SAND2006-5220P

Low Temperature Transport in Low Dimensional Systems

Research Interests

Coupled Nanoelectronic Systems

- Vertically coupled 1D wires
  Transport studies, time resolved transport
- Coupled quantum dots
  Quantum computing

2D electron physics

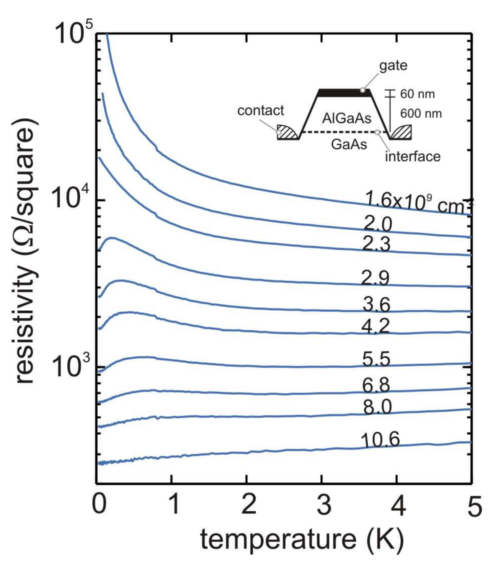
- Bilayers
  Electron-hole bilayers for exciton condensation
- Quantum Hall effects
- High mobility 2D electrons

Jumpstart User Project

2D metal-insulator transition

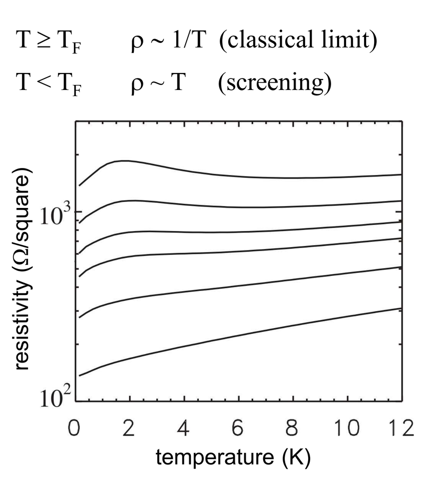
Apparent metal-insulator transition

Resistivity of ultra-clean 2D electrons



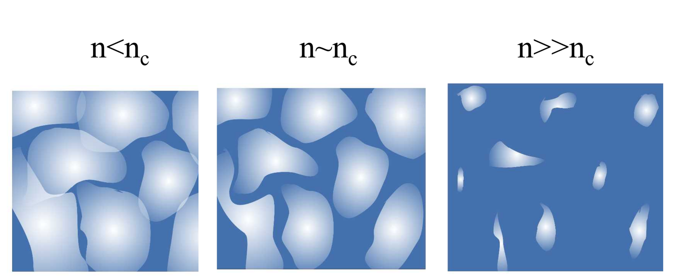
Boltzmann scattering theory

$T \geq T_F \quad \rho \sim 1/T$ (classical limit)
$T < T_F \quad \rho \sim T$ (screening)



Qualitative agreement with ionized impurity scattering

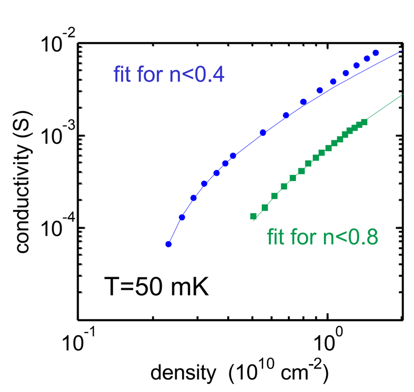
Percolation at low density



- Inhomogeneous density suggests considering a percolation model for transport at low density.

$$\sigma = A(n - n_c)^{\delta}$$

- in 2D, the percolation exponent is 4/3



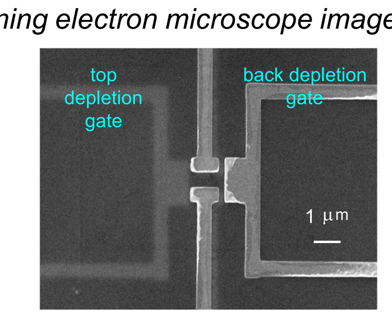
The values of both samples are close to the known percolation exponent of 4/3.

