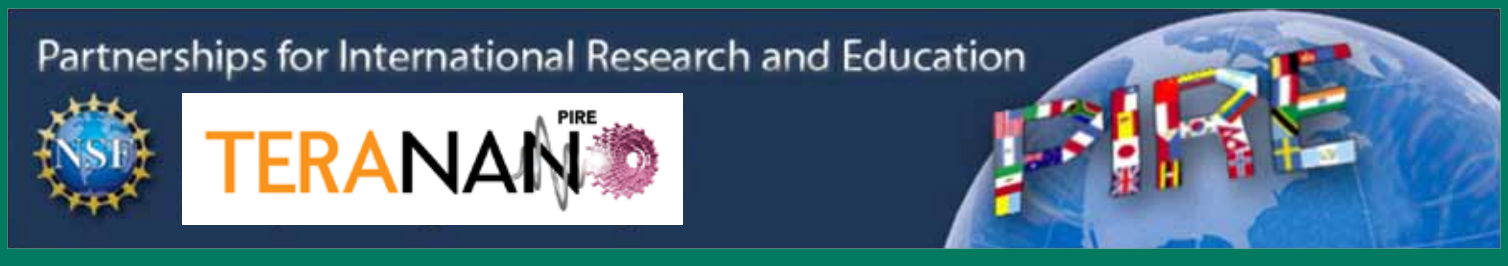
PIRE

TERANANO

Kick-Off Meeting

October 7 - 8, 2011 ~ Rice University ~ Houston, TX USA




Partnerships for International Research and Education
NSF
TERANANO
PIRE
PIRE

4 / Welcome Statement

Welcome to the TeraNano PIRE Kick-Off Meeting! We are honored that so many of our distinguished colleagues from the U.S., Japan, and Europe have been able to join us for this meeting.

Headquartered at Rice University, the TeraNano PIRE Center is a renewal award through the National Science Foundation's Partnerships for International Research and Education (PIRE) Program (OISE-0968405). This grant is a continuation of our successful PIRE I award (OISE-0530220) that has supported our research and education programs since 2006. Our renewal grant supports the expansion of a unique interdisciplinary U.S.-Japan research and education partnership focused on terahertz (THz) dynamics in nanostructures (TeraNano). By combining THz technology and nanotechnology, we can advance our understanding of THz physics while improving and developing THz devices. New discoveries provide insight into the possibilities for novel electronic, photonic, mechanical, and magnetic devices that have huge potential for future technological applications including communications, medicine and computation.

This unique U.S.-Japan research and educational exchange brings together leading researchers in the THz fields and experts in the field of international education and exchange. The U.S. and Japan are global leaders in both THz research and nanotechnology, and stimulating cooperation is critical to further advance THz science and develop commercial products from new ideas in the lab. However, obstacles exist for international collaboration - primarily linguistic and cultural barriers - and this PIRE project aims to continue breaking down these barriers. The project will also leverage large investments by both countries to achieve long-term scientific and societal impact by providing future generations of researchers with a better understanding of both the culture and the state-of-the-art technology in each country.

The TeraNano PIRE Kick-Off Meeting will bring together the majority of our U.S. and Japanese research professors and many of their students. The sessions will focus on the research and educational goals and objectives for the five-year term of this grant (2011 – 2015). In addition to invited talks and tutorials, our agenda will also include a poster session highlighting key aspects of our research collaborations and the NanoJapan: International Research Experience for Undergraduates Program.

Some owls made a very "wise" decision when they chose a place to make their nest – right on the Rice University campus! Not only is the university's mascot an owl, but owls are included in the school's academic seal as symbols of wisdom. Rice University photographer Tommy LaVergne shot photos of three baby owls born on the university's forested campus in June 2011.

The owls are Rufous Morphs owls – also called Texas Orange Screech owls – and are typically found in East Texas, but the people at Rice are glad the owls have chosen to reside on campus.

TeraNano PIRE PI & Co-PIs / 5

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In March of 2011 Rice University dedicated Brockman Hall for Physics, Rice's new state-of-the-art home for fundamental and applied physics research. Rice University President David Leebron stated, "Brockman Hall enhances Rice's status as one of the nation's premier research universities, and it ensures that Rice will remain a leader in fundamental and applied physics research for years to come. The impact of Brockman Hall goes beyond bricks and mortar. This facility forges new pathways between science and engineering, between theory and practice and between Rice's first and second centuries." Brockman is now home to dozens of experimental, theoretical and applied physicists from Rice's departments of Physics and Astronomy and of Electrical and Computer Engineering and supports research in atomic, molecular and optical physics; biophysics; condensed matter physics; nanoengineering and photonics.

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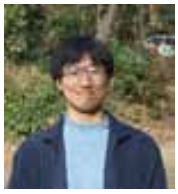

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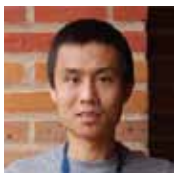

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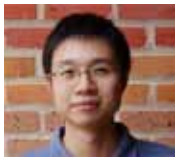

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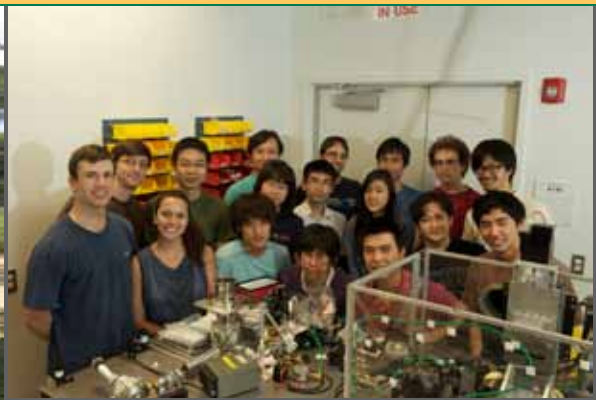
TeraNano PIRE Kick-off Meeting Schedule

19



Friday, October 7, 2011

Joint Session - 9:00 to 11:00
Rice Memorial Center, Grand Hall
Building 62 on Campus Map

TeraNano Poster Session - 11:00 to 1:00
Lunch Provided
Rice Memorial Center, Grand Hall
Building 62 on Campus Map

Research Session - 1:00 to 5:30
Keck Hall, Room 102
Building 41 on Campus Map

Education Session - 1:00 to 5:30
Keck Hall, Room 101
Building 41 on Campus Map

Evening Outing - 6:00 to 10:00
Treebeard's Restaurant, Downtown Houston
Shuttle Service Provided

Saturday, October 8, 2011

Research Tutorial - 8:45 to 12:00
Brockman Hall, Room 101
Building 10 on Campus Map

Education Team Working Session - 9:00 to 12:00
Brockman Hall, Room 300
Building 10 on Campus Map

Joint Lunch - 12:00 to 1:00
Brockman Hall Portico (Outside)

Optional Lab Tours - 1:00 to 2:30

Research Breakout Session - 2:30 to 5:00
Brockman Hall, Room 101
Building 10 on Campus Map

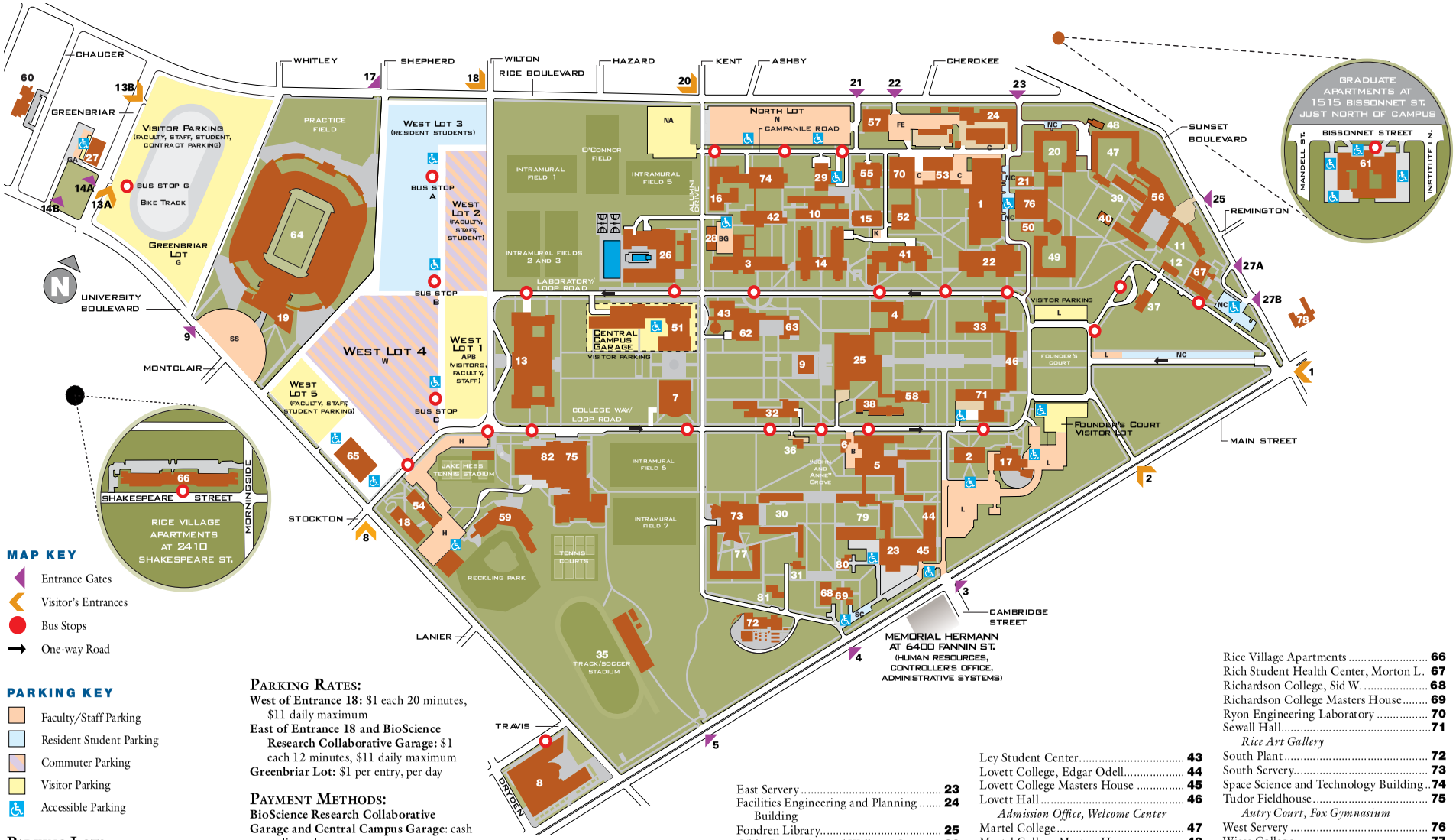
Education Team Working Session - 1:00 to 2:00
Brockman Hall, Room 300
Building 10 on Campus Map

Optional NASA Outing - 2:30 to 6:30
Shuttle Departs Rice and Returns to Hotel

EVENING FREE - ENJOY HOUSTON!

Rice University Campus Map

6/2011



MAP KEY

- Entrance Gates
- Visitor's Entrances
- Bus Stops
- One-way Road

PARKING KEY

- Faculty/Staff Parking
- Resident Student Parking
- Commuter Parking
- Visitor Parking
- Accessible Parking

Parking Lots:

APB Alice Pratt Brown Hall Lot
B Baker College–Housing & Dining Lot
BG Biology–Geology Lot
BRC BioScience Research Collaborative Garage
C Campanile Lot
CG Central Campus Garage
FE Facilities, Engineering and Planning Lot
G Greenbriar Lot
GA Greenbriar Annex
H Hess Court Lot
K Keck Lot
L Lovett Lot
N North Lot
NA North Annex Lot
NC North Colleges Residents Lot
SC South Colleges Residents Lot
SS South Stadium Lot
W West Lot

Parking Rates:

West of Entrance 18: $1 each 20 minutes, $11 daily maximum
East of Entrance 18 and BioScience Research Collaborative Garage: $1 each 12 minutes, $11 daily maximum
Greenbriar Lot: $1 per entry, per day

Payment Methods:

BioScience Research Collaborative Garage and Central Campus Garage: cash or credit card
Greenbriar Lot, Founder's Court, North and West Lots Visitor Section: credit card

BUILDINGS

ACADEMIC SCHOOLS

Friday, October 7, 2011	
8:15 - 8:45	**Rice Shuttle Departs Hotel Lobby for Rice University** *If you miss the shuttle then you will need to take a taxi to Rice University.*
8:45 - 9:00	**Breakfast, Grand Hall, Rice Memorial Center, Bldg. 62 on campus map**
Morning Joint Sessions - Grand Hall, Rice Memorial Center, Bldg. 62 on campus map	
9:00 - 9:15	**Welcome Remarks & Overview of TeraNano PIRE** *Junichiro Kono, Professor, Departments of Electrical & Computer Engineering and Physics & Astronomy, Rice University* *TeraNano PIRE Principal Investigator & Director*
9:15 - 9:30	**Partnerships for International Research and Education (PIRE)** *R. Clive Woods, Japan Program Director* *Office of International Science and Engineering, National Science Foundation*
9:30 - 9:45	**TeraNano PIRE Education Program Overview** *Cheryl A. Matherly, Associate Dean for Global Education, University of Tulsa* *PIRE co-Principal Investigator & Executive Committee Member - Education*
9:45 - 10:00	**U.S.-Japan-Germany TeraNano Collaborations via NSF-PIRE, JSPS & DFG** *Professor, Institute of Laser Engineering, Osaka University* *TeraNano PIRE Research Director, Japan*
10:00 - 10:15	**JSPS's Activities to Support International Research Collaborations** *Fumiyo Kaneko, Deputy Director* *Japan Society for the Promotion of Science (JSPS), Washington, D.C.*
10:15 - 10:30	**JST's Overview** *Takashi Ohama, Director* *Japan Science and Technology Agency, Washington DC Office*
10:30 - 11:00	**BREAK**

