Electrical modulation of weak-antilocalization and spin-orbit interaction in dual gated Ge/Si core/shell nanowires

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Outline

- Motivation
- Experimental Setup
- Weak Antilocalization
- Spin Relaxation
- Outlook

Motivation

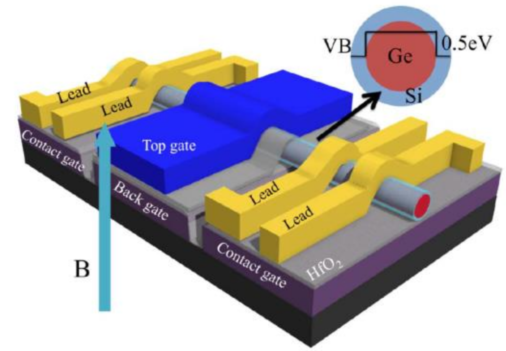
- direct Rashba spin-orbit interaction[1]
- scales linearly with transverse electric field
  - but direct, dipolar coupling to spin
- first order effect (compared to third order effect in conventional Rashba SOI)
  - expect one order of magnitude larger Rashba constant compared to e.g. InSb, InAs

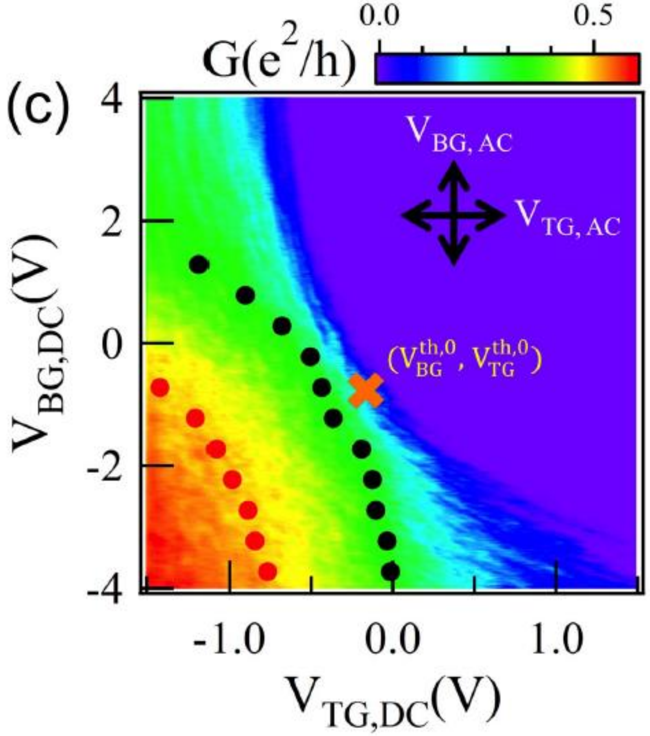
- Measurements on SOI in Ge/Si nanowires
  - statistical analysis of Coulomb peak distribution[2]
  - weak anti-localization study with single gate[3]

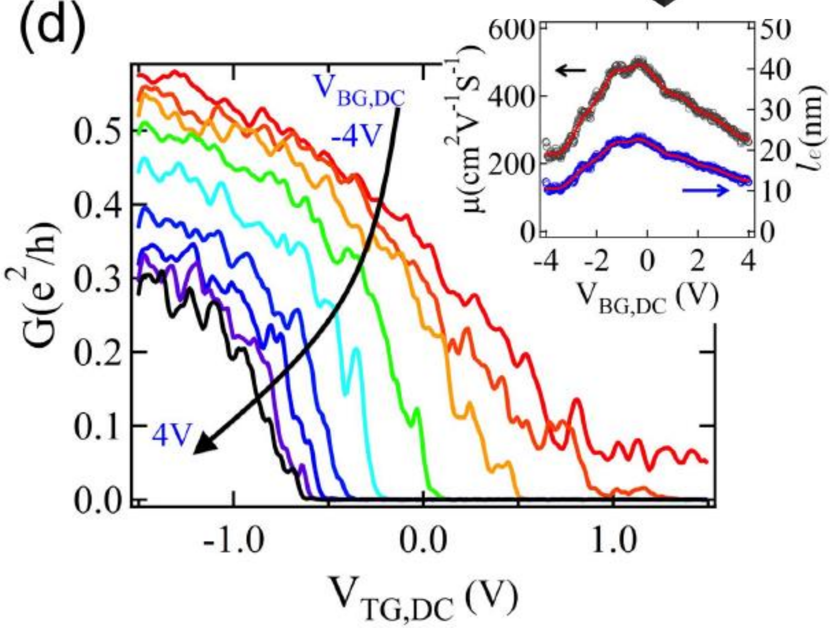
[1] Kloeffel et al., PRB **84**, 195314 (2011)
[2] Higginbotham et al., PRB **112**, 216806 (2014)
[3] Hao et al., Nano Lett. **10**, 2956 (2010)

