Cyclotron Resonance and Magneto-photoluminescence in Quantum Wells

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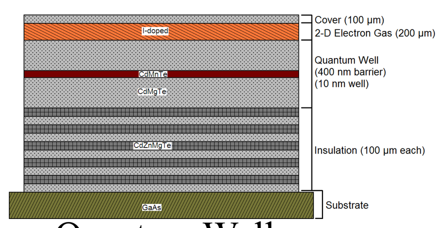
Abstract

Cyclotron resonance in ultrahigh magnetic fields is used to determine the effective mass of electrons in semiconductor compounds. We studied an n-type $Cd_{1-x}Mn_xTe/Cd_{1-y}Mg_yTe$ single quantum well where x = {0.3, 1.0, 1.8, 2.1%}, y = 13.7%, the well width L_z = 10 nm and the barrier width L_b = 400 nm. Above the quantum well was an iodine-doped layer that acts as a 2-D electron gas from which electrons could tunnel to the quantum well. Ultra-high magnetic fields up to 130 T were generated in a single-turn coil apparatus and the cyclotron resonances were measured at cryogenic temperatures using a far infrared water vapor laser. Several resonances were observed, corresponding to the different wavelengths of the laser, from which the effective mass was calculated. The sample was then studied in lower magnetic fields to observe magneto-photoluminescence effects, specifically charged exciton transitions. Charged excitons can contain two electrons and one hole or two holes and one electron, analogous to H^+ or H^- ions, and have become a very interesting field of study in semiconductor physics.

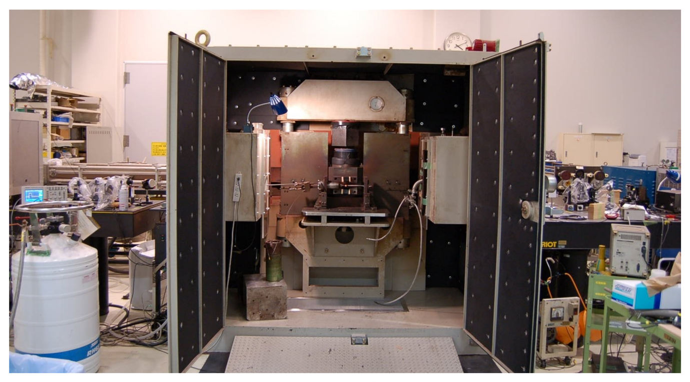
Sample and Setup

•N-doped $Cd_{1-x}Mn_xTe/Cd_{1-y}Mg_yTe$ Quantum Well
- •x = {0.3, 1.0, 1.8, 2.1} %
- •y = 13.7 %
- •10 nm well
- •400 nm barrier
- •I-doped layer as electron gas

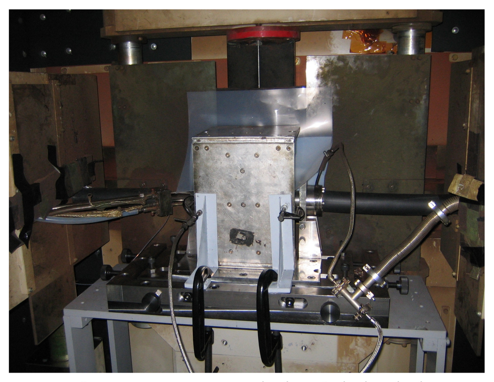


Quantum Well in Real Space

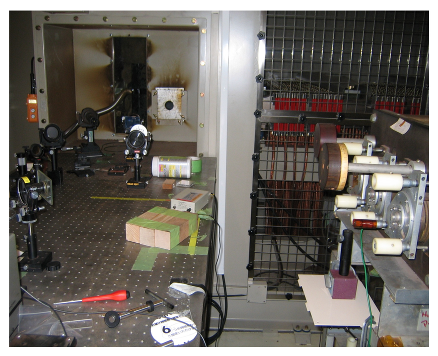
•Experiment Setup
- •Single-turn coil with 12 mm diameter
- •Far-infrared water vapor laser (λ = 16.3, 27.9 μm) directed through sample to detect resonance
- •Copper-doped gallium photoconductive detector
- •Sample is cooled with liquid helium and temperature is measured with a AuFe/NiCr thermocouple
- •Cryostat is evacuated for insulation
- •Optical equipment is used where possible and electrical equipment is well shielded to reduce noise from magnet
- •Phenyl-resin cryostat to hold sample is nonconducting to prevent large currents from being generated