The agreement between experiment and theory for both the non-monotonic resistivity and the percolation scaling in the insulating regime suggest that the standard picture of Fermi liquid physics can explain the 2D metal-insulator transition in high mobility 2D electrons.

Coupled Nanoelectronics

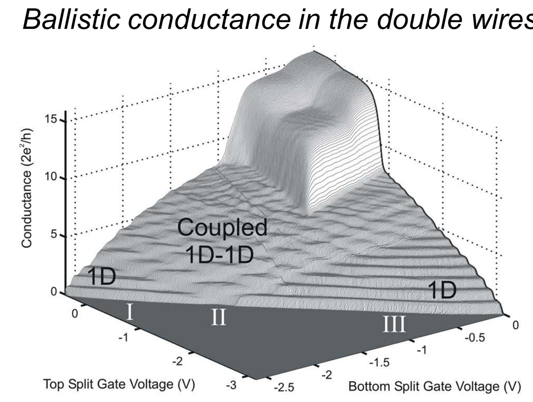
Vertically coupled double quantum wires

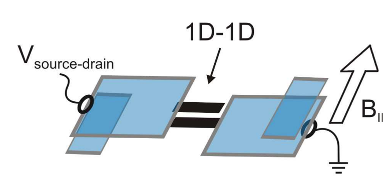
Scanning electron microscope image of device



- GaAs/AlGaAs double quantum wells form bilayer
- Metallic gates define the coupled nanoelectronic structure

Ballistic conductance in the double wires





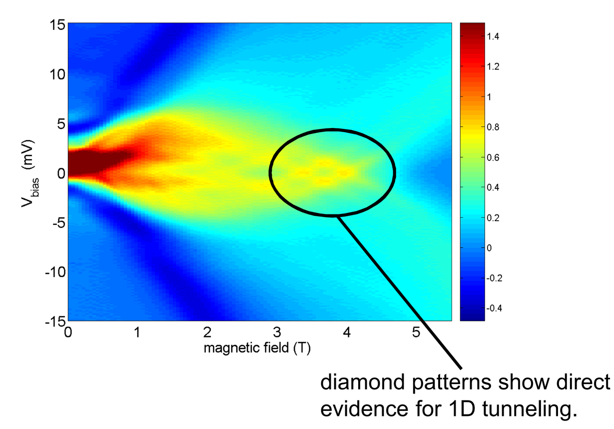
Transport from the top to the bottom layer can only occur through 1D tunneling.

- Voltages applied to the top and bottom split gates change the 1D density in the wires.
- Ballistic conductance steps are observed for each wire (demonstrates low disorder 1D systems)

Conductance “map” allow precise control over 1D electronic state

1D Tunneling

Tunneling spectroscopy in 1D-1D system

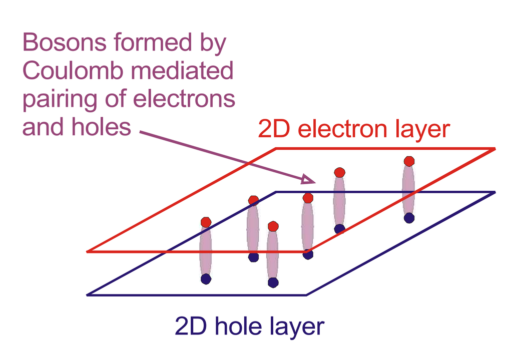


Energy and momentum of the tunneling electron can be varied with a voltage and magnetic field – *allows measurement of spectroscopy*

Non-interacting model cannot account for all of the features observed in the measurements. Coulomb interactions can lead to the *emergence* of new phenomena (Luttinger liquids in 1D)

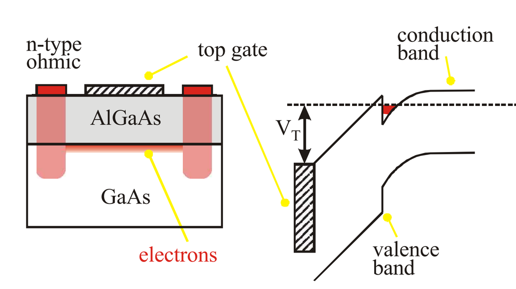
Electron-hole bilayer fabrication for exciton condensation