Experimental Setup

- nanowire with diameter of 18-22 nm
- bottom and top gate allow for tuning of carrier density and electrical field inside nanowire

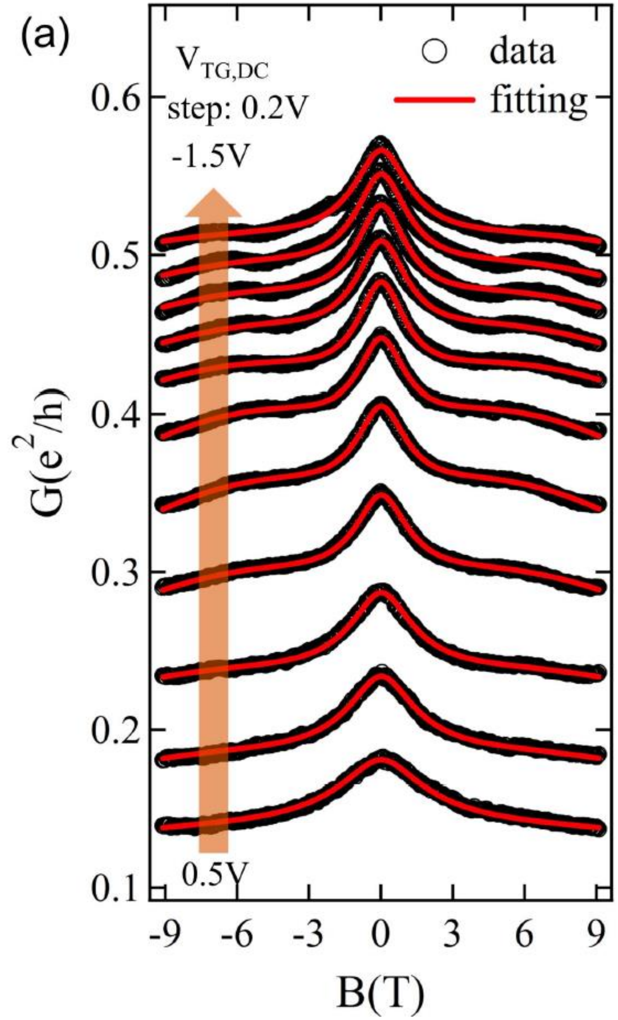






mobility and mean free path are largest when the holes are in the center of the wire