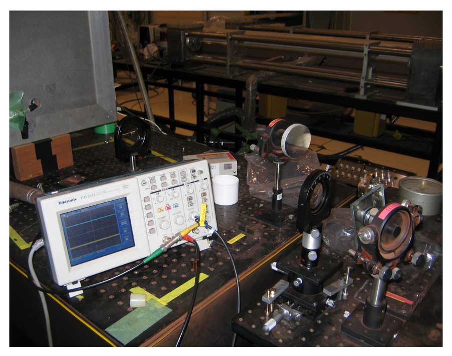
Overview



Cryostat with Shield



Laser and Mirrors



Detector and Optics

Detector

Cyclotron Resonance

•Used to determine the effective mass of electrons in semiconductors.

•Using a semiclassical approach, it can be shown that:

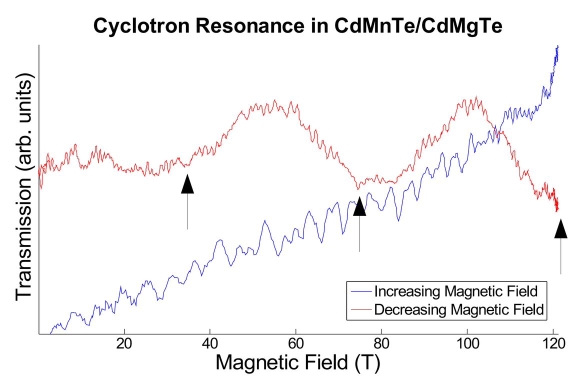
$$m_c^* = \frac{e\|\vec{B}\|}{\omega_c}$$

where:
- m_c^* = Effective mass
- e = Electron charge
- $\|B\|$ = Magnitude of the magnetic field perpendicular to the sample at resonance
- ω_c = Laser's angular frequency

•Resonances are only observed at low temperatures, where the relaxation time τ is longer, and very high magnetic fields.

$$\omega_c \tau \gg 1$$

•Measurement
- •Sample is cooled to cryogenic temperatures using liquid helium (to anywhere from 5 to 80 K)
- •Laser pulse is directed through the sample and synchronized with the magnetic field
- •Transmitted light is detected by a Cu-doped Ga photoconducting sensor
- •Laser radiation is absorbed at resonance



Calculated Effective Masses

	λ = 16.3 μm	λ = 27.9 μm
34.5 T	$0.0524*m_e$	$0.0898*m_e$
74.4 T	$0.1132*m_e$	$0.1937*m_e$
120.1 T	$0.1827*m_e$	$0.3127*m_e$

•Graph shows one shot with transmission before and after the field reaches its peak.

•Strong absorptions are observed near B = 35, 74 and 120 T

•Calculating effective mass
- •Possible effective masses are given for each absorption
- •Wavelength is unknown, so calculations are made for both possible wavelengths
- •Accepted value for CdTe: $0.11*m_e$
  - •We take $0.0989*m_e$ at 35 T and $0.1186*m_e$ at 74 T
  - •Absorption at 120 T must be noise

Magneto-photoluminescence

•Observation of electron transitions when under the influence of a magnetic field.

•Measures energy of absorbed and emitted photons

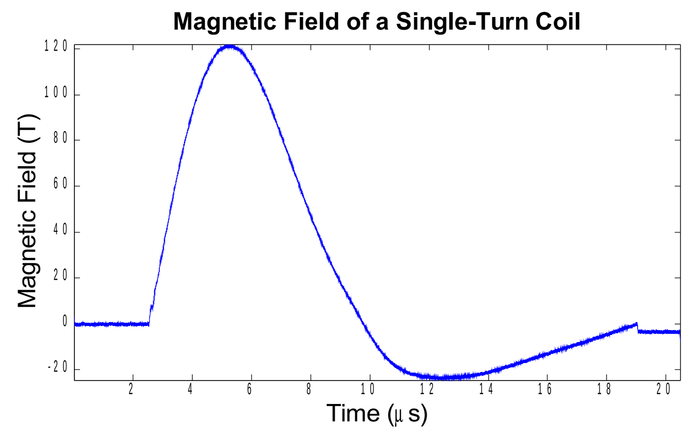
•Charged excitons, or trions, consist of two electrons and one hole or two holes and one electron and are studied in low magnetic fields.

