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A near-infrared spectroscopy in magnetic fields above 100 T

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Abstract Development of the first measurement system for near-infrared absorption spectra between 0.9 and 1.7 μm under ultra-high magnetic fields is reported. Spectral signals were integrated for 1 μs with an InGaAs photodiode array around the top of a very short pulsed megagauss field. The magnetic fields were generated using a single-turn coil system. The measurement system was demonstrated in the study of exciton states in single-walled carbon nanotubes up to megagauss fields. A nearly noiseless absorption spectrum with well-resolved absorption peaks was obtained at 105.9 T in the Voigt configuration where the magnetic field was applied parallel to the alignment of the nanotubes.

Keywords near-infrared magneto-absorption, ultra-high magnetic field

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1 Introduction

Megagauss pulsed fields have been applied greatly to the study of physical properties of materials and have contributed to reveal unknown properties and to enhance our understanding of solid state physics.^{1,2} Since megagauss fields are generated very shortly (typical pulse width of several micro seconds) and destructively, development of measurement techniques has been elaborated. Among various measurement techniques, optical approaches have been employed most intensively as

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the optical equipments can be settled at a respectable distance and no electrical wiring to the samples is required.³ Extremely fast and sensitive spectroscopy using a streak camera and an image intensifier has been a powerful tool to investigate optical properties of semiconductors in the megagauss region as one can obtain spectral information for the whole range of a single pulsed field generated destructively.⁴ However, the application of this technique to megagauss spectroscopy has been limited to the visible region and not available in the near-infrared region (NIR). Development of an NIR spectroscopy system in the megagauss region is useful from the viewpoint of both basic science and application as the NIR region is used for optical communication.

In this paper, we report an attempt to obtain NIR absorption spectra above 100 T by exposing an InGaAs photodiode array for 1 μ s around the top of the very short pulsed fields. Examples of the first successful NIR absorption spectra obtained in the megagauss region are exhibited for single-walled carbon nanotubes (SWCNTs).

2 Experimental setup

Figure 1 exhibits the experimental setup. A xenon short-arc flash lamp (Eagle corp., 600 V, 30 J) was employed as a light source and operated at the discharge voltage of 450 V. The light was delivered to an optical probe through a visible-NIR optical fiber. Transmission measurements were conducted in the Voigt configuration by sandwiching a sample with two right-angled prisms made of BK7 at room temperature. Transmission light was conveyed to a 0.3 m spectrometer (Acton SpectraPro-2300i) with gold coated mirrors through another visible-NIR optical fiber. The employed fibers were of the graded-indexed type with a core of 800 μ m in diameter. Spectral light intensities were detected with an InGaAs photodiode array (Xenics, XLIN 1.7, 0.9-1.7 μ m, 512 pixels of 25 μ m in pitch and 500 μ m in height). The detector was cooled down to 260 K thermo-electrically during the measurements.

Ultra-high magnetic fields above 100 T were generated using a single-turn coil system with a fast capacitor bank (40 kV, 100 kJ)⁵. Though the single-turn coils were destroyed after discharge due to the strong Maxwell stress, the probe settled in the coil bore was not damaged as the coil was destroyed outward. A pick-up coil for the measurement of magnetic fields was positioned away from the field center by 2.3 mm along the radial direction in the optical probe. The deviation of the measured field from the center field was estimated at 1.5% at most when a field coil with both the inner diameter and the width of 12 mm was used.⁶

The xenon short-arc flash lamp, the InGaAs photodiode array and the capacitor bank were triggered using multi-channel delayed pulse generators. The transient recorders and the photodiode array were also settled in an electrically shielded room. The trigger signals were transmitted optically outside the shielded room. The photodiode array was controlled to integrate spectral signals for only 1 μ s around the pulsed field top.

The measurement system was demonstrated in the absorption measurement of composite films of SWCNTs (CoMoCAT) dispersed in gelatin matrix. The SWCNTs were four times stretch-aligned along the plane of the films⁷. Magnetic fields were applied in parallel to the alignment of SWCNTs (the Voigt configuration).