Weak Antilocalization

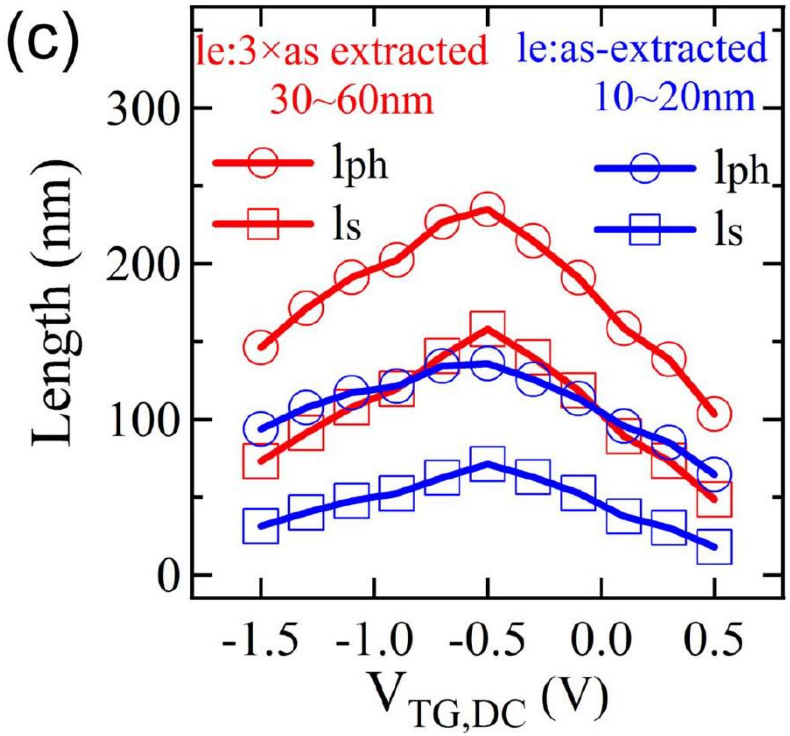


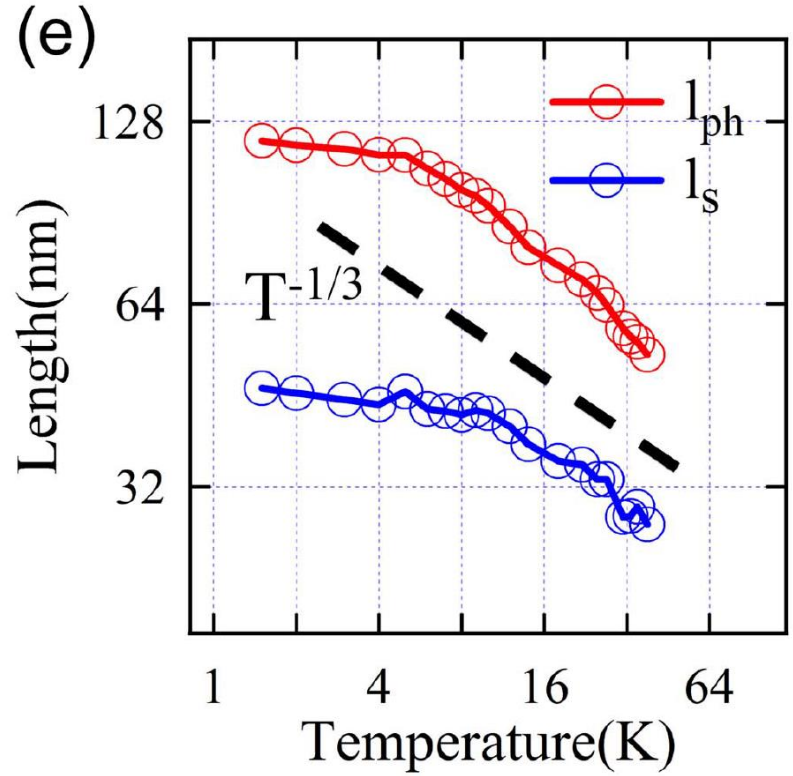
- WAL over a wide range of densities $n = 0.7\text{-}7 \times 10^9\ m^{-1}$
- magnetoconductance traces fit to eq. (3) + classical magnetoresistance

$$G(B) = G_\infty - \frac{2e^2}{hL} \times \left[\frac{3}{2}\left(\frac{1}{l_{ph}^2} + \frac{4}{3l_s^2} + \frac{1}{l_B^2} \right)^{-\frac{1}{2}} - \frac{3}{2}\left(\frac{1}{l_{ph}^2} + \frac{4}{3l_s^2} + \frac{1}{l_e^2} + \frac{1}{l_B^2} \right)^{-\frac{1}{2}} - \frac{1}{2}\left(\frac{1}{l_{ph}^2} + \frac{1}{l_B^2} \right)^{-\frac{1}{2}} + \frac{1}{2}\left(\frac{1}{l_{ph}^2} + \frac{1}{l_e^2} + \frac{1}{l_B^2} \right)^{-\frac{1}{2}} \right]. \quad (3)$$

$$l_B^2 = C_1 l_e l_m^4 / W^3 + C_2 l_e^2 l_m^2 / W^2$$

Dephasing and Charge Decoherence





- thin diameter of nanowire
  - no magnetic field induced dephasing of carriers
- from temperature dependence of characteristic lengths
  - charge decoherence dominated by Nyquist process