Friday, October 7, 2011

Poster Session & Lunch - Grand Hall, Rice Memorial Center, Bldg. 62 on campus map

Planned Presenters and Poster Titles

1. Layla Booshehri (Rice, Kono Lab) - "Simultaneous Observation of Electron and Hole Cyclotron Rseonance in Graphene in the Magnetic Quantum Limit"
2. Kevin Chu (Rice, NanoJapan 2010) - "Chemical Vapor Deposition Synthesis of Graphene from Alcohol"
3. Matthew Diasio (Rice, NanoJapan 2010) - "Fabrication and Characterization of Carbon Nanotube Field-Effect Transistors"
4. Dr. Erik Einarsson (U of Tokyo, Maruyama Lab) - "Diameter-Dependent Separation of Single-Walled Carbon Nanotubes by Density Gradient Ultracentrifugation"
5. Sujoy Ghosh (SIUC, Talapatra Lab) - "Investigation of Electrochemical Gate Controlled Charge Transport in Large Area Boron-Nitrogen Doped Graphene"
6. Ken Hackenberg (Rice, Ajayan Lab) - "Atomic Layers of Patterned Graphene with Boron Nitride and Nitrogen Enriched Boron Nitride"
7. Erik Haroz (Rice, Kono Lab) - "Enrichment of Armchair Carbon Nanotubes via Density Gradient Ultracentrifugation: Resonant Raman Population Mapping"
8. Dr. Hideki Hirori (Kyoto Univ., IICMS) - "THz Pulse Induced Photoluminescence from GaAs Multiple Quantum Wells"
9. Dr. Iwao Hosako (NICT) - "Terahertz Stand-Off Video Rate Imaging Through Hot Carbon Aerosol (Smoke)"
10. Dr. Yasutaka Imanaka (NIMS) - "Cyclotron Resonance in InGaAs/InAlAs Two-Dimensional Rashba Systems"
11. Ryosuke Kaneko (Osaka Univ., Tonouchi Lab) - "THz Difference Frequency Generation From DASC AND DAST Using a CR:Forsterite Laser"
12. Dr. Ji-hee Kim (Rice, Kono Lab) - "Observation of Cohherent Phonons in Single-Walled Carbon Nanotubes and Graphene"
13. Ryuhei Kinjo (Osaka Univ., Tonouchi Lab) - "Anisotropy of Optical Conductivity of SrRuO3 Thin Films Observed by Terahertz Time-Domain Spectrocopy"
14. Yinbin Ma (Rice, Imambekov Lab) - "Magneto-Raman Spectra Due To Inter-Landau-Level Transitions In Graphite"
15. Claire McTaggart (UCSB, NanoJapan 2009) - "Growth, Fabrication and Characterization of Carbon Nanotube Based Field Effect Transistors"
16. Darius Morris (Rice, Kono Lab) - "Third Harmonic Generation in Highly Aligned Carbon Nanotubes"
17. Baleeswaraiah Muchharla (SIUC, Talapatra Lab) - "Tuning the Electrical Properties of Large Area Grahene Through Boron-Nitrogen Co-Doping"
18. Yu Mukai (Kyoto Univ., Solid State Spectroscopy) - "Terahertz Field Ionization of Accepters in p-Ge"
19. Marcus Najera (NanoJapan 2010, UTSA) - "Integration of ZnO Nanorod Biosensor with Field-Effect Transistor"
20. G. Tim Noe (Rice, Kono Lab) and Jean Leotin (Laboratoire National des Champs Magnétiques Intenses) - "Demonstration of Giant Faraday Rotation in Terbium Glass Using a Table-Top Pulsed Magnet"
21. Dr. Sebastien Nanot (Rice, Kono Lab) - "Ultra-broadband Photodetectors Based on Macroscopicallyg-Aligned Ultra-Long Single-Walled Carbon Nanotubes"
22. Dr. Yasuhide Ohno (Osaka Univ., ISIR - Matsumoto Lab) - "Chemical and Biological Sensors Using Graphene Field-Effect Transistors"
23. Satoshi Okuda (Osaka Univ., ISIR - Matsumoto Lab) - "Label-Free Immunosensors Using Horizontally Aligned Carbon Nanotubes"
24. Lei Ren (Rice, Kono Lab) - "Terahertz Conductivity of Low-Dimensional Carbon Nanostructures"
25. William Rice (Rice, Kono Lab) - "Time-Resolved Photoluminescence Quenching in Quantum Wells Using a Terahertz Free-Electron Laser"
26. Dr. Thomas Searles (Morehouse College, Physics) - "Diameter Dependence of the Magnetic Susceptibility Anistropy in Metallic Carbon Nanotubes"
27. Kazunori Serita (Osaka Univ., Tonouchi Lab) - "Scanning Laser Terahertz Imaging System"
28. Cody Sewell (U of Tulsa, NanoJapan 2010) - "Electron Spin Resonance of Graphite and Graphene"
29. Dr. Eiji Shikoh (Osaka Univ., Shiraishi Lab) - "Bias Dependence of Spin Signals in Graphene and a Novel Magnetic Switching Effect in Fullerene-Cobalt Nanocomposites"
30. Rohini Sigireddi (Rice, NanoJapan 2011) - "Quantitative Dark-Field Microscopy of Gold Nanoshells in Cells"
31. Kirby Smithe (U of Tulsa, NanoJapan 2010) - "Characterization of Phosphorus Deposition onto Silicon (111) 7x7 Nanostructures for Applications in Quantum Computing"
32. Prof. Saikat Talapatra (SIUC) - "Synthesis and Characterization of Carbon Nanotubes Produced from Thermal Decomposition of Nickellocene"
33. Shuntaro Tani (Kyoto Univ., Tanaka Lab) - "Terahertz-wave induced near-infrared transparency in Graphene"
34. Theerapol Thurakitseree (U of Tokyo, Maryuama-Shiomi Lab) - "Toward the Realization of Narrow Diameter Distribution in As-Grown Single-Walled Carbon Nanotubes"
35. Dr. Xuan Wang (Rice, Kono Lab) - "Transport Study of Carbon Nanotube Networks with Different Ratios of Semiconducting and Metallic Nanotubes"
36. Takayuki Watanabe (Tohoku Univ., Otsuji Lab) - "Excitation of Terahertz 2D-Plasmon Modes in a Graphene Ribbon Array"
37. Joseph Vento (Rice, NanoJapan 2011) - "Ultra-High Surface Area Single and Multi-Walled Carbon Nanotube 3-Dimensional Hybrid Structure"
38. Qi Zhang (Rice, Kono Lab) - "Origin of the Terahertz Absorption Peak in Single-Walled Carbon Nanotubes"

Friday, October 7, 2011	
Afternoon Research Sessions - Keck Hall, Room 102 (Bldg. 41 on campus map)	
Research I - Session Chair: Christopher J. Stanton, University of Florida	
1:00 - 1:30	**Synthesis and Characterization of Graphene and Boron Nitride Layers and their Hybrids** *Pulickel M. Ajayan, co-PI, Rice University, U.S.*
1:30 - 2:00	**Coherent Phonon Spectroscopy of Single-Wall Carbon Nanotubes** *Riichiro Saito, Department of Physics, Tohoku University, Japan*
2:00 - 2:30	**Terahertz Optics of Carbon-Based and Semiconductor Nanostructures** *Alexey A. Belyanin, Sr. Personnel, Texas A&M University, U.S.*
2:30 - 3:00	**Terahertz Sensing and Imaging with Carbon Nanotubes and Graphene** *Yukio Kawano, Tokyo Institute of Technology, Japan*
3:00 - 3:30	**COFFEE BREAK**
Research II - Session Chair: Alexey A. Belyanin, Texas A&M University	
3:30 - 4:00	**Ericson Oscillations in Graphene** *Jonathan P. Bird, co-PI, SUNY Buffalo, U.S.*
4:00 - 4:30	**Coherent Terahertz Magneto-spectroscopy of Quantum Hall Systems** *Takashi Arikawa, Kyoto University, Japan*
4:30 - 5:00	**Phonon and Noise Spectroscopy of Graphene** *Christopher J. Stanton, co-PI, University of Florida, U.S.*
5:00 - 5:30	**Toward the Creation of Terahertz Graphene Injection Lasers** *Victor Ryzhii, CNEL, University of Aizu, Japan, Maxim Ryzhii, CNEL, University of Aizu, Japan, Vladimir V. Mitin, Dept. E.E., University at Buffalo, SUNY, USA, and Taiichi Otsuji, RIEC, Tohoku University, Japan*

Friday, October 7, 2011	
Afternoon Sessions: Education - Keck Hall, Room 101 (Bldg. 41 on campus map)	
Session Chair: Cheryl A. Matherly, University of Tulsa	
1:00 - 1:30	**Education Team Meeting with Brian Whalen**
2:00 - 3:00	**NanoJapan Student Panel** *Moderator: Cheryl A. Matherly, University of Tulsa* *Panelists: Kevin Chu (NJ 2010), Matthew Diasio (NJ 2010), Michelle Jin (NJ 2009), Ryosuke Kaneko (NJ - U.S. 2011), Georgia Lagoudas (NJ 2010), Claire McTaggart (NJ 2009), Marcus Najera (NJ 2010), Clare Ouyang (NJ 2008), Cody Sewell (NJ 2010), Rohini Sigireddi (NJ - U.S 2011), Kirby Smithe (NJ 2010), Theerapol "Zun" Thurakitseree (NJ - U.S. 2011)*
3:00 - 3:30	**COFFEE BREAK**
3:30 - 4:00	**Learning Objectives & Assessment of NanoJapan - U.S. 2011 Program** *Cheryl A. Matherly, University of Tulsa and Sarah R. Phillips, Rice University*
4:00 - 4:30	**Overview of NanoJapan Japanese Lanugage Program** *Mitsuaki Shimojo, University at Buffalo (SUNY)*
4:30 - 5:00	**Internship Programs by the Center for Engineering Education and Development (CEED) and the Educational Effects** *Kozo Yoshikawa, Center for Engineering Education & Development, Hokkaido University* *Sarah Phillips, TeraNano PIRE Education & Int'l Initiatives Manager, Rice University*
5:00 - 5:30	**Open Discussion**
Evening Outing to Treebeard's in Downtown Houston - Open to All Attendees	
5:45	**Shuttles Depart Rice** *PIck-up along Campanile Rd. Behind Hamman Hall/Brockman Hall*
6:30 - 9:00	**Dinner - Treebeards Restaurant** *315 Travis St., Houston, TX ~ (713) 228-2622*
9:00	**Large Bus Returns to Rice University and Continues on to Crowne Plaza Hotel Reliant Park** *Attendees can opt to stay later and enjoy Downtown Houston on their own. For transportation back to the hotel you can call the hotel shuttle, (713) 748-3221, take a taxi, or you can take the Southbound Houston Metrorail Line to the Reliant Park stop and walk approximately 1 mile back to the hotel. See map on pg. 74 and dining/entertainment recommendations starting on pg. 75.*

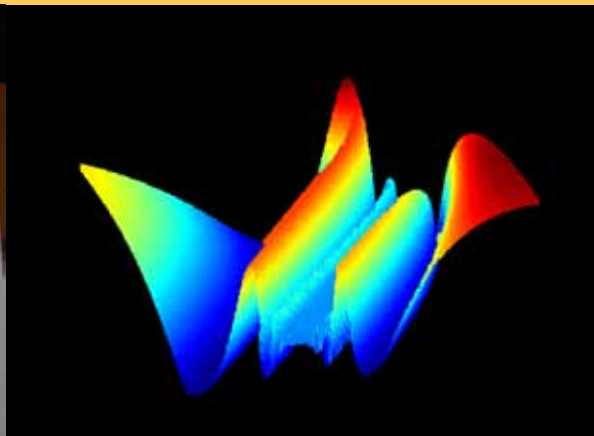
Saturday, October 8, 2011 - Research	
6:30 - 8:00	**Breakfast Available at Crowne Plaza - Reliant Park** *TeraNano PIRE will cover the cost of breakfast for those staying at the hotel. Provide your name and room number to the server and the cost will be billed to Rice.*
8:15	**Rice Shuttle Departs Hotel Lobby for Rice University** *If you miss the shuttle you will need to take a taxi to Rice University.*
Morning Research Tutorial - Brockman Hall, Room 101 (Bldg. 10 on campus map)	
Session I Chair: Saikat Talapatra, Southern Illinos University, Carbondale	
8:45 - 9:30	**Synthesis, Characterization, and Applications of Carbon Nanotubes** *Prof. Morinobu Endo, Faculty of Engineering, Shinshu University, Japan*
9:30 - 10:15	**Intersubband Transitions and Quantum Cascade Lasers** *Prof. Manfred Helm, Forschungszentrum Dresden-Rossendorf, Germany*
10:15 - 10:30	**COFFEE BREAK**
Session II Chair: Jonathan P. Bird, University at Buffalo (SUNY)	
10:30 - 11:15	**Probing Terahertz Dynamics at High Magnetic Fields** *Prof. Jean Léotin, Laboratoire National des Champs Magnétiques Intenses de Toulouse (LNCMI-T), France*
11:15 - 12:00	**Physics with Broadband and Intense Terahertz Pulses** *Prof. Rupert Huber, Department of Physics, University of Regensburg, Germany*
12:00 - 1:00	**LUNCH**
Research Lab Tours - Optional - Open to All	
1:00 - 2:30	*Sign up for your preferred tour during lunch. See pg. 60 for lab overviews. Tours will be led by Kono Group members and will depart from outside Brockman Hall. Each lab visit will take approximately 20 - 25 minutes with three labs per tour. You will return to Brockman Hall at the end of your tour.* • *Tour 1: Kono Lab (Abercrombie), Ajayan Lab, Du Lab* • *Tour 2: Du Lab, Kono Lab (Brockman), Mittleman Lab* • *Tour 3: Ajayan Lab, Mittleman Lab, Kono Lab (Brockman)* • *Tour 4: Kono Lab (Brockman), Kono Lab (Abercrombie), Ajayan Lab* • *Tour 5: Mittleman Lab, Du Lab, Kono Lab (Abercrombie)*
2:30	**Hotel Shuttle Departs for Crowne Plaza Reliant Park Hotel** *Pick-up Behind Hamman Hall/Brockman Hall*

