Conductance Quantization at Zero Magnetic Field in InSb Nanowires

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Friday Afternoon Meeting-Talk
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Challanges/Motivation

- Majoranas:
  - 1D semiconductor
  - Strong SOI
  - Proximity induced super conductivity
Challenges/Motivation

- Majoranas:
  - 1D semiconductor  **Hard to achieve**
  - Strong SOI
  - Proximity induced super conductivity

- No disorder between S and D (O(μm))!
  - Structural/crystal imperfection of NW
  - Surface states in (i.e InAs)

- More trajectories in 2D → less affected by disorder
Challenges/Motivation

• Majoranas:
  • 1D semiconductor
  • Strong SOI
  • Proximity induced super conductivity
  • No disorder between S and D (O(μm))!
    • Structural/crystal imperfection of NW
    • Surface states in (i.e InAs)
  • More trajectories in 2D → less affected by disorder
  • Achievement of ballistic conductance at finite B fields → not desired for observation of Majoranas

Normal confinement in 2D
- Confinement in x and y direction
  \(\rightarrow\) depletion of 2DEG beneath contacts
  \(\rightarrow\) subbands each carrying \(2e^2/h\)
Confinement

- Normal confinement in 2D
  - Confinement in x and y direction
  - Depletion of 2DEG beneath contacts
  - Subbands each carrying $2e^2/h$

- NW has rotational symmetry $\rightarrow$ different subband spacing
  - Geometric confinement (causes degeneracy)
  - Electrostatic confinement via gates (could lift degeneracy)
Bottom up approach:

• Bottom gate definition
• hBN as dielectric for protection of NW
• Place InSb NW (grown via MOVPE)
• Contacts Cr/Au (10/100nm) 150-400nm spacing
• ammonium polysulfide etching $\rightarrow$ sulfur passivation $\rightarrow$ local surface doping $\rightarrow$ better contacts
• Measurements at 15mK BT using standard lock-in techniques
• InSb NW: electron wave function confined to the center of the NW
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DC bias

- Pinch-off traces for 4 different devices (same chip)
- Jumps in conductance from $1G_0$ to $3G_0$ and $3G_0$ to $5G_0$
- Investigate green device in more detail
DC bias spectroscopy

- Sweep DC bias and gate voltage
- Areas of constant conductivity → diamond shaped
- Allows to investigate the subband spacing:
  - $\Delta E_{\text{subband}}$ and lever arm $\eta = \frac{\Delta E_{\text{subband}}}{V_{\text{gate}}}$
  - Small $2G_0$ plateau → small energy splitting between 2nd and 3rd subband
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  - Small \( 2G_0 \) plateau \( \rightarrow \) small energy splitting between 2nd and 3rd subband
- Apply B field to lift spin degeneracy:
  - \( E_n \downarrow \uparrow \rightarrow E_n \downarrow , E_n \uparrow \)
Zero bias conductance

- Apply B-field along $B_z$
- First subband splits as expected ($\leftrightarrow$, $\leftrightarrow$)
Zero bias conductance

- Apply B-field along $B_z$
- First subband splits as expected ($\leftrightarrow$, $\leftrightarrow$)
- Second subband behaves differently

$E_{2,3}^{\uparrow}$

$E_{2,3}^{\downarrow}$

$g\mu_B B$
Zero bias conductance

- Apply B-field along $B_z$
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- Second subband behaves differently

$3T \rightarrow 1.5G_0$ emerges
Zero bias conductance

- Apply B-field along $B_z$
- First subband splits as expected ($\leftrightarrow$, $\leftrightarrow$)
- Second subband behaves differently
- Determine $g$-factors (using gate lever arm)

$g_1 = 39; g_{2,3} = 38$ (c.f. bulk value $\sim 50$)
Orbital effects of B-field

- Orbital effects depend on direction of magnetic field
- Simulate [1] the effect of in-plane and out-of plane B-field on subband dispersion
- Include spin-orbit interaction
- $E_2$ and $E_3$ increase until the spin down branches cross
  - Crossing not observed in experiment $\rightarrow$ would correspond to a jump by $G_0$

Effect of out plane B-field

Perpendicular to the wire (along z direction):
- 0.5, 1G₀ plateaus visible
- 1.5G₀ plateau not visible but 2.5G₀
Effect of out plane B-field

Perpendicular to the wire (along x direction):
• 0.5G₀ plateau from B~0.6T
• Jump from 1 to 2G₀
• 1.5G₀ plateau not visible, 3G₀ slightly visible
Effect of in plane B-field parallel to the wire along (y direction)

- Bands split at $B \sim 0.75T$ into 4 subbands
- Agrees better with simulations
- Almost no orbital effects!
Ballistic Transport and Exchange Interaction in InAs Nanowire Quantum Point Contacts

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InAs NW (d~100nm)
- high-k dielectric (100nm thick)
- gates 180nm wide and 30nm spacing
- field effect measurements:
  - $\mu=25000\text{cm}^2/\text{Vs}$
  - $n_{3D}=1\times10^{17}\text{cm}^{-3}$
  - $l_e=250\text{nm}$
Conductance quantization

- splitting of subbands upon applying B-field
- no degeneracy of 2\textsuperscript{nd} and 3\textsuperscript{rd} subband
DC bias spectroscopy

- At small DC bias resonances $\rightarrow$ Fabry-Perot interferences $\rightarrow$ derive effective channel length ($\sim 210$nm)
- Determine g-factors
  - $|g| \sim 7$ for 1$^{st}$ subband (bulk $\sim 15$)
  - g factor decreases with subband index
    - close to pinch off $\rightarrow$ stronger confinement $\rightarrow$ increase of exchange interaction
Conclusion

- Conductance quantization at B=0 in ballistic InAs and InSb NW
  - Using high-k dielectrics (hBN and LaLuO$_3$)
- Kammhuber et al.
  - investigated subbands
    - degenerate due to confinement of NW
    - spin degeneracy lifted with magnetic field $\rightarrow$ depends on direction due to orbital effects
    - difference between data and simulation $\rightarrow$ SOI modification due to gating and/or change of confinement ?
- Heedt et al.
  - g factor varies with subband index due to confinement
  - observe Fabry-Perot interference
  - 0.7 Anomaly present at elevated temperatures $\rightarrow$ further investigation