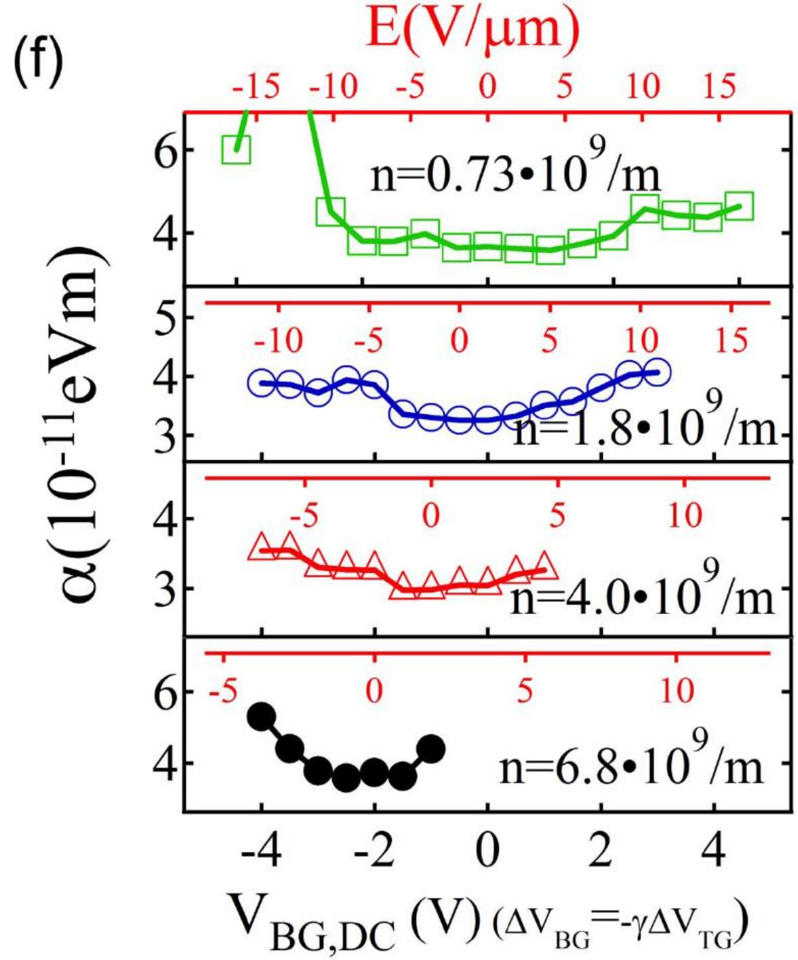
Spin Relaxation

- Elliot-Yafet effect (spin relaxation due to scattering)
  - expect spin relaxation lengths of 500-1000 nm
  - incompatible with experimentally extracted spin relaxation length
- D‘yakonov-Perel effect (spin relaxation between scattering events)
  - include suppression of spin relaxation due to dimensional confinement $\frac{1}{l_s^2} = \frac{1}{D\tau_s} = \frac{W^3}{C_3 l_e l_R^4}$

l_R = 4 - 10 nm
α = 3 - 6 x 10^{-11} eVm
E_{RSOI} = 1.5 - 3 meV

Electric Field Control

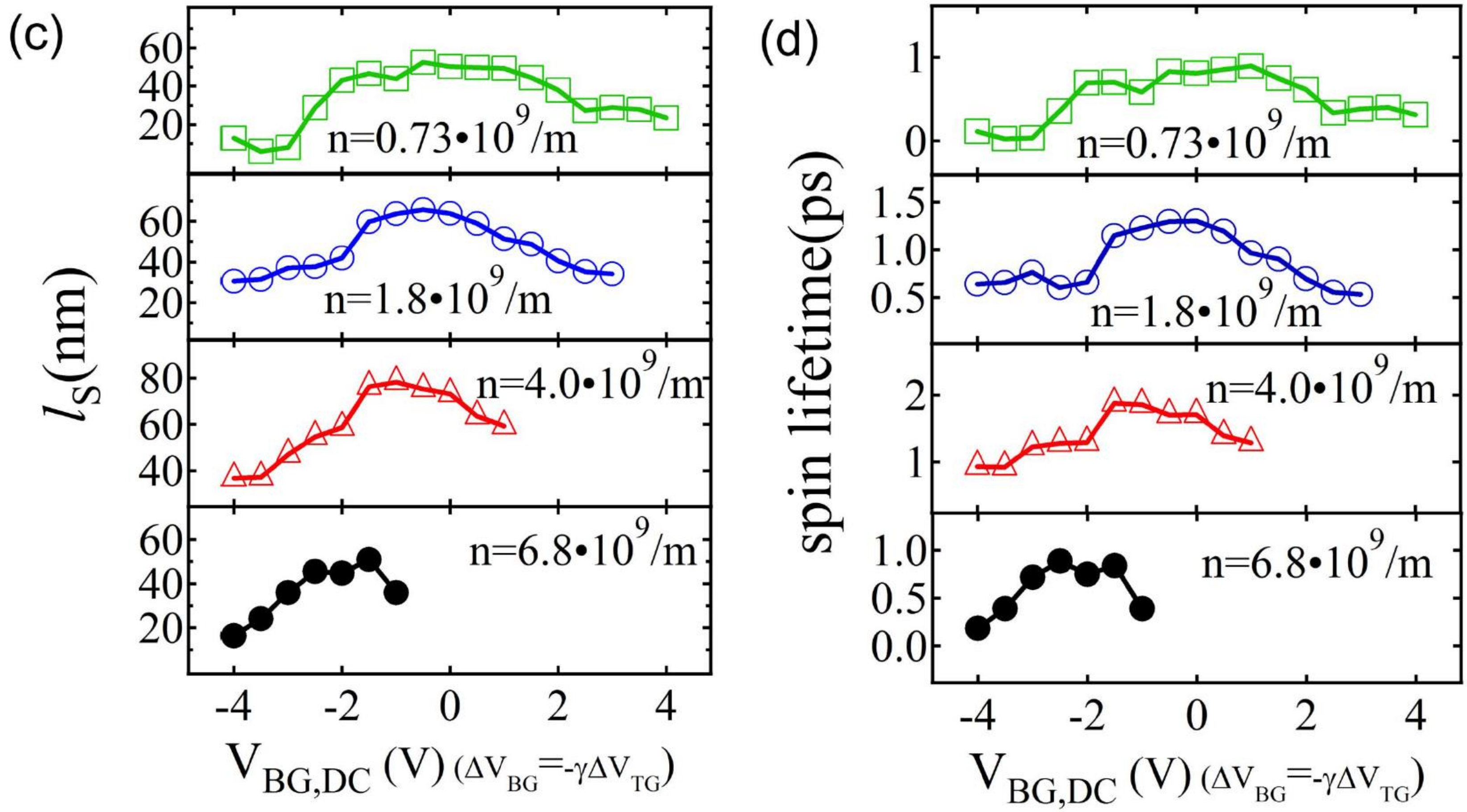
- Rashba SOI coefficient α varies with electric field inside the wire
- large Rashba constant of 5 nm^2
- **evidence for dipole coupled, direct Rashba spin-orbit interaction**