Saturday, October 8, 2011 - Research	
Afternoon Research Breakout Sessions for Professors & Researchers Brockman Hall, Rooms 101 & 103 (Bldg. 10 on campus map)	
Breakout Session I	
2:30 - 3:00	• **I-A: Jonathan Bird (discussion leader), Masayoshi Tonouchi, Erik Einarsson, Yukio Kawano** • **I-B: Robert Vajtai (discussion leader), Yuichi Ochiai, Iwao Hosako, Eiji Shikoh** • **I-C: Alexey Belyanin (discussion leader), Rui-Rui Du, Kazuhisa Sueoka, Akinori Umeno** • **I-D: Pulickel Ajayan (discussion leader), Junichiro Kono, Yasutaka Imanaka, Tetsuo Ogawa** • **I-E: Christopher Stanton (discussion leader), Saikat Talapatra, Yasuhide Ohno, Taiichi Otsuji**
3:00 - 3:30	**COFFEE BREAK**
Breakout Session II	
3:30 - 5:00	• **II-A: Yuichi Ochiai (discussion leader), Jonathan Bird, Akinori Umeno, Robert Vajtai** • **II-B: Masayoshi Tonouchi (discussion leader), Rui-Rui Du, Yasutaka Imanaka, Kazuhisa Sueoka** • **II-C: Saikat Talapatra (discussion leader), Alexey Belyanin, Iwao Hosako, Tetsuo Ogawa** • **II-D: Taiichi Otsuji (discussion leader), Pulickel Ajayan, Yukio Kawano, Yasuhide Ohno** • **II-E: Junichiro Kono (discussion leader), Christopher Stanton, Eiji Shikoh, Erik Einarsson**
5:15	**Hotel Shuttle Departs for Crowne Plaza Reliant Park Hotel** *Pick-up Behind Hamman Hall/Brockman Hall*
Optional Afternoon Outing to NASA for Students, Post-docs, and Other Guests	
2:30	**Shuttle Departs Rice University from Front of Brockman Hall** *Shuttle Driver: Sandra Lopez (832) 630-3033*
3:30 - 5:30	**NASA Space Center Houston** *Estimated cost $25 for transportation and admission.* *Registered Attendees (24): Kevin Chu, Matthew Diasio, Rupert Huber, Michelle Jin, Ryuhei Kinji, Jeff Lee, Jean Leotin, Claire Mctaggart, Yu Mukai, Marcus Najera, Andres Novoa, Satoshi Okuda, Keiko Packard, Sarah Phillips, Lei Ren (+3), Kazunori Serita, Kirby Smithe, Shuntaro Tani, Zun Thurakitseree, Kozo Yoshikawa, Qi Zhang*
5:30	**Shuttle Departs for Houston** *First drop-off at Crowne Plaza Reliant Park Hotel at approximately 6:30. Shuttle will depart hotel at 6:45 for transportation to Prof. Kono's home for invited guests.*
Evening	**Free - Dinner on Your Own - Enjoy Houston!** *For transportation back to the hotel you can call the hotel shuttle, (713) 748-3221, take a taxi, or you can take the Southbound Houston Metrorail Line to the Reliant Park stop and walk approximately 1 mile back to the hotel. See map on pg. 74 and dining/entertainment recommendations starting on pg. 75.*

Saturday, October 8, 2011 - Education	
	Breakfast at Crowne Plaza - Reliant Park *TeraNano PIRE will cover the cost of breakfast for those staying at the hotel. Provide your name and room number to the server and the cost will be billed to Rice.*
8:45	**Meet Cheryl in Lobby to Depart for Rice**
Afternoon Education Working Sessions Brockman Hall, Rooms 300 (Bldg. 10 on campus map)	
Attendees: Cheryl Matherly, Keiko Packard, Sarah Phillips, Mitsuaki Shimojo **Lunch served at 12:00**	
9:00 - 2:00	• **Evaluation of NanoJapan 2011 U.S. Program (Reverse NanoJapan)** • **Discussion of Possible Continuation of Reverse NanoJapan Progam- Tentative** • **Review & Discussion of Japanese Distance Learning Program** • **Revisions to Career and Cultural Education Activities** • **NanoJapan Emergency Response Protocol** • **Frontiers Journal Article** • **Team Logistics**
Afternoon	**Return to Crowne Plaza Reliant Park Hotel OR NASA Trip (See pg. 27)**

Poster Abstracts

29



SIMULTANEOUS OBSERVATION OF ELECTRON AND HOLE CYCLOTRON RESONANCE IN GRAPHENE IN THE MAGNETIC QUANTUM LIMIT

L. G. Booshehri[1,2], C. H. Mielke[2], D. G. Rickel[2], S. A. Crooker[2], Q. Zhang[1], L. Ren[1], E. H. Haroz[1], C. J. Stanton[3], Z. Jin[4], Z. Sun[4], Z. Yan[4], J. M. Tour[4], J. Kono[1,5]
[1]Department of Electrical and Computer Engineering, Rice University, Houston, TX 77005
[2]National High Magnetic Field Laboratory, Los Alamos, NM 87545
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[4]Department of Chemistry, Rice University, Houston, TX 77005
[5]Department of Physics and Astronomy, Rice University, Houston, TX 77005

The unusual band structure of graphene, with unique linear dispersions, has led to the discoveries of a variety of surprising phenomena, primarily in DC transport, in the last several years. Here we report that graphene's AC or infrared properties are also highly unusual. Specifically, we have observed *electron* cyclotron resonance in *p*-type graphene – a non-intuitive phenomenon that is possible only via graphene's unique Landau-level structure. Using ultrahigh magnetic fields up to 170 T, we performed cyclotron resonance (CR) measurements in large-area graphene grown via chemical vapor deposition (CVD) at room temperature. Polarization and wavelength dependence using a tunable CO_2 laser determined the carrier type of doping and the value of the Fermi energy. Polarization-dependent magneto-transmission measurements through the use of circularly-polarized light revealed a strong unintentional *p*-type doping of CVD graphene with a small CR feature at 10 T and a larger CR feature at 65 T that corresponds to the $n = 0$ to $n = -1$ and $n = -1$ to $n = -2$ Landau level (LL) transitions, respectively. Furthermore, wavelength-dependent measurements determined the Fermi energy to be -250 meV. After annealing the graphene samples in vacuum to remove physisorbed molecules, we demonstrate that the Fermi energy can be shifted closer to the Dirac point (-34 meV), resulting in the simultaneous appearance of electron and hole CR in the magnetic quantum limit, i.e., the $n = 0$ to ± 1 transitions, with similar intensities.

CHEMICAL VAPOR DEPOSITION GROWTH OF GRAPHENE FROM ALCOHOL

Kevin Chu[1,2], Bo Hou[2], Xiao Chen[2], Pei Zhao[2], Erik Einarrson[2], Shohei Chiashi[2] and Shigeo Maruyama[2]

1. NanoJapan Program and Department of Electrical & Computer Engineering, Rice University
2. Department of Mechanical Engineering, The University of Tokyo

Previously presumed to not exist as it was speculated to be thermodynamically unstable on a nanoscale, graphene now garners much interest as a new material for the next generation of electronic devices due to its impressive electrical and thermal conductivity as well as its remarkable mechanical properties (strongest tensile strength material as of 2009).

This research project presents a parametric study on the synthesis of graphene, with ethanol and dimethyl ether (DME) as the carbon source, by means of chemical vapor deposition (CVD). The influences of growth time, CVD temperature, CVD pressure are systematically examined. The optimized CVD conditions are found to be around 850~900˚C, 100~500 Pa, along with a growth time of approximately 10 minutes.

In characterizing our samples, Raman spectroscopy and Scanning Electron Microscope (SEM) are used. By looking at both the G-band and the 2D-band of the Raman shift and Raman intensity, we confirm the growth of graphene from alcohol.

Our choice of the two carbon sources mentioned above not only enables the production of pure and homogeneous graphene, but also dramatically cuts the potential prohibitively high production costs, thus allowing this method to be employed for future low cost, high purity and mass production. Further understanding of the growth mechanism can lead to improvements in yield and quality of graphene grown.

FABRICATION AND CHARACTERIZATION OF CARBON NANOTUBE FIELD-EFFECT TRANSISTORS

Matthew Diasio[1,2], H. Gojuki[2], D. Kato[2], T. Ohya[2], A. Subagyo[2], and K. Sueoka[2]
[1] NanoJapan Program and Department of Physics and Astronomy, Rice University
[2] Graduate School of Information Science and Technology, Hokkaido University, Sapporo, Japan

Carbon nanotubes (CNTs) have been the subject of much research in nanoscale electronics due to their unique material properties. One emerging area of research is that of CNT field-effect transistors (CNTFETs), where their ability to efficiently conduct charge on molecular scales could lead to new computing technologies. Currently, CNTFET charge conduction is limited by the uncontrollable, large resistance of the electrode-CNT junction. Using an 'end-contact' geometry, we investigate the effect of different electrode materials on the performance of the transistor. An end-contact set-up was chosen as the direct line-up of the end of the CNT to the electrode allows for more efficient charge carrier conduction across the junction than typical arrangements where the CNT is placed along the side of the electrode and there are few direct bonds. We fabricated CNTFETs with electrodes using metals with different work functions, one of the main factors that determine the behavior of the electrode-CNT junction. We evaluated the current-voltage characteristics of the CNTFETs at different temperatures. The weak spin-orbit coupling of CNTs also means that CNTFETs should be able to preserve spin polarization of injected carriers, allowing for spintronic applications of CNTFETs. We briefly look at how electrode material affects the spin injection efficiency and spin coherence length of CNTFETs.

DIAMETER-DEPENDENT SEPARATION OF SINGLE-WALLED CARBON NANOTUBES BY DENSITY GRADIENT ULTRACENTRIFUGATION

Pei Zhao[1], Erik Einarsson[1,2], Georgia Lagoudas[3], Shohei Chiashi[1], Junichiro Shiomi[1], Shigeo Maruyama[1]
[1]Department of Mechanical Engineering, The University of Tokyo, Tokyo, Japan
[2]Global Center of Excellence for Mechanical Systems Innovation, The University of Tokyo, Tokyo, Japan
[3]Department of Bioengineering, Rice University, Houston, TX, U.S.A.

We present a protocol to selectively isolate single-walled carbon nanotubes (SWNTs) using density gradient ultracentrifugation (DGU). SWNTs synthesized by the alcohol catalytic chemical vapor deposition (ACCVD) method were dispersed using *sodium deoxycholate* (DOC) and *sodium dodecyl sulfate* (SDS) as co-surfactant encapsulating agents. By changing the order in which surfactants were added and their respective concentrations we were able to separate the dispersed SWNTs into several colored layers. Each successive layer was found to contain SWNTs of increasing diameter, with the topmost violet layer containing more than 95% (6,5) SWNTs. Spectroscopic methods including optical absorbance, photoluminescence excitation (PLE), and resonance Raman spectroscopy were used to characterize the SWNTs before, during, and after DGU. These measurements helped clarify the sequence of events leading to the resulting diameter-dependent dispersion as well as the role of each surfactant in the DGU process. We expect this improved understanding will be helpful in obtaining higher purity extractions of single-chirality SWNTs.