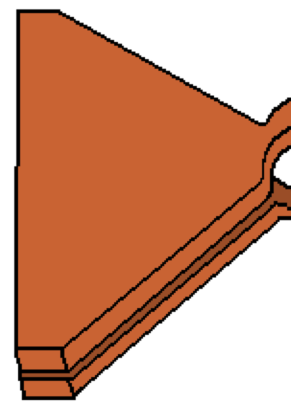
•Trions are semiconductor analogues to H^+ or H^- states and have become an interesting new field to study.

Single Turn Coil

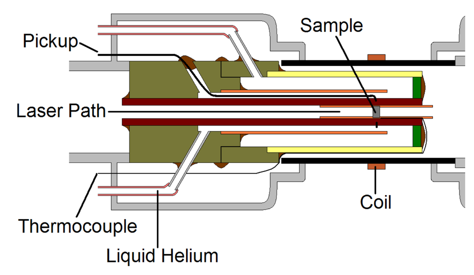
•Reliable method to create ultrahigh magnetic fields
- •Can produce fields over 200 T in a 7 μs pulse
- •Large coil with one turn to minimize inductance
- •200 kJ condenser bank produces 3 MA current
- •Coil is violently destroyed during each shot

•Advantages
- •Consistently creates megagauss fields
- •While the coil is destroyed, the sample survives and can be studied in subsequent experiments
- •Relatively quick turnaround time between shots

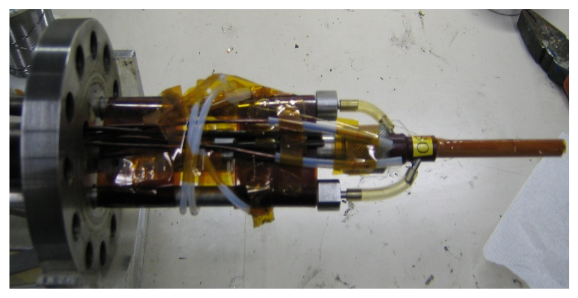




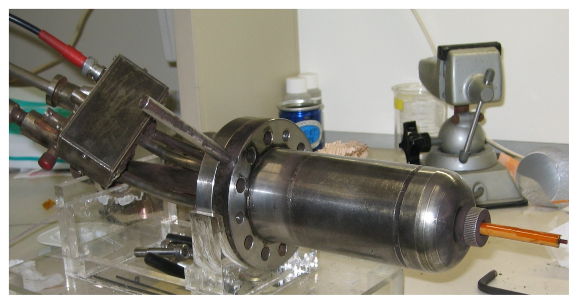
Single-Turn Coil



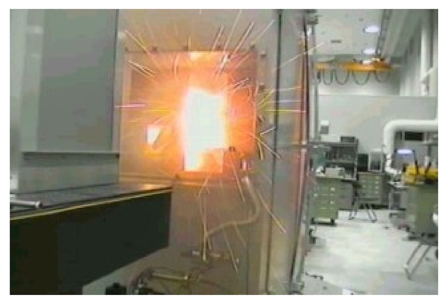
Cryostat and Sample Holder



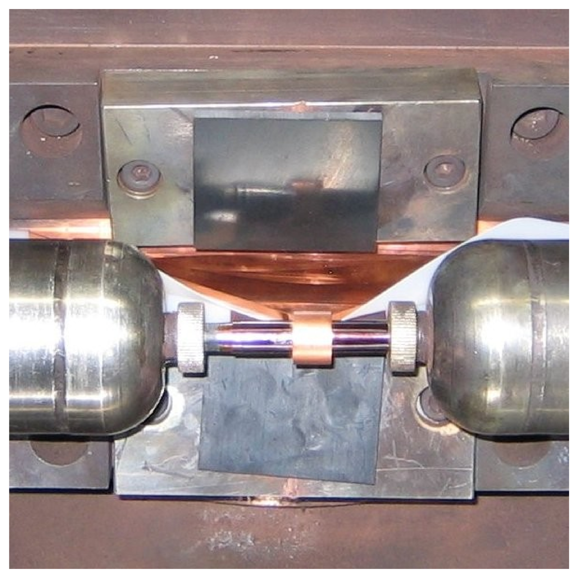
Sample Holder



Completed Cryostat



Shot in Progress



Before Shot

After Shot

Acknowledgments

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