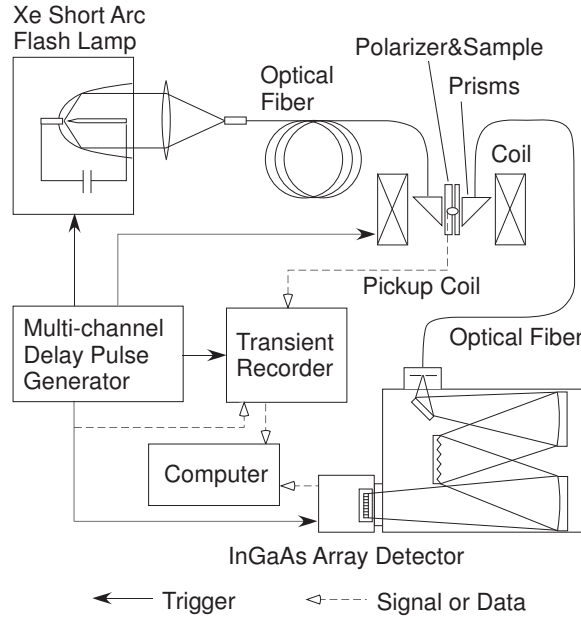


Fig. 1 Schematic diagram of the experimental system for spectral measurements of NIR absorption under ultra-high magnetic fields.

The light incident on the sample was also polarized in parallel to the alignment of SWCNTs with an NIR linear polarizer. Concerning the spectrometer, a grating with the blaze wavelength of $1.2\ \mu\text{m}$ and the grating density of 150 line/mm was used, and the width of the entrance slit was adjusted to $250\ \mu\text{m}$. The spectral resolution was estimated at 6 meV around the photon energy of 1.15 eV ($1.08\ \mu\text{m}$ in wavelength).

3 Results and Discussion

Field variation during the measurement of an absorption spectrum integrated for $1\ \mu\text{s}$ depended on the size of field coils and the discharge voltage. The smaller the coil diameter was and the larger the discharge voltage was, the larger the rate of the field variation was. In the case of a coil with the diameter of 12 mm and a discharge voltage of 35 kV, where the maximal field was 108.3 T, the field variation for $1\ \mu\text{s}$ around the field pulse top was 1.2%.

Absorption spectra of the SWCNT sample obtained at several fields are shown in Fig. 2. The absorption peaks observed at 0 T are corresponding to the exciton absorption at the first subband gap in semiconducting SWCNTs with different chiralities. It was recognized successfully that additional absorption peaks emerge by the application of the very high fields. This phenomenon can be attributed to magnetic conversion of optically unallowed excitons into allowed ones via the Aharonov-Bohm effect⁸.

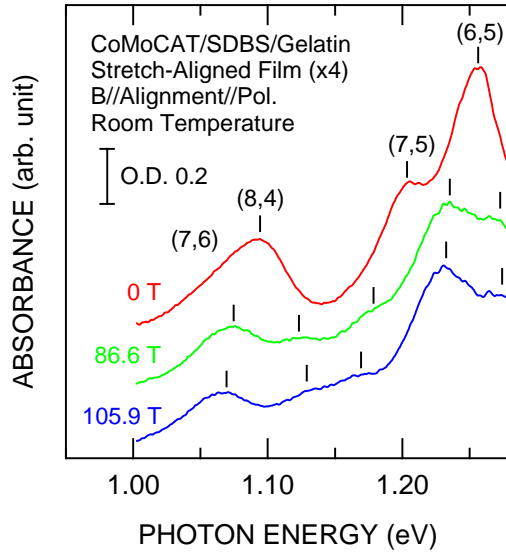


Fig. 2 (Color online) NIR magneto-absorption spectra of an SWCNT sample with four chiralities (6,5), (7,5), (8,4) and (7,6) at 0, 86.6, and 105.9 T. Markers indicate the peak positions of exciton absorption.

4 Conclusions

Magneto-absorption measurements in the NIR region between 0.9 and 1.7 μm have become available at high magnetic fields above 100 T for the first time. The developed experimental system enables one to obtain nearly noiseless and well-resolved absorption spectra, and is promising for the study of physical properties of materials for optical devices in the NIR region.

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References

1. N. Miura, *Physica B* **201**, 40 (1994)
2. N. Miura et al., *J. Low. Temp. Phys.* **133**, 139 (2003)
3. H. Yokoi et al., *Phys. Rev. B* **44**, 6519 (1991)
4. N. Miura et al., *Physica B* **256-258**, 308 (1998)
5. K. Nakao et al., *J. Phys. E: Sci. Instrum.* **18**, 1018 (1985)
6. S. Takeyama et al., *J. Phys. E: Sci. Instrum.* **21**, 1025 (1988)
7. Y. Kim et al., *Appl. Phys. Lett.* **86**, 073103 (2005)
8. H. Yokoi et al., to be published elsewhere