INVESTIGATION OF ELECTROCHEMICAL GATE CONTROLLED CHARGE TRANSPORT IN LARGE AREA BORON-NITROGEN DOPED GRAPHENE

S. Ghosh[1], S. Kar[2], Z. Liu[3], R. Vajtai[3], P. M. Ajayan[3], S. Talapatra[1]

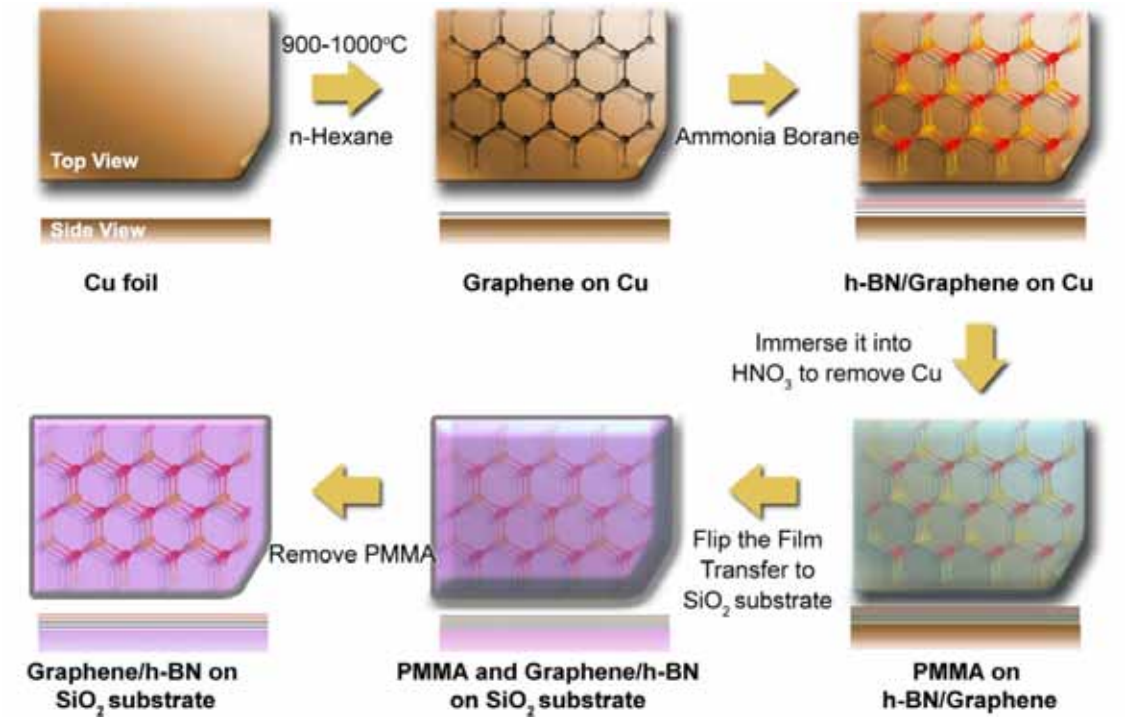
[1]Department of Physics, Southern Illinois University Carbondale, IL-62901
[2]Department of Physics, Northeastern University, Boston, MA-02115
[3]Department of Mechanical Engineering & Materials Science, Rice Univ., Houston, TX-77054

We report on the investigation of charge transport measurements of B and N doped graphene C (B,N) under the influence of an electrochemical gate. These C (B,N) systems are expected to have unique electronic properties due to the combination of impurities including both atomistically separated B and N species, as well as hexagonal boron nitride (*h*-BN) units within the graphitic C lattice. In the past, such measurements focused on micron scale graphene and were able to provide crucial information regarding electron mobility, quantum capacitance etc. In our investigations, we have used large area BN doped graphene in order to investigate the effect of topological disorders, grain boundaries and other substrate-related effects in electrochemical gate driven transport in such samples. Investigations were performed on devices fabricated with different BN doping levels. The electrochemically gate controlled interfacial capacitance and quantum capacitance of BN doped graphene devices were measured. The effect of doping on the quantum capacitance and electron mobility will be discussed.

ATOMIC LAYERS OF PATTERNED GRAPHENE WITH BORON NITRIDE AND NITROGREN ENRICHED BORON NITRIDE

K. Hackenberg, Z. Liu, L. Ma, A. Shi, R. Vajtai, P. Ajayan
Department of Mechanical Engineering & Materials Science, Rice University, Houston, TX, U.S.A

Hybrid graphene and boron nitride atomic layers have received a lot of research attention recently due the interesting electronic properties of graphene as well as the insulating properties of h-BN. Due to their similar 2-D honeycomb lattice structure as well as similar lattice parameter, boron nitride is a key candidate for use in future graphene based electronics. In order to build a 2-D nanostructured device, a few atomic layer graphene film on a copper substrate was patterned by e-beam lithography. The sample was then reacted with ammonia borane in a CVD chamber causing the exposed Cu regions to allow h-BN growth. The figure below shows a schematic of our process.



We have also grown h-BN films from ammonia borane with additional ammonia as a reactant to produce nitrogen enriched h-BN. Samples were analyzed with EELS, Raman spectroscopy, AFM, and TEM.

ENRICHMENT OF ARMCHAIR CARBON NANOTUBES VIA DENSITY GRADIENT ULTRACENTRIFUGATION: RESONANT RAMAN SCATTERING POPULATION MAPPING

E. H. Hároz[1], W. D. Rice[1], B. Y. Lu[1], R. H. Hauge[2], J. G. Duque[3], S. K. Doorn[3], J. Kono[1]

[1]Department of Electrical and Computer Engineering, Rice University
[2]Department of Chemistry, Rice University
[3]Center for Integrated Nanotechnology, Los Alamos National Laboratory

Using resonant Raman scattering spectra collected over a broad range of excitation wavelengths (440-850 nm), we have constructed Raman excitation profiles of the radial breathing mode phonon for each (*n,m*) species present in as-produced and metal-enriched single-walled carbon nanotube ensemble samples. From this, we determine the relative abundances of all metallic and semiconducting chiralities. Strikingly, the data clearly show that our density gradient ultracentrifugation (DGU) process enriches the metal-enriched sample in armchair and near-armchair species. In particular, we observe that armchair carbon nanotubes constitute more than 50% of each metallic ($2n + m$) family and ~70% of the entire metal-enriched sample. Such data combined with absorption and photoluminescence measurements elucidate elements of the mechanism of the DGU metallic type-enrichment process and the importance of surfactant micelle composition. Finally, we compare our measured relative abundances determined from Raman spectroscopy to absorption area estimates to assess the validity of the usage of absorption spectroscopy for determining % metallicity of ensemble nanotube samples.

THz Pulse Induced Photoluminescence from GaAs Multiple Quantum Wells

H. Hirori[1,2], K. Shinokita[2,3], M. Shirai[1,2], S. Tani[2,3], Y. Kadoya[2,4], and K. Tanaka[1,2,3]
[1]Institute for Integrated Cell-Material Sciences, Kyoto University, Kyoto, Japan
[2] Core Research for Evolutional Science and Technology, Japan Science and Technology Agency, Saitama, Japan
[3]Department of Physics, Graduate School of Science, Kyoto University, Kyoto, Japan
[4]Department of Quantum Matter, Hiroshima University, Japan

Carrier multiplication caused by impact ionization scattering plays an important role in the efficient working of photovoltaic nanomaterials, electroluminescent emitters, and highly sensitive photon detectors used in optical quantum information applications. Fundamentally, carrier-initiated impact ionization occurring in strong electric fields critically affects nonequilibrium quantum transport phenomena, but the elementary process of carrier scattering relevant to ballistic transport has not yet been clarified. Here we show that a 1-MVcm^{-1} terahertz pulse (1 THz = 10^{12} Hz), unlike a DC bias, can generate a substantial number of electron-hole pairs forming excitons that emit near-infrared luminescence. The bright luminescence associated with carrier multiplication suggests that the carriers coherently driven by a strong field can efficiently gain enough kinetic energy to induce a series of impact ionizations, which we demonstrate for the first time can increase the number of carriers by about three orders of magnitude on picosecond timescale (1 ps = 10^{-12} s). The carrier increase with an increase in the THz electric field was in agreement with phenomenological theory based on an impact ionization model including an electron motion in *k*-space with a pristine band structure. In the future, to reveal the microscopic origin of the observed carrier multiplication, a full quantum kinetic theory treatment of carrier dynamics in a band structure modified by an intense THz electric field should be performed and our results will spur such effort on. Also, our findings of efficient ultrafast carrier multiplication bode well for future applications in ultrahigh-speed devices such as high-quantum-efficiency THz-biased avalanche photodiodes that have femtosecond resolution and are sensitive to a single photon, and they may also be exploited in the development of efficient electroluminescent and photovoltaic nanoscale devices.

TERAHERTZ STAND-OFF VIDEO RATE IMAGING THROUGH HOT CARBON AEROSOL (SMOKE)

I. Hosako
National Institute of Information and Communications Technology, Tokyo, Japan

Terahertz (THz) imaging is a powerful technique that exploits a nonionizing (i.e., safe) portion of the electromagnetic spectrum located between microwaves and the IR. Directed toward an appropriate sample, such as wood or ceramics, THz light passes through and is detected by a camera. Because of its nondestructive nature, THz imaging is applicable to many areas. For example, it has advantages over x-rays for diagnosis of skin cancer and can detect sketches underlying paintings. The technique is also potentially advantageous in conditions of hot carbon aerosol (hot black smoke), where conventional imaging is unsuitable. Even ordinary smoke is difficult to see through at visible wavelengths, and hot, black smoke saturates and scatters IR radiation. THz wavelengths are absorbed by hot smoke less strongly and transmitted more readily through it, compared with the IR. However, although wellplaced for (bio)materials analysis, THz imaging was until recently considered ill-adapted for hot conditions, limiting its utility in search and rescue missions.

We report a THz video rate imaging system consisting of a quantum-cascade laser light source, and a microbolometer focal-plane array (an IR detector common in thermal cameras). The camera is based on one we previously designed, but with improved power and sensitivity. We describe two applications of our imaging system: stand-off imaging for search and rescue in a fire disaster, and label-free biomaterial detection.

With these technical improvements in place, we performed stand-off (~5m distance) THz-imaging experiments under simulated fire conditions. We were able to obtain images in hot, black smoke (with an SNR of ~140 versus ~6000 with no smoke) that blocked visible light and and induced signal saturation in the long-wavelength IR (LWIR) region. These results clearly show an advantage of THz compared with LWIR or visible imaging. Our camera is particularly adapted to search and rescuemissions due to its 60Hz (real-time) image acquisition rate.

In pharmaceutical drug discovery, molecular interactions are commonly tracked using chemical ‘labels’ that are costly and prone to error. We applied our THz camera to label-free detection of small-molecule reactions with proteins. The THz waves are readily absorbed and enable sensing of very small changes in biomaterials. The detection sensitivity of a label-free biotin-streptavidin reaction (routinely used in biotechnology), for example, was nearly the same as that of conventional methods, and the THz system has the advantage of high throughput and low cost.We note that for real life-science applications, our detection system requires a very large biomaterial spectral database in the THz range.

Acknowledgment
This research was supported by the project of National Institute of Information and Communications Technology; “Research & Development of Terahertz Technologies for Realizing Safety and Security by ICT”. The author is very much grateful to all the members of the above project.

Cyclotron Resonance in InGaAs/InAlAs two-dimensional Rashba systems

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Large zero-field spin splitting has been studied intensively in various semiconductors for realizing novel spintronic applications, such as the spin FET. Among narrow gap semiconductors, an InGaAs system, which has a larger spin-orbit interaction, is one of good candidates for studying the structure induced spin splitting, namely, the Rashba effect. The zero-field spin splitting energy was estimated mostly through the Shubnikov-de Haas oscillation (SdH) measurements. On the other hand, the optical method, such as cyclotron resonance (CR), is also an appropriate method, in particular, to obtain the magnetic field dependence of the spin splitting energy. Because the Zeeman splitting becomes dominant at higher magnetic fields in comparison with the Rashba spin splitting, the CR measurement at a wide range of the frequency range is quite essential to determine the Rashba spin-orbit interaction and the effective g-factor quantitatively.

In this study, we measured the CR in high In-content InGaAs/InAlAs inverted heterostructures at the wide range of a terahertz region by using a millimeter vector network analyzer (MVNA) and a Fourier transform infrared spectrometer. The samples were grown by the molecular beam epitaxy method on semi-insulating GaAs substrates. The SdH oscillation and the quantum Hall plateau are observed at integer filling factor by the high field transport measurements. The carrier concentration and the mobility are obtained as $n \sim 10^{12} cm^{-2}$ and $\mu = 20 m^2/Vs$, respectively.

A single CR peak is observed at the wide frequency region, and the electron effective mass is obtained as $m^* = 0.04 m_0$ from the magnetic field dependence of the resonant frequency. This value is coincident with the previous work in the THz cyclotron resonance with using a FIR laser. In addition, we also found that an additional resonant peak was appeared only at some frequency region. The anomalous two resonant peaks are confirmed by the R-θ analysis of the CR data, and this is probably due to the anti-crossing of different spin levels that are coupled through the large spin-orbit interaction of the InGaAs systems.

OPTICAL AND TERAHERTZ SPECTROSCOPY OF CdSe/ZnS QUANTUM DOTS

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Due to the unique properties of semiconductor quantum dots arising from the confined nature of their electronic states, they have potential applications in many fields, from biological imaging to photovoltaic cells. In this work, we made a polymer film with CdSe/ZnS core/shell quantum dots and characterized their electronic and vibrational properties by optical and terahertz (THz) spectroscopy. THz spectroscopy is also of interest due to the technology gap in the THz region and the ability to measure phase shifts using time delay. With linear THz spectroscopy, we could observe possible carrier transitions of electronic states as well as acoustic phonon excitations in the quantum dots. We measured temperature-dependent photoluminescence from the quantum dots in a polymer film, from 7 K to 300 K, and with excitation by a 532 nm laser. With increasing temperature, the emission peak photon energy decreased, the linewidth increased, and the photoluminescence intensity generally decreased. We then compared the shift of the peak emission wavelength and the change of the full width at half maximum (FWHM) of the emission curve with a previous study [1]. The results were comparatively similar, with discrepancies potentially due to the size of the quantum dots as well as the differences in the film matrix. We further performed linear THz spectroscopy of the film at various temperatures and analyzed the phase shift and amplitude change results. To observe any acoustic phonon effects, we plan to complete a reference experiment using only the polymer film without quantum dots and compare the results. To observe ultrafast dynamics of optically excited carriers, we also plan to perform THz spectroscopy with optical pump on the quantum dots.

