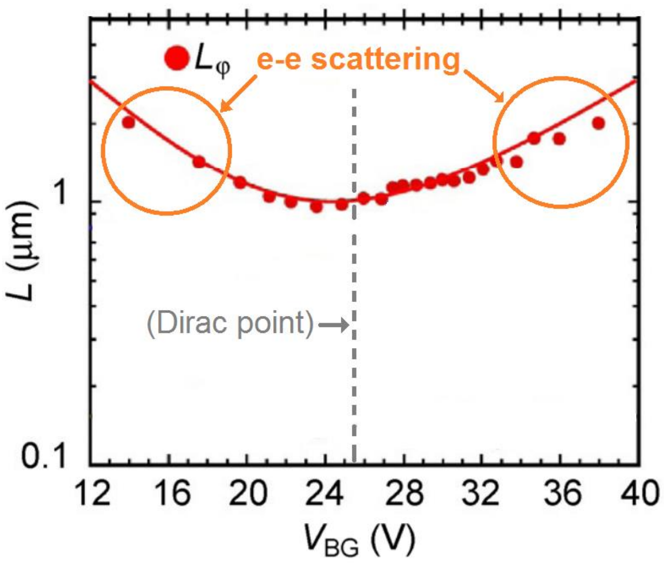
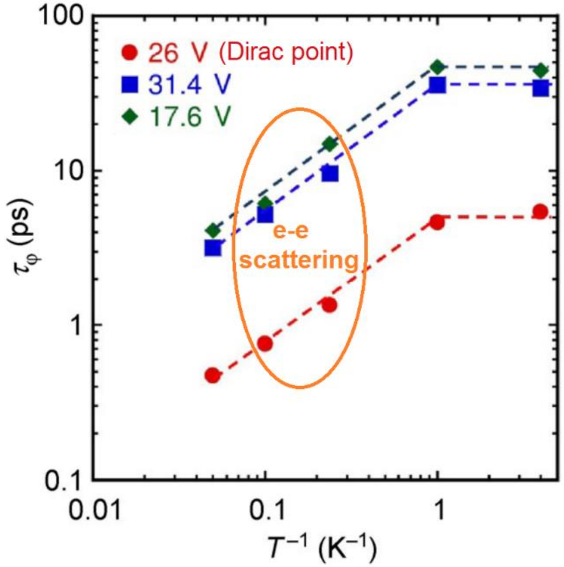
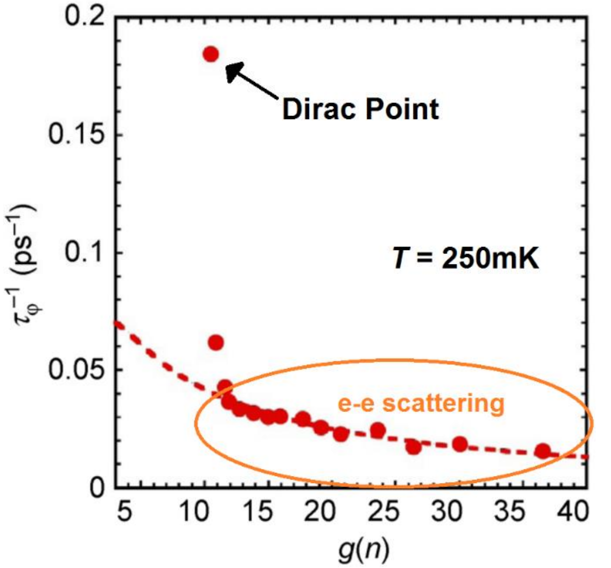
- $\tau^{-1}_\varphi(g(n))$ fit with Nyquist formula: where the fit agrees with data e-e is the main inelastic scattering mechanism.
- In the range where $\tau_\varphi \propto T^{-1}$ electron-electron interaction is the main inelastic scattering mechanism.







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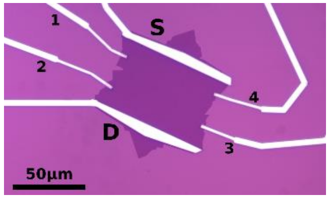
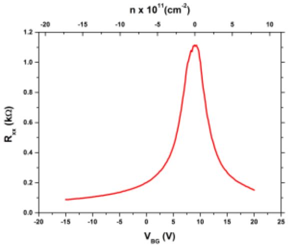
Conclusions

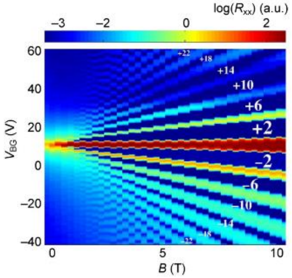
- We studied large monocrystalline CVD graphene flakes on SiO_2.



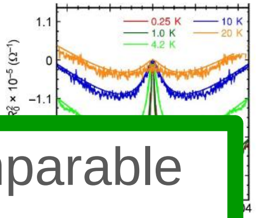
- High mobility and low intrinsic charge carriers measured.

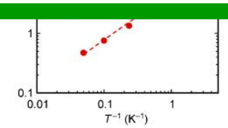


- Observed 12 well developed quantum Hall plateaus.



- Studied weak localization and measured a dephasing length above 1µm.





The quality of our CVD single crystal graphene is good and comparable to what is measured in exfoliated graphene.

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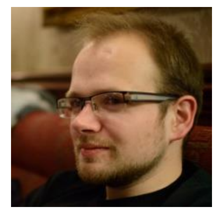
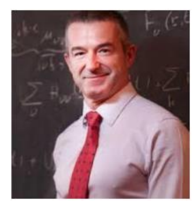


V. Miseikis

CNR-nano and SNS

L. Sorba



F. Beltram

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