

High-Field Study of Yb-Doped AlGaAs/GaAs 2-D Electron Systems

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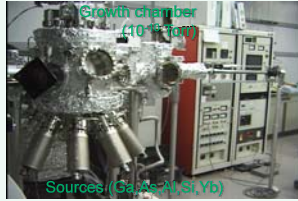
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Sample Preparation

Molecular Beam Epitaxy

T228 Sample	Yb116 Sample
GaAs 20 nm	GaAs 20 nm
AlGaAs:Si 40 nm	AlGaAs:Si 40 nm
AlGaAs 40 nm	AlGaAs 100 nm
AlGaAs 40 nm	Si δ-doped AlGaAs 20 nm
GaAs 30 nm	AlAs:Yb 10 nm
AlGaAs 10 nm	AlGaAs 10 nm
GaAs 2DEG 30 nm	ZDEG-GaAs 2DEG-GaAs

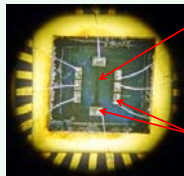
Substrate temperature: 630 °C, Al_{0.3}Ga_{0.7}As



Molecular Beam Epitaxy Machine

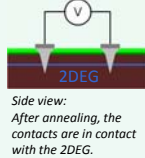
Hall Bar Fabrication

- Resist-coating
- Pre-bake
- Photolithography
- Post-bake
- Wet chemical etching
- Metal evaporation
- Annealing
- Wiring



Appearance of Sample

Hall Bar
Contacts



Experimental Setup

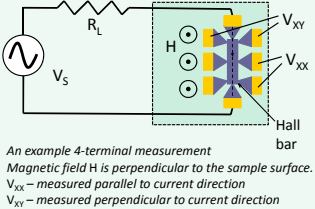
High magnetic field

We used both a superconducting magnet (up to 15 T) and a specially-designed water-cooled magnet (25 T). Each magnet has a cryostat and pump system, which was used to achieve experimental temperatures of ~1.5 K. Samples were inserted into the magnets using a probe with optical fiber and copper wiring.



The 25-T water-cooled magnet at NIMS

Transport Measurements



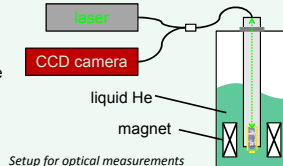
An AC excitation signal wired in series with a large load resistance and the contacts on opposite ends of the Hall bar. XX and XY (Hall) voltage were measured simultaneously using lock-in amplifiers.

Illumination conditions tested:

- dark
- strong 532-nm, solid-state laser
- monochromatic infrared (900-1000 nm) from a bulb

Optical Measurements

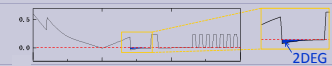
We shone a green, solid-state laser (532 nm) into the optical fiber of the probe. The photoluminescence (PL) signal returned via optical fiber to a spectrometer, which monitored light intensity over a range of wavelengths simultaneously.



What is the QHE?

Quantum Hall effect (QHE) is the name given to the exact resistance quantization exhibited by a 2-dimensional electron gas (2DEG) at low temperatures and high magnetic fields. At integer "filling factors" ν , R_{XY} plateaus at value $h/(\nu \cdot e^2)$ while R_{XX} becomes exactly zero. This result is independent of sample size and material. At higher magnetic fields,

additional R_{XY} plateaus can be observed as per the fractional QHE (fractional values of ν).



Conduction band and Fermi level of T228 sample. The 2DEG forms in a quasi-triangular potential well just below the Fermi level.

Motivation for Yb-Doping

- **Optical Devices:** Wavelengths of ~1 μm arises from 4f intra-level transitions in Yb³⁺ ions. These wavelength can be used in optical communications devices.

- **Quantum Computing:** Yb spin states manipulated by local sensing equipment are a possible candidate for quantum bits (qubits). Interaction between multiple qubits could be mediated by the macroscopic coherence of quantum Hall states.

Our Experiment

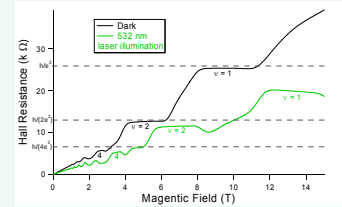
We fabricated both undoped and Yb-doped AlGaAs/GaAs heterostructures with standard Hall bar geometries. To investigate the properties of each sample's 2DEG, we made transport and magneto-photoluminescence measurements. Data were taken at low temperatures and high magnetic fields under a variety of sample illumination conditions.

Optical and Transport Data

T228: Typical Quantum Hall System

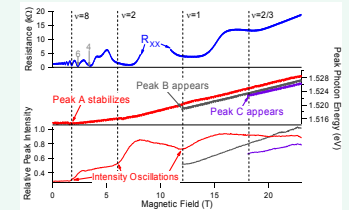
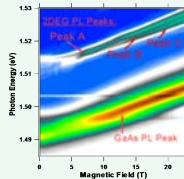
Transport

- Under **dark** conditions, we observe nearly ideal QHE. Plateaus become clearer with higher electron mobility.
- Under strong **illumination** of the 532 nm laser, carrier concentration increases from $2.6 \times 10^{11} \text{cm}^{-2}$ to $3.4 \times 10^{11} \text{cm}^{-2}$. R_{XY} plateaus decrease from their QHE values, while R_{XX} increases from zero in these regions.



Optical

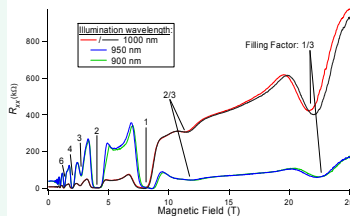
- Oscillations in the intensity of **Peak A** are correlated with some integer filling factors.
- New PL peaks appear at higher magnetic fields ($\nu = 1; 12 \text{ T}, \nu = 3/2; 18 \text{ T}$). This is likely due to the energy gain from the typical spin configuration at 1 and $3/2$.



Yb116: Effects of Yb-Doping

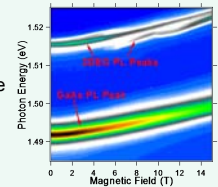
Transport

- Clear Shubnikov-de Haas oscillations are observed in R_{XX} data **only** when the sample is illuminated (900-1000 nm light).
- This illumination effect shows the controllability of the metal-insulator transition in Yb-doped quantum structures.
- XX resistance data differs greatly between 1000 and 950 nm illumination wavelengths.



Optical

- PL intensity oscillations are **not** observed in the Yb-doped sample. This is likely due to localization in the sample caused by the Yb atoms.
- Photoluminescence from a bulk GaAs:Yb sample is observed to be ~1.23 eV ($\lambda \approx 1 \mu\text{m}$).



Conclusions

In the undoped T228 heterostructure sample, we can observe oscillations in both transport and optical data. The QHE manifests itself clearly, and appearance of new photoluminescence peaks corresponds to the filling factors 1 and $3/2$. Remote Yb-doping appears to cause localization in the 2DEG, but the metal-insulator transition can easily be controlled using light in the 1 μm wavelength range. With the Yb116 sample illuminated oscillations in R_{XX} are very distinct, but no oscillations were detected in the optical data.



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