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THz DIFFERENCE FREQUENCY GENERATION FROM DASC AND DAST USING A CR:FORSTERITE LASER

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The tunable coherent terahertz (THz) wave source is one of the key devices for THz applications such as frequency domain spectroscopy and multispectral imaging. Recently, THz-wave radiation from nonlinear optical (NLO) crystal via difference frequency generation (DFG) has been extensively studied as a tunable coherent THz–wave source. Especially, 4-dimethylamino-N-methyl-4-stilbazolium tosylate (DAST) and DAST derivative organic NLO crystal, 4-dimethylamino-N-methyl-4-stilbazolium p-chlorobenzenesulfonate (DASC) are of great interest because of their wide tunability and high conversion efficiency. Therefore, it is important to research the details of the THz-DFG from those crystals such as the damage thresholds and the thickness dependences. In this study, we have investigated THz-wave radiation from DASC and DAST crystals via DFG process excited by a Cr:Forsterite laser. As for the results, the frequency ranges of the tunable THz-waves generated from the crystals were 1.8 to 7.5 THz from the 0.5 mm thick DAST crystal and 1.6 to 8.5 THz from the 0.1 mm thick DASC crystal. Considering the thickness of the crystals, the conversion efficiency of the DASC crystal is at least that of DAST crystal. Both crystals were damaged with the irradiation of a high power pump laser and the powers of the THz-wave radiations decreased after the damages. The damage thresholds of the DAST crystal and the DASC crystal were calculated to be 20 J/cm^2 and 27 J/cm^2 from the pump laser energy dependences of the THz-wave energies.

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OBSERVATION OF COHERENT PHONONS IN SINGLE-WALLED CARBON NANOTUBES AND GRAPHENE

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We present a real-time observation of coherent optical phonons in single-walled carbon nanotubes(SWNTs) and graphene. It is important to understand the dynamics of optical phonons in those materials. By using the pump-probe techniques with femtosecond laser pulses, generation and detection of coherent phonons in SWNTs and graphene have been studied. In these graphitic materials the most prominent phonon modes are the so-called G-modes having a 21 fs phonon period. For generation of the high frequency phonon mode, we built up a Ti:sapphire laser with a 12 fs of pulse duration which is shorter than the phonon period. The generation mechanisms of coherent phonons are explained as Impulsive stimulated Raman scattering (ISRS) process. For the detection methods, coherent G-mode phonons in single-walled carbon nanotubes (SWNTs) are investigated through stimulated Stokes and anti-Stokes Raman scattering process by performing spectrum-resolved detection, while coherent G-mode phonons in graphene films are observed by measuring the induced reflectivity changes according to the electro-optic effect.

Since SWNTs are the tubular form, the radial breathing mode (RBM) vibrating in diameter direction is additionally occurred. By analyzing the resonant frequency and resonant energy of the RBM, one can define the diameter and the chirality of the nanotube. It is difficult to investigate a specific chirality in an ensemble SWNT samples. By using a pulse-shaping technique, we have achieved a specific chirality-selective excitation of coherent RBM phonons in ensemble SWNT samples. This gives us to obtain the phase information and the modulation of the absorption in response to the pump pulse.

ANISOTROPY OF OPTICAL CONDUCTIVITY OF $SrRuO_3$ THIN FILMS OBSERVED BY TERAHERTZ TIME-DOMAIN SPECTROSCOPY

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$SrRuO_3$ (SRO) has attracted a great interest since interesting characteristics and capability of application to future functional devices with transition metal oxides that have perovskite or perovskite-like structures. SRO shows quite high electrical conductivity compared with the other oxide materials, and ferromagnetism below about 160 K. Because of these useful characteristics, SRO is expected to be applied to bottom electrodes of oxide devices or spintronics devices.

In this study, we deposited SRO thin films on various substrates by a pulse laser deposition method, and measured electric and optical characteristics of the SRO films in order to observe strain effects. Especially, we measured complex optical constants of the SRO films in a terahertz (THz) frequency region by THz time-domain spectroscopy (THz-TDS) in order to apply SRO to future high-frequency devices that can operate in a THz region.

SRO thin films were deposited on MgO(100), $(LaAlO_3)_{0.3}(SrAl_{0.5}Ta_{0.5}O_3)_{0.7}$ (LSAT)(100), $DyScO_3$ (DSO)(110) substrates. MgO and LSAT have cubic structures, and the lattice constants are 0.4212 nm and 0.3868 nm, respectively. DSO has orthorhombic structure and the lattice constants of $[1\bar{1}0]$ and [001] directions are 0.39457 nm and 0.39435 nm as a pseudocubic, respectively. We confirmed that all the films were good c-axis orientated by X-ray diffraction.

At room temperature, though we could not find any anisotropy for the SRO thin films on MgO and LSAT, large anisotropy was observed for the SRO films on DSO in direct-current(DC) conductivity measurements. DC conductivity of the SRO films on DSO for DSO$[1\bar{1}0]$ direction was 3333 $\Omega^{-1}cm^{-1}$ that was nearly equal to a bulk SRO crystal. However, DC conductivity of the film for DSO[001] direction was 319 $\Omega^{-1}cm^{-1}$ that was about a tithe of that of the DSO$[1\bar{1}0]$ direction.

We also measured optical conductivity of the SRO films in a THz region by THz-TDS at room temperature. Large anisotropy was observed for the SRO film on DSO, while no anisotropy was observed for the SRO films on MgO and LSAT as DC measurements. The frequency dependences of the optical conductivities of all the films were roughly flat in a measurable frequency region, and the values of the optical conductivities of all the films in a gigahertz region approximately corresponded to the value of the DC conductivities of the films. We also measured thickness dependence of the optical conductivities of the SRO films on DSO. The optical conductivity of the 80-nm thickness SRO films for DSO$[1\bar{1}0]$ direction increased as compared with that of the 250-nm and 120-nm thickness SRO films for DSO$[1\bar{1}0]$ direction, though that of all the SRO films for DSO[001] direction had almost the same values.

From these results, such an anisotropic conductivity of the SRO thin films on DSO seems to be due to different amount of strains between $[1\bar{1}0]$ and [001] directions caused by a DSO substrate.

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MAGNETO-RAMAN SPECTRA DUE TO INTER-LANDAU-LEVEL TRANSITIONS IN GRAPHITE

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We analysis the Raman spectroscopy of electronic excitations in graphite, focusing on the temperature dependence of spectral linewidth. In the presence of an external magnetic field parallel to c-axis, in plane motion is quantized into Landau levels, while out of plane motion remains free. Effectively, Landau levels can be treated as one dimensonal bands in graphite, leads to theoretical prediction of von Hove singularity of the spectra at the K point, while experimentally a finite width is observed. From the four bands tight-binding calculation, we find 2 one-dimensional low energy bands crossing the Fermi level with negligible curvature, which makes graphite a candidate for the application of Luttinger liquid (LL) theory. Introducing interaction between excited electron-hole pair and the low energy bands, the von Hove singularity get modified, $(\varepsilon-\Delta)^{-1/2+\beta}$. As the low energy bands are sensitive to temperature, introducing the interaction may give us a possible explanation for the linewidth at finite T. Considering finite temperature behavior of Luttuinger liquid, power law singularity breaks down and the spectra gets broadened with increasing T. According to our model, we predict the linewidth has a linear dependence on temperature.

GROWTH, FABRICATION AND CHARACTERIZATION OF CARBON NANOTUBE BASED FIELD EFFECT TRANSISTORS

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With favorable electrical and optical properties, carbon nanotube (CNT) based field effect transistors (FETs) are a promising area of nano-scale research. Compared to conventional MOSFETs, CNT-FETs can be used to create smaller, higher speed devices. However, due to the lack of precise control over CNT growth and the CNT's sensitivity to adhesive materials on the surface, it has been a difficult task to fabricate CNT-FETs with uniform electrical properties. Our experimental project consists of two parts. The first is to learn the basic micro-fabrication techniques used to make CNT-FETs with single-walled CNT channels. To make these samples, we used p-type silicon wafers with layers of SiO_2. First, spin-coating was used to place two layers of resist on the substrate; the first to improve the bond between the substrate and the photo-resist and to prevent excess material from being deposited on the ends and then a layer of photo-resist. Through positive-type photolithography, the locations of the catalysts were patterned. Next, electron beam deposition was used to add the catalysts for CNT growth. Then, utilizing chemical vapor deposition, CNTs were grown. Following this, electron beam and thermal evaporation thin film deposition were used to place layers of Ti and Au on the substrate for use as electrodes. Finally, via atomic layer deposition, HfO_2 was deposited to add passivation and to decrease the hysteresis on the samples. For our measurement setup, we used a semiconductor parameter analyzer to measure current versus voltage and current versus ground voltage, for both source-drain and gate-drain applied voltages. In the second part of the project we will design CNT-FETs with suspended CNT channels. According to the design, electron beam lithography will be used to make the holes underneath the CNT channels and will be investigating appropriate conditions for the reactive ion etching process to make the hole. Electrical properties of the devices will be investigated in detail.

MID-INFRARED THIRD HARMONIC GENERATION IN HIGHLY-ALIGNED SINGLE-WALLED CARBON NANOTUBES

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Optical properties of carbon nanotubes (CNTs) have been extensively investigated during the last decade, and much basic knowledge has been accumulated on how light emission, scattering, and absorption occur in CNTs. However, their nonlinear optical properties remain largely unexplored. Due to inversion symmetry, the lowest observable nonlinear processes in achiral ('armchair' and 'zig-zag') CNTs are third order processes. In chiral nanotubes, while $\chi^{(2)}$ is finite, the 50%-50% mixture of right-handed and left-handed nanotubes in a typical macroscopic ensemble of CNTs precludes the observations of second-harmonic generation. Here, we have observed third harmonic generation (THG) from samples consisting of highly aligned CNTs on sapphire with linearly-polarized intense mid-infrared femtosecond radiation. A third harmonic signal was not measured from the sapphire substrate, thus the induced third harmonic signal is generated in the highly aligned CNT sample. Through polarization-dependent third harmonic generation experiments, the nonzero tensor elements of $\chi^{(3)}$ have been extracted. The contribution of the weaker tensor elements to the overall $\chi^{(3)}$ signal has also been calculated to be approximately 1/3 of that of the dominant $\chi^{(3)}_{zzzz}$ component, which is consistent with theory and other measured values.

TUNING THE ELECTRICAL PROPERTIES OF LARGE AREA GRAPHENE THROUGH BORON-NITROGEN CO-DOPING

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The effect of impurities on the physical properties of materials with an otherwise perfectly crystalline order have intrigued scientist for decades. In this respect, the availability of 2D layered materials such as graphene and the ability to introduce structural imperfections in them through doping has opened up possibilities for studying the consequence of disorder at the atomic level. In this study, we report on investigation of low temperature electrical transport measurements of B and N co-doped graphene layers C(B,N). These systems have a unique combination of impurities including both atomistically separated B and N species, as well as hexagonal boron nitride (*h*-BN) units within the graphitic C lattice. Despite its graphene-like lattice structure, *h*-BN is a wide band-gap material (>4.5 eV) due to a breakdown in its sublattice mirror symmetry. Hence, asymmetrically co-doped C(B,N) with $n_B \neq n_N$, is a unique combination of impurity doping and alloy formation within a 2D confined geometry. Earlier, the presence of *h*-BN it has been shown to open up a band gap in the otherwise gap-less graphene. In this work, we present a detailed investigation of the temperature dependence of transport in asymmetrically co-doped C(B,N). We find that the temperature dependence of resistance ($5K < T < 400$ K) of pure graphene shows a metallic behavior, whereas the C(B,N) samples show an increasingly semiconducting behavior with increasing doping levels. The temperature dependence of these samples could be approximately classified into two regimes. Within the studied range, at higher temperatures, the doped samples showed a band-gap dominated Arrhenius-like temperature dependence. At the lowest temperatures, the temperature dependence deviates from an activated behavior, and presents evidence for a conduction mechanism that is consistent with Mott's 2D-Variable Range Hopping (2D-VRH).

TERAHERTZ FIELD IONIZATION OF ACCEPTERS IN p-Ge

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The ultrafast control of bound carriers is of great interest for switching of conductivity and magnetic properties. In many cases, bound electrons (holes) at the shallow trap have narrow absorption lines in THz region and thus should be a candidate for the quantum control devices. Recently, coherent control of the donor transition has been reported in the n-type Si:P system with THz pulses from the free electron laser. However, such a high electric field of the THz pulse is potentially capable to undergo field-ionization of the bound carriers, which is inadequate for the coherent control. We demonstrate THz field ionization process in p-Ge induced by intense THz pulse.

We measured absorption spectra of the p-Ge crystal with different incident THz electric fields. Intense THz pulses were generated by a tilted pulse-front optical pulse with a high-$\chi^{(2)}$ $LiNbO_3$ crystal. A Ga-doped p-Ge crystal (resistivity: 2.67-4.46 ohm cm, thickness: 500 μm) was mounted in the liquid-He cryostat and cooled down to 9K. THz electric field was in parallel with [100] direction of the crystal.

In the low field strength limit, one can see clearly two accepter transitions around 2 THz. These two lines are attributed to (8+0)→(8-02) transition for 2.0 THz peak and (8+0)→(7-0) transition for 2.2 THz peak, respectively. Around 5kV/cm, broadening of both lines is observed. This result suggests that the excited state of the accepter level becomes unstable under the THz electric field larger than 5 kV/cm because of the tunneling ionization in the excited state. Above 15 kV/cm, both transitions are disappeared and Drude-like dispersion appears. This suggests that the accepter level should be completely ionized above 15 kV/cm and generated free carriers become responsible for the Drude dispersion. Since our THz pulse is almost half-cycle in time domain, the THz-field ionization should take place in very short time scale faster than 1 ps.

