MAGNETO-PHOTOLUMINESCENCE OF CARBON NANOTUBES AT ULTRALOW TEMPERATURES

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Single-walled carbon nanotubes (SWNTs) exhibit novel optical and electronic properties not found in its multiwalled counterpart. Specifically, SWNTs have the potential to combine electronic and optical functionality in the same nanoscale circuit because of their direct band gaps. Although much research has been conducted on SWNTs, there still remain questions concerning the optical and electronic properties and the possible applications that the answers to these questions may hold. One such issue is the poor photoluminescence quantum efficiency exhibited by the SWNTs, which manifests itself in low photon emission when submitted to photo-excitation. This phenomenon presents a significant roadblock to any possible optoelectronic applications, and many theories concerning the origin of the characteristic quantum efficiency have been presented. Of these, one theory predicts that optically inactive or "dark" excitonic states exist below the first bright exciton state and can trap the majority of the exciton population at low temperature. To investigate such a possibility, we are studying temperature and magnetic field dependent photoluminescence and micro-photoluminescence of SWNT thin films at >20 mK temperatures using unique facilities at Tohoku University. By using an optically capable dilution refrigerator in conjunction with a cryostat (vessel used to maintain cryogenic temperatures by adding He_4) at 4.2 K, laser, and monochrometer, the resulting photoluminescence caused by photo-excitation may be observed under a high magnetic field. So far, photoluminescence has been confirmed at room temperature with on-resonance excitation, and the proceeding step will be to gradually decrease the temperature to the >20 mK range. This ultralow temperature setup is expected to yield significant new insight into many of the unanswered questions as to the effects of disorder and non-thermal distribution of excitons in SWNT.

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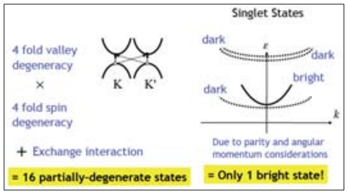
Introduction

Carbon nanotubes are cylindrical carbon molecules that exhibit extraordinary strength. Of the two types, single-walled and multi-walled nanotubes, single-walled carbon nanotubes (SWNTs) possess highly unusual electronic and optical properties, making them objects of great interest for basic scientific studies as well as potential applications [1]. In particular, because they have direct band gaps, SWNTs are a leading candidate to unify electronic and optical functionality in the same nanoscale circuitry. The past several years have witnessed remarkable progress in our understanding of light emission and absorption processes in SWNTs, revealing the unusual properties of one-dimensional excitons and opening up possibilities for making SWNT-based optoelectronic devices including lasers.

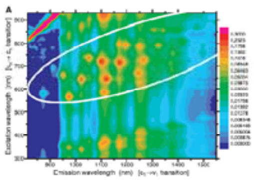
Problem

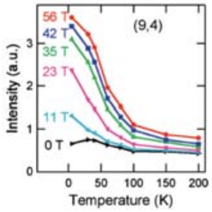
- Poor SWNT photoluminescence quantum efficiency
- Theory proposes that optically inactive "dark" excitonic states exist below the first bright excitonic state
- Majority of exciton population trapped by dark excitonic states at low temperature [5-10]



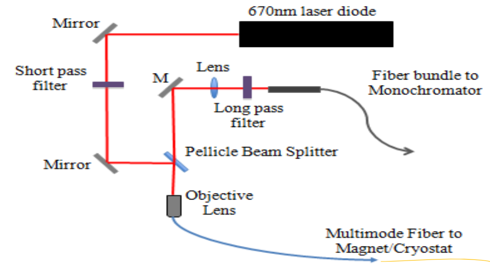
Previous Work

- Previous work has focused on understanding the influence of temperature and magnetic field on SWNT photoluminescence intensity
- Theory suggests that photoluminescence will disappear at low temperatures [5-11]
- However, increases in photoluminescence quantum efficiency have been observed at low temperature (1.5K) [13]
- Previous work also emphasizes that magnetic fields can brighten a dark excitonic state

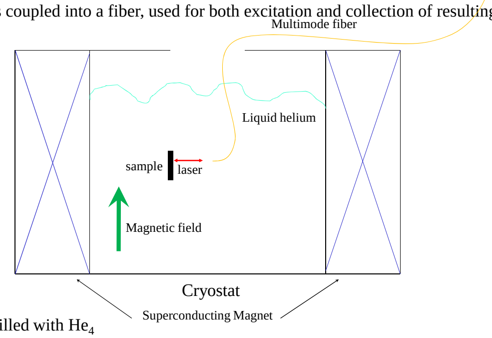




Experimental Setup

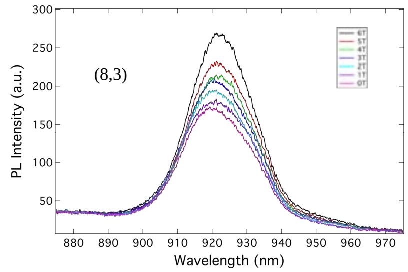


- Provides optical excitation using a laser diode system
- Particular laser chosen to be on-resonance with particular nanotubes in sample
- Laser is coupled into a fiber, used for both excitation and collection of resulting light



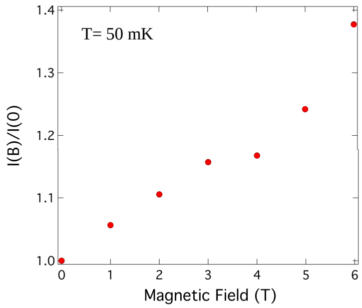
- Vessel filled with He_4
- Maintains cryogenic temperatures for experiments
- Allows submersion of sample and exciting/collecting fiber
- Flanked by superconducting magnet, which allows for magnetic field influence experiments

Results



Notes:
- Data treated for cosmic rays
- Applied boxcar filter with consideration for resolution

Analysis



- Excitonic brightening of (8,3) nanotube at mK temperature
- Apparent magnetic field dependence of photoluminescence
- Nonlinear magnetic brightening behavior → further magnetic field and temperature dependence data needed.

Conclusion/Future Work

- We were able to successfully investigate magnetic brightening of photoluminescence of the (8,3) nanotube at 50mK.
- Nonlinear magnetic field dependence was observed.
- Further magneto-PL data is needed in the mK regime to obtain a complete understanding of the excitonic states and distribution of excitons.
- Additionally, further ultra low measurements can possibly provide information about non-thermal behavior.

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