Summary + Outlook

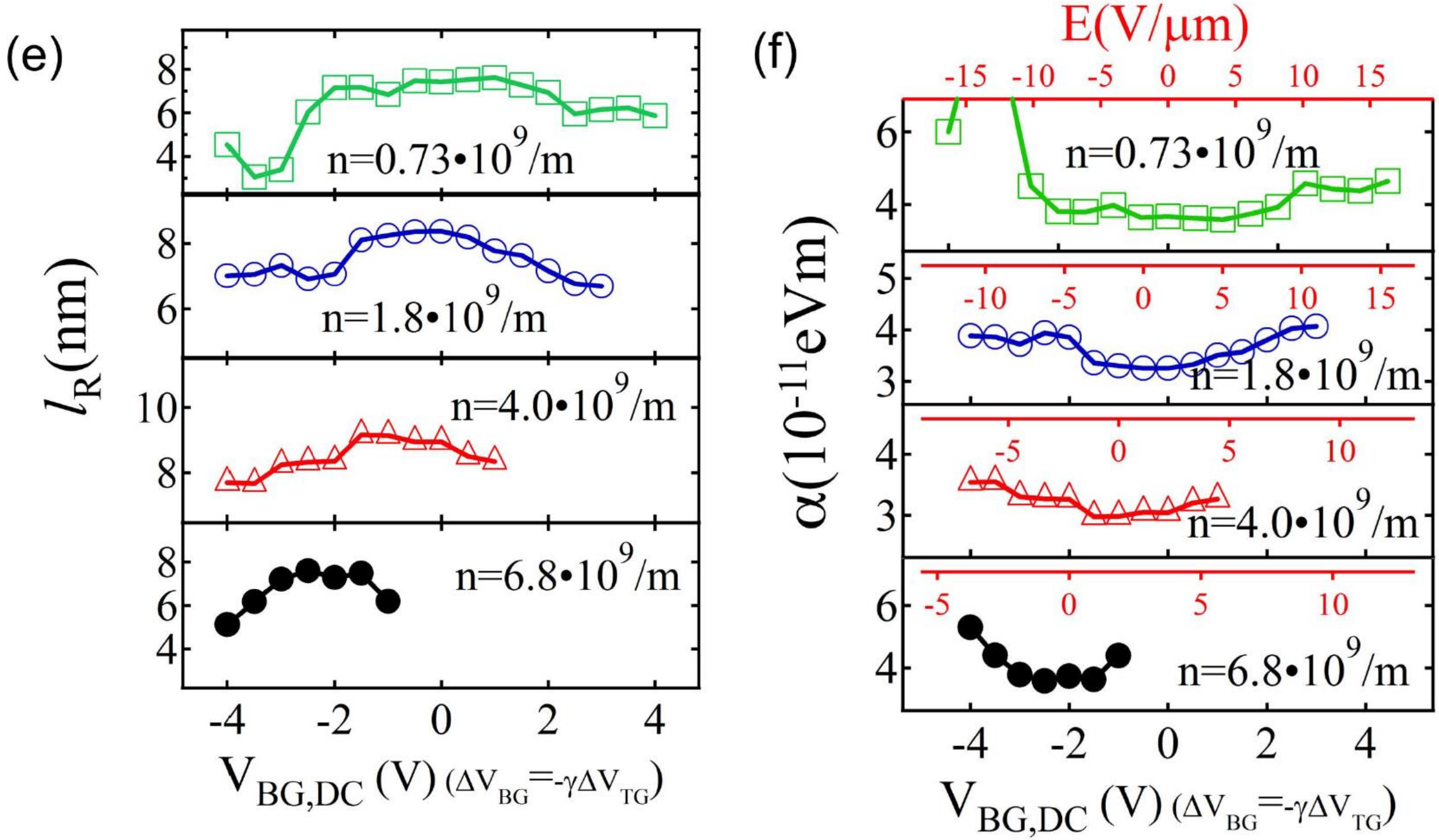
- independent control of carrier density and electric field with dual-gated sample
- observation of large spin-orbit energy: 1-6 meV
- tunable by a factor of 3 with electrostatic field
- evidence for predicted direct Rashba spin-orbit interaction