INTEGRATION OF ZnO NANOROD BIOSENSOR WITH FIELD-EFFECT TRANSITOR

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Recent technological advances in fabrication of novel hybridized semiconductors and inorganic nanomaterials may provide the tools necessary to immobilize bio-molecules such as enzymes. The objective of this research is to combine extended-gate field-effect transistors (EG-FET's) to prior research utilizing high aspect ratios of ZnO nanorods (NR's) to achieve a high surface area for glucose immobilization. EG-FETs provide a useful mechanism by aiding in sensitivity and utilizing energy more efficiently. The method is carried out by means of electron-beam deposition; titanium is deposited on Si (001) substrate in a 20nm layer, followed by gold deposition of 100 nm. A parametric low temperature hydrothermal microwave-irradiated growth of ZnO NRs in (0001) orientation on gold substrate is then followed. At this point the substrate undergoes a characterization process of optical microscopy, alpha-step profiling, x-ray diffraction, and scanning electron microscopy to ensure that proper growth has taken place. The substrate is then attached to a circuit board, with an EG-FET wired to the substrate via soldering. Glucose is then immobilized on the substrate using covalent and electrostatic bonding methods. Measurements can then be carried out using a semi-conductor parameter analyzer to measure the concentration and effect of glucose. Lastly, immobilized ZnO NRs are characterized using x-ray photoelectron spectroscopy to observe that glucose was effectively immobilized.

Demonstration of Giant Faraday Rotation in Terbium Glass Using a Table-Top Pulsed Magnet

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Magneto-optical spectroscopy began with the original experiments of Michael Faraday in 1845. Since then, advances in magnet technology have provided high magnetic fields for optical measurements with a variety of approaches, all of them requiring either liquid helium for superconducting magnets up to 20 T or access to large scale facilities for non-destructive pulsed resistive magnets up to 70 T. Here, we present and demonstrate the operation of a 10-T portable pulsed magnet appropriate for magneto-optics. The magnet and its power supply are readily prepared for an optical table measurement setup. The coil sits in liquid nitrogen in a simple polycarbonate transparent cryostat with horizontal optical access to a bore diameter of 6 mm for the sample. The pulse lasts for 5 ms and can be periodically repeated every 5 s up to 5 T. Given this setup, we demonstrated a giant Faraday rotation in terbium glass referenced as M18 Faraday glass [http://www.kigre.com]. The sample temperature was set at 110 K, and the sample was placed between two parallel polarizers and illuminated by a red laser-pointer beam. We found that the output beam displays a periodic sinusoidal intensity as a function of magnetic field, as $I = I_m(\cos\frac{\pi B}{B_F})^2$. We obtained up to six periods as the magnetic field was swept up and down from 0 to ±5 T. The data evidence a giant Faraday rotation that follows the Malus law ($= I_m \cos\theta^2$), and therefore, the rotation angle is given by the expression $= \frac{\pi B}{B_F}$. On the other hand, since the Faraday angle is proportional to the sample length L, according to the Verdet law, $\theta = CLB$, the material Verdet constant is directly obtained as $C = \frac{\pi}{LB_F}$. Here, L = 1 cm, and thus, the Verdet constant C = 160 rad/Tm. The Verdet constant in this paramagnetic material becomes larger at lower temperatures, exhibiting the Curie law ($\propto 1/T$). Another advantage of the portable setup is the very high signal-to-noise ratios achievable simply by using the repetitive pulsed mode and averaging. In this situation, one does not need to implement modulation techniques. A final and unique advantage of the repetitive mode is to allow a step-scan recording mode of magneto-spectroscopy. This mode of operation provides a three-dimensional plot of spectra as a function of magnetic field. This mode was recently demonstrated in the THz frequency range [IRMMW-THz 2011].

ULTRA-BROADBAND PHOTODETECTORS BASED ON MACROSCOPICALLY-ALIGNED ULTRA-LONG SINGLE-WALLED CARBON NANOTUBES

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Optoelectronic devices based on carbon nanomaterials provide new opportunities for basic and applied studies. Strong Coulomb interactions among 1-D carriers and excitons in single-walled carbon nanotubes (SWNTs) are expected to significantly enhance light absorption, carrier generation, and transport. Here, we demonstrate that a two-terminal device consisting of macroscopically-aligned, ultralong SWNTs acts as a photodetector in an extremely wide spectral range covering the visible, near-infrared, and mid-infrared. We used films of SWNTs grown via chemical vapor deposition and laid down on Si/SiO_2 substrates. Metallic electrodes were then deposited with distances of 50 μm between contacts. Scanning photocurrent and photovoltage measurements, together with in-situ imaging, were successfully made at wavelengths of 658 nm and 1350 nm with a focal-point diameter of ~1 μm; local photocurrent or photovoltage as high as 333 nA/mW and 1350 μV/mW have been achieved. A careful analysis of the observed position-dependent response suggests the presence of a built-in potential at the nanotube-electrode interface. Furthermore, we explored this effect to design detectors with asymmetric contacts using different metal electrodes such as Au, Pd, Ag, and Ti. This allowed us to observe significant photoresponse under global illumination, obtaining a photovoltage of 6.5 μV/mW under visible excitation, as well as go to the mid-infrared range. We detected photoresponse signal up to 3.2 μm wavelength using an optical parametric oscillator and are collecting data using quantum cascade lasers operating at 10 μm. Hence, these devices are very promising for potential solar cell as well as broadband photodetector applications.

CHEMICAL AND BIOLOGICAL SENSORS USING GRAPHENE FIELD-EFFECT TRANSISTORS

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Graphene, planar sheet of sp^2-bonded carbon atoms densely packed in a honeycomb crystal lattice, have high potential for sensing applications. Gas molecules and protein adsorptions onto the graphene surface have been electrically detected by graphene field-effect transistors (G-FETs). In this work, we investigated the chemical and biological sensing characteristics using bare and modified G-FETs. As results, solution pH and monovalent ions can be detected by the bare G-FETs with very high sensitivity. And charged proteins can be also electrically detected. By using modified G-FETs, specific biological sensing could be realized.

Single-layer graphene flakes were obtained from kish graphite (Covalent Materials Corp., Tokyo, Japan) by a mechanical micro-cleavage technique using adhesive tape. The G-FET was fabricated on a thermally oxidized 280--nm--thick SiO_2 layer on a p^+-Si substrate. Single-layer graphene flakes were identified by Raman spectroscopy. Gold source and drain electrodes were formed by conventional electron beam lithography, vacuum evaporation, and lift-off procedure. In sensing measurements, a silicone rubber pool was put on the device and an Ag/AgCl reference electrode was used as the top-gate electrode to minimize environmental effects.

The drain current (I_D) versus top-gate voltage (V_{TG}) changed by the solution pH, monovalent ions. Especially, the detection limit (Resolution: signal/noise=3) of the solution pH is as small as 0.025, indicating their high potential for the chemical sensors. The bare G-FETs can also electrically detect the protein adsorption on the graphene channel surface because proteins usually charged in the buffer solution owing to their amino and carboxyl group. However, the bare G-FETs cannot distinguish the each of proteins. In order to realize the specific sensing, receptor-modified G-FETs are needed.

There are two requirements for functionalization process. One is that the height of the receptor molecules on the graphene channel must be smaller than that of the Debye length (Electric double layer). The other is that the functionalization processes must be carried out without introducing defects on the graphene surface. In this study, immunoglobulin E (IgE) and anti-IgE aptamers were used as a target and receptor molecules, respectively. Aptamers are the oligonucleic acid binding to the specific target molecules. The aptamers were functionalized on the graphene surface with 1-pyrenebutanoic acid succinimidyl ester. The pyrenyl group of the linker interacts strongly with the basal plane of graphite via π-stacking. After functionalization process, the drain current increased owing to the negatively charged aptamers. And the slopes of the I_D-V_{TG} curves were almost identical, indicating that no defects were introduced on the graphene surface by the functionalization process. The drain current suddenly decreased after adding the buffer solution with target IgE molecules while almost no current changes were observed after adding the solution with non-target proteins of bovine serum albumin and streptavidin.

The dissociation constant (K_D) between IgE and IgE aptamers was estimated by the IgE concentration dependence of the I_D change. From the fitting curve with Langmuir adsorption isotherm, the K_D was estimated to be about 50 nM. The value of the K_D was comparable with those of other sensing techniques such as quartz crystal microbalance, capillary electrophoresis, fluorescent, and gradient micro free flow electrophoresis, indicating that the modified G-FETs are promising candidates for label-free biological sensors.

LABEL-FREE IMMUNOSENSORS USING HORIZONTALLY ALIGNED CARBON NANOTUBES

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Direct growth of horizontally aligned single-walled carbon nanotubes (SWNTs) on single-crystalline quartz substrates offers several advantages for the application of carbon nanotube field-effect transistors (CNTFETs). The multiple, parallel transport pathways in CNTFETs provide large drain current (I_D) and active areas together with statistical averaging effect in properties, even with tubes that individually have widely different properties. In addition, the aligned arrays have advantages compared to the random networks because they avoid percolation transport pathways, unusual scaling of device properties, tube/tube junction resistances. Recently, guided growth of SWNTs on single-crystalline quartz substrates has been reported. They have found that SWNTs are aligned along the specific crystalline directions by angle-dependent van der Waals interactions between the SWNTs and the quartz lattice. This is one of the most facile routes to obtain horizontally aligned SWNTs. In this study, we demonstrate label-free immunosensing based on CNTFETs using horizontally-aligned CNTs as channels of FET.

In the experiments, aligned CNTs were grown on ST-cut Quartz substrates by alcohol CVD. The substrates were annealed at 900ºC for 12 hours in air to re-crystalize the surfaces before the growth. Source and drain electrodes of Ti (2 nm)/Au (30 nm) were formed. To measure protein adsorption in solution, the device was surrounded by a silicone rubber barrier attached to the substrate. The target protein is human immunoglobulin E (IgE), which plays an important role in allergy. To enable electrical detection of IgE, IgE aptamers were chemically modified on CNT channels.

First, we measured specific sensing characteristics of aptamer-modified CNTFETs. Time dependence of I_D was monitored in phosphate-buffered solution (PBS). Nontarget protein, namely, bovine serum albumin (BSA 4 μm) and avidin (4 μm), and the target IgE (500 nM) was added into PBS. Upon addition of nontarget proteins, I_D remained almost constant. In contrast, when the target IgE was introduced into the SWNT channels, I_D suddenly decreased. This result indicates that selective detection of IgE was successfully performed.

Next, we estimated the detection range of IgE concentration by monitoring I_D at various IgE concentrations. The target IgE at concentrations of 50, 75, 155, 250, 350, 400, 500 nM was introduced into an aptamer-modified CNTFET while I_D was monitored in real time. I_D decreased stepwise after injection of IgE at various concentrations. Then, the change in net source-drain currents (ΔI_D) before and after introduction of IgE (C_{IgE}) at each concentration is plotted. The experimental results were fitted well by the Langmuir adsorption isotherm, which is given by

$$\frac{\Delta I}{\Delta I_{max}} = \frac{C_{IgE}}{K_d + C_{IgE}}$$

where K_d is the dissociation constant of the reaction between IgE molecules and IgE aptamers and ΔI_{max} is the amount of saturated drain current. From the fitted curve, the detection range was estimated to be from 16.4 nM to 1.18 μM.

In conclusion, we have investigated an aptamer-modified CNTFET with multi channel as a label-free immunosensor. Dense, well-aligned SWNTs grown on quartz substrates were utilized as channels of CNTFETs. The CNTFET electrically detected IgE protein, whereas other proteins were not detected. The detectable range of IgE concentration was from 16.4 nM to 1.18 μM, which is a clinically relevant concentration regime. These results indicate that CNTFETs with multi channel is promising platforms for label-free immunosensors.

TERAHERTZ CONDUCTIVITY OF LOW-DIMENSIONAL CARBON NANOSTRUCTURES

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Low-dimensional carbon nanostructures – single-walled carbon nanotubes (SWNTs) and graphene – offer new opportunities for terahertz (THz) science and technology. Metallic SWNTs and graphene are zero-gap systems with a linear, photon-like energy dispersion, which leads to a plethora of exceptional properties, including unusual nonlinear and non-equilibrium electrodynamic properties that are expected for new THz device applications. THz dynamic conductivity measurements allow us to probe the dynamics of such photon-like electrons, or Dirac fermions. Here, we use THz time-domain spectroscopy and Fourier transform infrared spectroscopy (FTIR) to investigate THz carrier dynamics in films of highly-aligned CVD-grown SWNTs and large-area graphene grown from solid state carbon source.

Experimental results demonstrate extremely anisotropic THz conductivity in aligned SWNTs. When the THz polarization is perpendicular to the alignment axis, no absorption is observed, while there is strong absorption (OD ~ 1) when the polarization is parallel to the alignment direction. We Fourier-analyzed the data and determined the complex conductivity tensor elements of this one-dimensional electronic system. The real part of the parallel conductivity increases with increasing frequency, which disobeys the Drude model used to describe the free carriers in conventional conductors. After broadening the bandwidth via FTIR, it exhibits a peak in the FIR range, whose origin is currently under debate. Unlike SWNTs, the THz & FIR conductivity of graphene shows a Drude-like frequency dependence, through which the two important semiconductor parameters, mobility and Fermi energy, could be extracted out. We found that after thermal annealing, the Fermi level of graphene shifted toward the Dirac point. In addition, by applying an external gate voltage, we were able to electrically tune its Fermi level, which in turn modulated the transmission of THz waves.