Exciton condensation



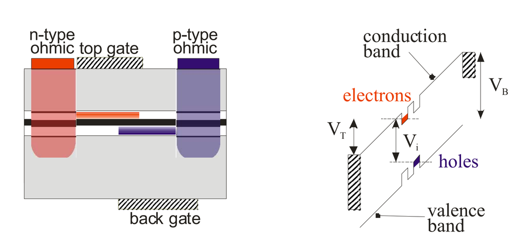
Excitonic condensation requires:
1. closely spaced layers
2. low density
3. low temperature
4. high mobility

FET design for GaAs



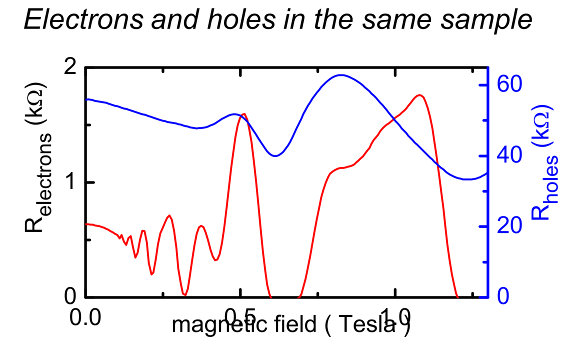
- Carrier type depends on contacts, not doping
- Variable density (used for 2D metal insulator trasition)

Electron-hole bilayer design



The prediction of exciton condensation 60s dates to the and 70s. Experimental implementation of electron hole bilayers, especially for transport, is quite difficult

Electrons and holes in the same sample



Technique is ideal for electron-hole bilayers: consistent with high mobility, low density, and bipolar operation.

Next – Coulomb drag to detect condensation

Associated Capabilities

Low temperature transport

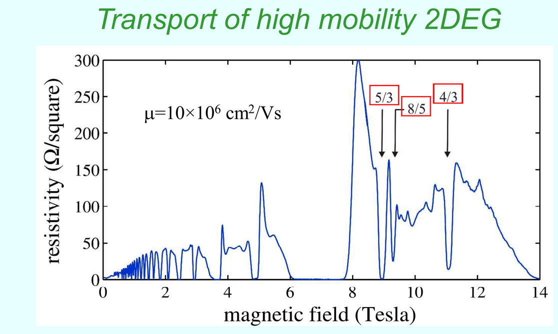
- Oxford MX400 Dilution refrigerator (available Winter 2006)
  Base temperature < 10 mK
  Multiple experimental inserts
  - dc transport, high frequency, rotation
- 3He system for rapid characterization (available Fall 2006)
  Temperature range 0.3 to 300 K
- 13 T superconducting solenoid magnet
  3” bore, provides extra
  High homogeneity (1 part in 10^5)
  Field cancelled region at mixing chamber

Oxford MX400

III-V molecular beam epitaxy

- Ultra-clean GaAs/AlGaAs heterostructures
  10 million mobility 2D systems
  bilayers and complex structures
- MBE system for experimental materials

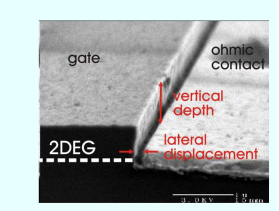
Transport of high mobility 2DEG



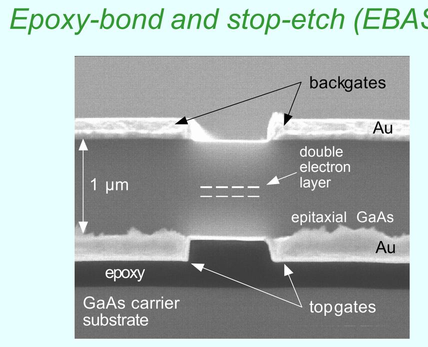
Sample processing

- Techniques for new devices
  FET design 2D systems
  Variable density bilayers
  Thinning techniques (EBASE)
- Electron beam lithography

FET design for 2D systems



Epoxy-bond and stop-etch (EBASE)



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