Electric Field Control I

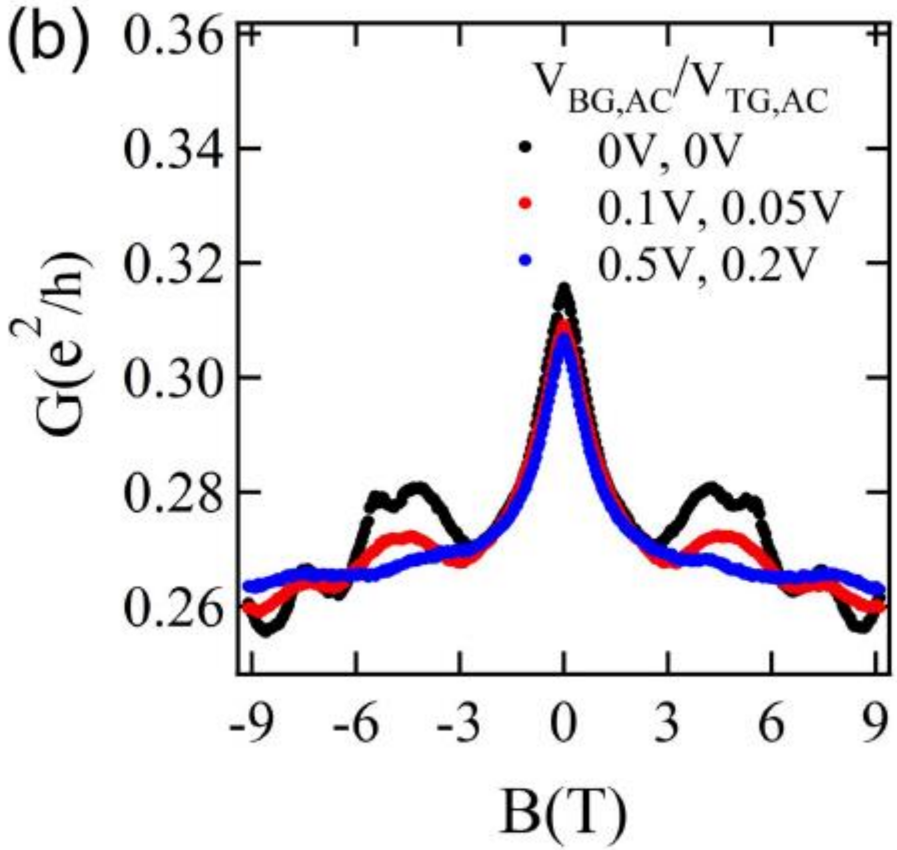


spin lifetime is largest when holes are confined in the center of the wire

Electric Field Control II



Universal Conductance Fluctuations



apply small AC voltages to top and bottom gate to average over UCF