TIME-RESOLVED PHOTOLUMINESCENCE QUENCHING IN QUANTUM WELLS USING A TERAHERTZ FREE-ELECTRON LASER

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We have measured time-resolved photoluminescence (TRPL) quenching in strained $In_{0.2}Ga_{0.8}As$ quantum wells induced by intense free-electron laser-generated (FEL) terahertz (THz) radiation. A picosecond-pulse Ti:Sapphire laser was used to create photoluminescence (PL), which was then collected using a streak camera-monochromator assembly. By changing the temporal separation of the Ti:Sapphire excitation pulse and the THz quenching pulse, we could investigate PL quenching when the system was more plasma-like (unbound correlated electron-hole pairs) and when it was more excitonic (Coulombically bound electron-hole pairs). For all THz wavelengths investigated, we saw more PL quenching when the system was more excitonic. The slow increase of the quenching with increasing excitation pulse-quenching pulse time delay suggests excitonic formation times on the order of a nanosecond. To study excitonic dynamics more fully, we utilized the tunability of the FEL, which is a narrowband THz source, to access photon energies above, at, and below the intra-excitonic 1*s* to 2*p* transition. We observed that when the photon energy was resonant with the 1*s*-2*p* transition, the PL quenching was enhanced. However, when the off-resonant THz photon energy was below the 1*s*-2*p* transition energy, the PL quench was larger than when the THz photon energy was above that energy, a fact we attribute to free-carrier absorption. Thus, both resonant and non-resonant processes are able to produce a quench in PL emission from the 1*s* energy state. In addition to PL quenching, we also observed time-resolved, THz-induced 2*s* excitonic PL. This emission occurs when FEL-created 2*p* excitonic states are Coulombically scattered to energetically degenerate 2*s* states, a process that occurs after ~100 ps. We find that the lifetime of the 2*s* emission is in the hundreds of picoseconds, which is an order of magnitude shorter than the 1*s* emission.

DIAMETER DEPENDENCE OF THE MAGNETIC SUSCEPTIBILITY ANISOTROPY IN METALLIC CARBON NANOTUBES

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The magnetic properties of single-walled carbon nanotubes (SWNTs) – both metallic and semiconducting species – change with the direction of the magnetic field with respect to the tube axis, yielding a magnetic anisotropy given by $\Delta\chi = \chi_{//} - \chi_{\perp}$. Metallic nanotubes are paramagnetic along the tube axis ($\chi_{//} > 0$) and diamagnetic in the perpendicular direction ($\chi_{\perp} < 0$), whereas semiconducting tubes are diamagnetic in all directions ($\chi_{//}$, $\chi_{\perp} < 0$). This anisotropy of magnetic susceptibilities results in the nanotubes in solution aligning as the magnetic field is increased. This, combined with the anisotropic optical absorption properties of SWNTs, allows for the use of polarization-dependent optical absorption to measure the degree of alignment through magnetic linear dichroism (MLD) spectroscopy. Our previous MLD measurements on a length-sorted, (6,5)-enriched CoMoCAT SWNT suspension found that the (6,6), (5,5), and (7,4) nanotubes align more rapidly with the magnetic field than semiconducting nanotubes found in our sample [1].

As a complementary experiment, here we investigated a metallic-enriched HiPco SWNT sample [2] that was selected not only for its larger population of metallic species relative to our previous sample but its specific enrichment in armchair, or (*n*,*n*), carbon nanotubes. Utilizing the 35 T Hybrid Magnet in the High Magnetic Field Facility of the National Institute for Materials Science in Tsukuba, Japan, we measured absorption with light polarization both perpendicular and parallel to the magnetic field to determine MLD. By relating these values with the nematic order parameter for alignment, we found that the metallic carbon nanotubes do not follow a strict diameter dependence across the 7 chiralities present in our sample.

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Scanning Laser Terahertz Imaging System

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Terahertz (THz) imaging technique has attracted much attention for various applications from biology to security. For practical use of this technique, there are several problems to be overcome, such as imaging speed and spatial resolution. Recently, to overcome these problems, we have developed a scanning laser THz imaging system using a galvano meter and a nonlinear optical crystal as a two dimensional (2D) THz emitter. In this system, 1.56 μm femtosecond laser pulse beam is modulated by using an optical chopper or an acousto-optic modulator (AOM) and scanned over the 2D THz emitter by using the galvano meter. THz pulses that are locally generated at the laser beam irradiation spots transmit through a sample that is set directly on the emitter are detected by a photoconductive antenna. Therefore, we can observe a THz transmission image of the sample by monitoring the amplitude of the THz pulses. Using this system, we could observe THz transmission images of a triangle-shaped cupper sheet sample and a human hair sample. The images are composed of 512 x 512 pixels, and the imaging speed is about 47 seconds/image at a modulation frequency of 100 kHz. In the image of a cupper sheet sample, we could observe a clearly visible screening of the THz waves. As for a human hair sample, we could observe a clear thin shape of the hair sample, and several strong THz radiation spots were observed as well as weak THz radiation spots inside the identical hair sample. These may indicate that THz waves relate to the inner structures or internal constituent of the human hair. The spatial resolution in this measurement reaches up to 56 μm, although the main frequency is located around 0.4 THz in the broadband spectrum of the generated THz waves. This spatial resolution is achieved probably due to near-field effect. Further details about the system configuration and the experimental results will be presented.

ELECTRON SPIN RESONANCE OF GRAPHITE AND GRAPHENE

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Graphene, a single layer of sp^2-bonded carbon atoms arranged in a honeycomb lattice, is quickly becoming an ideal next generation material for electrical components. With industry pushing silicon to its physical limits, the properties of graphene are becoming more attractive to engineers and scientists alike. With photon-like, massless electronic band dispersions, graphene boasts of a high electron mobility (100 times that of silicon at room temperature), the ability to switch between insulating and conducting states, and a strong likelihood of bridging the terahertz technology gap. Furthermore, the small spi-orbit coupling of carbon atoms makes graphene an ideal candidate material for constructing spintonic devices. However, relatively little is known spin properties of graphene, compared to graphite. Here, we explore the spin properties of graphene via electron spin resonance (ESR) experiments. In an ESR experiment, the sample of interest is subjected to a DC magnetic field of strength B_0 and an AC (or microwave) magnetic field of frequency ν. The sample absorbs the microwave field resonantly when $\hbar\nu = g\mu_B B_0$ is satisfied, where $\hbar$ is the reduced Planck constant, μ_B is the Bohr magneton, and g is the Lande g-factor of the material. This equation physically means that the spin splitting (i.e., the Zeeman energy) of electrons is equal to the microwave photon energy. In practical experimentation, the strength of the DC magnetic field B_0 is scanned while microwave absorption is recorded. ESR thus appears as an absorption peak as a function of magnetic field. The resonance magnetic field as well as the microwave frequency ν (~ 9.14 GHz in our case) allow us to determine the g-factor using the above equation. We have already observed ESR in graphite using our current setup and are currently attempting to observe ESR in a graphene sample exfoliated from graphite. Once ESR in graphene is observed, we will systematically compare its g-factor with that of graphite as a function of temperature and magnetic field orientation to further elucidate its fundamental spin properties. If the sensitivity of this standard ESR method turns out to be not high enough to detect ESR in a single flake of graphene, we will attempt to use a novel resistive technique for ESR detection.

BIAS DEPENDENCE OF SPIN SIGNALS IN GRAPHENE & A NOVEL MAGNETIC SWITCHING EFFECT IN FULLERENE-COBALT NANOCOMPOSITES

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1st topic: Spintronics using graphene garners much attention since 2007. Several groups, including us, successfully observed spin injection, generation of a pure spin current and Hanle-type spin precession in single- and multi-layer graphene at room temperature. Spin precession was conducted by applying an external magnetic field perpendicular to the graphene (Hanle-type spin precession), and spin diffusion length and time are so far estimated to be 1.6 μm and 150 ps at room temperature. The spin diffusion length is possibly enhanced up to ~5 μm in multi-layer graphene. After the breakthrough, a number of studies have been conducted from various points of views, such as anisotropic spin relaxation, a spin drift effect, bias dependence of spin signals, enhancement of spin diffusion time, and so on. Among them, the bias current dependence of spin signals for positive and negative electric current has been revealed to be unique. In the presentation, we introduce the basic concept of spin injection and generation of a pure spin current for observing spin transport in graphene, and then focus on the bias dependence of the spin signals in single- and multi-layer spin valves.

2nd topic: Study on organic molecule(OM)-ferromagnetic metal(FM) nanocomposites, where nanoparticles of ferromagnetic metal are embedded in organic molecules, has played an important role in the field of organic spintronics. In such a structure, tunnel magnetoresistance(MR) effect appears as the result of spin-dependent electron tunneling between Co nanoparticles and it has been revealed that MR ratio was enhanced by high order co-tunneling within a Coulomb Blockade(CB) region and high spin polarization due to existence of the compound of OM and FM. Remarkably, the MR ratio in C_{60}-Co granular reaches to several hundreds % at 4.2 K, which is extremely larger than that observed in inorganic (Al-O_x)-Co granular. We have obtained huge MR ratio of 1,400,000% at 1.8 K in C_{60}-Co nanocomposites around the first threshold voltage of CB, where about 4 percent reduction of the V_{th} of the CB under external magnetic field of 5 T was clearly observed. In addition, the *I-V* characteristic exhibited the same magnetic field dependence at the second threshold voltage as observed in the first threshold voltage, which was originated not from Avalanche breakdown or a space charge effect but from the CB effect. Although a similar phenomenon was reported, where MR ratio was 3,000%, the background physics was unclear. We conclude that our finding is ascribed to correlation between superparamagnetism of the Co nanoparticles and the CB effect from a theoretical model building. In the presentation, we introduce the details of the above topic.

QUANTITATIVE DARK--FIELD MICROSCOPY OF GOLD NANOSHELLS IN CELLS

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Gold nanoshells are biologically inert nanoparticles with unique optical properties. Biological molecules can be affixed to the exterior of gold nanoshells and thus transported into cells. Upon laser irradiation, the affixed molecules can be controllably released. This technique allows for the transport and controlled delivery of a variety of therapeutic molecules, such as DNA and proteins, and thus holds possibility for a variety of medical applications in disease treatment. However, the number of therapeutic molecules delivered depends upon the number of gold nanoshells that can be placed in cells, and this quantity remains unknown. We have constructed a transmission dark---field microscope for imaging and quantifying the number of nanoshells taken up within individual cells. Controlled by a custom---written LabView software program, this dark field---microscope collects a series of images which are then processed, resulting in a quantitative estimate of the number of gold nanoshells inside of a cell and a three dimensional representation of their location.

CHARACTERIZATION OF PHOSPHORUS DEPOSITION ONTO SILICON (111) 7x7 NANOSTRUCTURES FOR APPLICATIONS IN QUANTUM COMPUTING

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A computer that utilizes quantum mechanical phenomena is theoretically superior to conventional, transistor-based computers for performing specific types of computational operations. The model we attempt to fabricate uses the nuclear spin of individual ^{29}Si atoms oriented up and down to represent Boolean logical data. These quantum bits are placed in wires on a substrate of ^{28}Si, which has no nuclear spin, and are bounded by a NiFe magnet on one side and a single ^{31}P atom on the other, which are used for initialization and readout as well as maintaining a necessary magnetic field. We utilize mechanical and chemical polishing of the silicon substrate at a 1° tilt from the [111] direction to produce a stair-step pattern with kinks, which are straightened by long duration DC annealing. It is on these edges that the wires of ^{29}Si and ^{31}P can be grown via molecular beam epitaxy. However, little is known about the behavior of phosphorus, identified via scanning tunneling spectroscopy, when deposited onto these step edges. By varying the temperature of deposition and observing the results by scanning tunneling microscopy, the temperature dependence of phosphorus deposition can be characterized.

SYNTHESIS AND CHARACTERIZATION OF CARBON NANOTUBES PRODUCED FROM THERMAL DECOMPOSITION OF NICKELLOCENE

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Over the past two decades investigations pertaining to various properties of carbon nanotubes (CNTs) have indicated that they are one of the most promising engineering materials available today for future technology development. However, deploying these materials in developing a wide variety of applications will require large volume production of CNTs. For example applications such as battery electrode additives, multi-functional composites, supercapacitor electrodes, field emission displays/lighting – CNT-based inks for printing etc. will require large amounts of CNT materials in the form of thick films, random network, assembled sheets and fibers. Therefore, simple and cost effective techniques for bulk production of CNTs in forms of thin films, self assembled network or sheets are being explored vigorously since these architectures will possess physical properties such as high strength, low density, high specific surface area, good thermal and electrical conductivity needed for most of the aforesaid applications. We have employed a direct thermal deposition technique, which used Nickellocene both as the catalyst as well as the carbon source, to grow films of carbon nanotubes (CNT). The CNT films obtained using this procedure were characterized using Transmission Electron Microscopy which indicated the presence of thin diameter carbon nanotubes as well as single walled CNT ropes. Volumetric adsorption measurements were performed to determine the porosity and specific surface areas of these samples. Electrical transport measurements performed on long ropes of CNTs extracted from these bulk films will be presented and will be discussed in the framework of transport theories of quasi-one dimensional systems.

TERAHERTZ-WAVE INDUCED NEAR-INFRARED TRANSPARENCY IN GRAPHENE

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Graphene possesses many unique properties arising from its truly 2D honeycomb structure, and offers us solid state playground of Dirac fermions. One of the exciting properties in graphene is its ultra-high conductivity even at room temperature, and the understanding of ultrafast carrier transport phenomena in its massless band structure is essential both for fundamental physics and industrial applications such as high-speed graphene-based circuit. Numerous efforts have been paid for the dc transport properties of graphene, where the carrier transport is limited by LO-phonon scattering. Thanks to recent advances in terahertz (THz) technologies, we can apply high electric field on graphene in the ultrashort time duration, which enables us to accelerate carriers without LO-phonon disturbance. This will open the door of non-perturbative carrier transport. In this study, we focused on near-infrared absorption change that reflects the non-thermal carrier distribution caused by the THz pulse excitation. We found that a considerable number of highly excited carriers are generated by the intense THz-wave excitation.

We performed transient absorption measurement in near-infrared region (800 nm) under the intense THz excitation at room temperature. The sample is CVD growth graphene which is transferred on a SiO_2 substrate from the original metal substrate. Transmissivity of graphene at 800-nm is 97%, which reflects the single-layer nature of the sample. Air plasma THz generation method is employed so that we can switch on and off the applied electric field over 300 kV/cm within less than 200 fs.

Figure 1 shows the transmission changes $\Delta OD / OD = (OD_{pump}-OD_{ref})/OD_{ref}$ as a function of delay time, where OD_{pump} is the optical density of graphene with THz excitation and OD_{ref} is that without excitation. Positive transmission changes mean that near-infrared transparency is induced under THz field incidence, which goes back to zero with a relaxation time around 1 ps. This induced transparency reaches almost 14%, which corresponds to the same amount of population occupation change that contributes to near infared transition in graphene.

The inset of Fig.1 shows the maximum transmission changes as a function of THz field amplitude. Superlinear field-dependence is clearly observed as shown by the solid line of the power law fitting. This huge induced transparency and quadratic behavior could not be explained by carrier thermalization nor ballistic carrier motion, but suggests strongly the importance of carrier multiplication

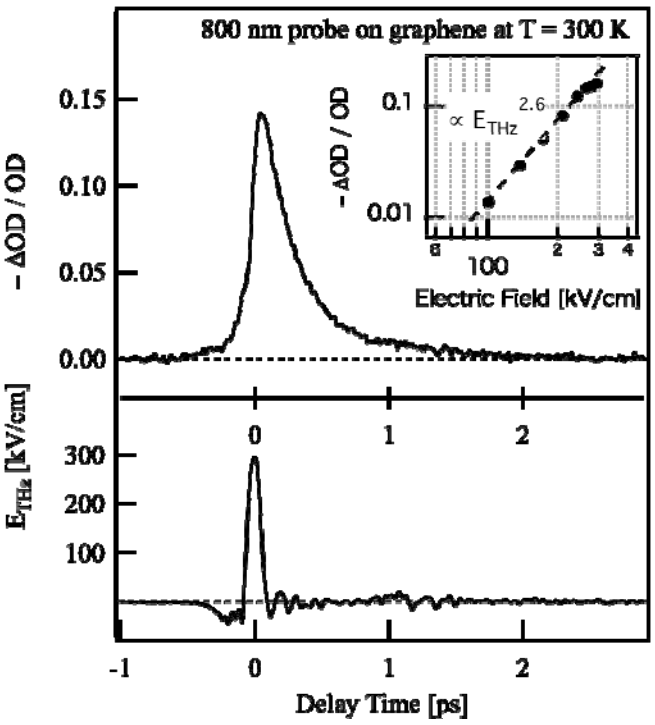

Figure 1 : Transmission changes at 800 nm and incident THz waveform as a function of delay. The inset shows the maximum transmission changes as a function of THz field amplitude.

TOWARD THE REALIZATION OF NARROW DIAMETER DISTRIBUTION IN AS-GROWN SINGLE-WALLED CARBON NANOTUBES

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Modifying electrical and optical properties of single-walled carbon nanotubes (SWNTs) has been obtained by structure controlling or chemical doping. Because of their intrinsic electrical property, those nanotubes have been given an emphasis on many applications. The direct synthesized SWNTs, however, are still lacked of structure controlling. In this study, we narrow SWNT diameter distribution with alternative of no-flow CVD using acetronitrile (CH_3CN) as the carbon feedstock. The Co/Mo binary catalyst was used as catalysts amd deposited on quartz substrate by a liquid dip-coating process. SWNTs were dispersed in D_2O with sodium deoxycholate (DOC) for further optical measurements. As for the results, the SWNT diameter seems to be dramatically small, and the diameter distribution was also narrowed, compared to that from alcohol. However, the vertical aligned morphology was achieved even at high temperature as 800°C. The small diameter peaks in RBM region with three different excitation wavelengths (488, 514, 633 nm) were, for acetonitrile sample, found to be about 240-300 cm^{-1}, indicating small diameter with narrow distribution. The small in mean diameter of as-grown SWNTs was rectified by UV-Vis-NIR optical absorption measurement, showing the absorption peak around 1000 nm which correspond to 0.8-1 nm in diameter. Additionally, the PLE map of dispersed SWNTs also showed a strong dominance of (6,5) nanotube.

TRANSPORT STUDY OF CARBON NANOTUBE NETWORKS WITH DIFFERENT RATIOS OF SEMICONDUCTING AND METALLIC NANOTUBES

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An important goal of current nanotechnology research is to obtain a quantitative understanding of how electrons drift and tunnel through junctions of nanostructures and how the overall electrical conductivity of networks of nanostructures is determined. Such knowledge is crucial for a broad range of future applications of macroscopic assemblies of nanostructures. Here, we present a comprehensive study of DC transport properties of macroscopic single-walled carbon nanotube (SWNT) networks with different ratios of metallic and semiconducting nanotubes. Our temperature-dependent transport measurements show that when the length of SWNT is orders of magnitude smaller than the dimensions of the network, the resistance mainly comes from inter-tube junctions, which can be well explained by hopping (or tunneling) models. Particularly, we found that the probability of hopping (or tunneling) through a metal-metal junction is higher than that of a metal-semiconductor or semiconductor-semiconductor junction, leading to a much higher conductance in a metal-enriched network than the others at low temperature. However, the conductance of semiconductor-enriched network starts to catch up at higher temperature when the hopping probability starts to saturate. This is because accidental doping in semiconducting SWNTs increases the available number of carriers for hopping through the junctions and thus increases the overall conductance.

EXCITATION OF TERAHERTZ 2D-PLASMON MODES IN A GRAPHENE RIBBON ARRAY

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A graphene ribbon array (GRA) is a novel structure that can hold various types of two-dimensional plasmons (2DPs) of graphene. Due to the unusual electronic dispersions of graphene, the fundamental plasmon frequency easily falls in the terahertz (THz) region even for a ribbon width > 10 μm. We observed THz 2DPs in an optically-pumped GRA by using terahertz time-domain spectroscopy.

A GRA sample having a 50-μm ribbon width and space was prepared from an exfoliated graphene on a SiO_2/Si substrate. The sample was optically pumped by an 80-fs, 1550-nm, 2-mW pulsed fiber laser with a 20-MHz repetition rate with polarization parallel to the ribbon direction. Then a THz probe pulse was impinged onto the sample 3.5 ps after each pulsed pumping. The temporal response of the THz probe pulse transmitted through the sample was electro-optically detected using a CdTe sensor crystal. The photogenerated electrons/holes relax their energy by emitting optical phonons, accumulating around the Dirac point, resulting in population inversion in 10s of ps duration after pumping. When the pumping intensity is below the threshold, the THz dynamic conductivity retains in positive so that the 2DPs exhibit distinctive resonant absorption spectra during the energy relaxation of photocarriers. In conclusion, as is expected, the GRA exhibits clear absorption peaks corresponding to the 2DP modes with the fundamental mode as high as 450 GHz even for a wide ribbon width of 50 μm, demonstrating superior electron transport properties in graphene.

Furthermore, we also measured THz absorption in another GRA sample having a 6-μm graphene ribbon width and 14-μm empty space on a 6H-SiC substrate. THz radiation was generated from a ZnTe crystal excited by an 800-nm, 800-mW mode-locked Ti:Sapphire laser with a 80-MHz repetition rate. The transmitted THz radiation was detected by a photoconductive antenna. Polarization and frequency dependence of THz transmission will be discussed.

ULTRA-HIGH SURFACE AREA SINGLE AND MULTI-WALLED CARBON NANOTUBE 3-DIMENSIONAL HYBRID STRUCTURE

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Carbon-based structures prove promising candidate materials in many applications including flexible electronic devices, membranes, sensors, and energy storage devices, the primary reason being their ability to achieve unprecedented surface areas at the nanoscale level. Here, we synthesize a unique high surface area 3-dimensional hybrid nanostructure by combining carbon nanotube growth on two templates, anodized aluminum oxide (AAO) and spherical silica nanoparticles. First, we fabricated a low-aspect ratio AAO template and applied chemical vapor deposition (CVD) to synthesize multi-layered graphitic structures known as nanocups. After the first growth, we inserted silica nanoparticles and conducted another round of CVD to generate a network of single-walled nanotubes (SWCNTs) inside the carbon nanocups. This novel hybrid carbon nanostructure demonstrates an enhanced conductive surface area that paves the way for many potential applications, including improved charge density on super-capacitors.

ORIGIN OF THE TERAHERTZ ABSORPTION PEAK IN SINGLE-WALLED CARBON NANOTUBES

Q. Zhang[1], L. Ren[1], E.H. Haroz[1], T. Arikawa[1], C. L. Pint[2], F. Mirri[2] ,R. H. Hauge[2] and J. Kono[1]

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[2] Department of Chemical and Biomolecular Engineering, Rice University, TX, U.S.A

Single-walled carbon nanotubes (SWNTs) are promising for high-frequency electronics and terahertz (THz) applications, as well as for fundamental studies of finite-frequency dynamics of one-dimensional electrons. Previous studies of dynamic conductivities of various types of SWNTs have revealed a pronounced and broad absorption peak in the THz frequency range, whose origin has been a matter of controversy. Both the effects of curvature-induced band gaps and plasmonic absorption due to finite lengths have been proposed to be important, but a consensus has not emerged. The curvature-induced band-gap scenario predicts several experimental signatures: (1) existence only in non-armchair "metallic" tubes, (2) strong tube diameter dependence of the THz peak position, (3) strong temperature dependence, and (4) suppressed by doping. On the other hand, the plasmonic absorption theory predicts that the peak should (1) be enhanced by doping and (2) exhibit a length dependence. Both of these theories predict the same polarization dependence. To examine all these signatures, we have studied the THz absorption peak in highly-aligned and length-controlled CVD grown SWNT films as well as highly metallic and semiconducting enriched SWNTs prepared via the density gradient ultracentrifugation (DGU) technique, through Fourier-transform infrared spectroscopy and THz time-domain spectroscopy.

Except the polarization dependence that can be interpreted by both theories, all other four signatures of the curvature-induced band gap scenario are disproved by our observations. Therefore, it can be ruled out from the candidate theories of the THz absorption peak. The plasmonic resonance theory is supported by the fact that the THz peak is enhanced by doping. However, no clear length dependence of the peak position was observed. Further investigations are needed for fully understanding the origin of this absorption peak.

Ajayan Laboratory

Website: http://www.owlnet.rice.edu/~rv4/Ajayan/

Our research focuses on the development of functional nanostructured materials for variety of applications. We look at the materials science and engineering aspects of these novel materials with three different focused application areas:

Nanomaterials in Energy Generation and Storage: There is a tremendous opportunity today in the development of new materials for applications in energy. We are working on integrating nanomaterials in several key areas of energy technologies. Engineered architectures based on carbon nanotubes, nanowires and nanocomposites are being looked at in our laboratory for the development of new designs of supercapacitors, battery and their hybrids. Similarly electrodic applications of nanostructures are being pursued in the energy generation (e.g. hydrogen) area. In addition, energy management is also of interest, in particular thermal management using nanomaterials and development of new catalyst and support materials for fuel cells.

Multifunctional Composites, Nano-enabled bio-mimetic Systems: Lightweight multifunctional materials are critical for the continued development of next generation structural materials. This is especially the case where loading conditions and harsh environments require smart material solutions capable of addressing needs such as payload, damping/vibration control, EMI and lightning shielding, thermal management, and health-monitoring. Our approaches will look at engineering and integration of nanostructures into composites and hybrid materials in intelligent and scalable ways that mimic biological systems and have applications in a variety of areas in materials science and bio-technology. Some bio-mimetic concepts (membranes, dry adhesive tapes etc.) are also being pursued to build novel and smart material systems.

Nanoelectronics, Nanosensors, Active Nanosystems: The revolutionary nanotechnology will follow breakthroughs in electronics and sensors. We have been looking at the role of nanomaterials in electronics, as devices and interconnects. We focus on carbon nanotubes, graphene, hybrid nanowires and molecular materials for developing the new generation of integrated electronic components. Materials such as carbon nanotubes and graphene seem to have big advantages over conventional silicon based devices and copper based interconnects. The challenges in large scale assembly, junctions and contacts between nanodevices and integration into existing technologies are topics of interest. In addition we are also pursuing various approaches to build sensor devices and sensor network systems using nanostructures and their assemblies. Finally our ultimate goal is to build active, smart assemblies of nanostructures that can be controllably manipulated.

Du Laboratory - Quantum Transport Research Lab

Website: http://www.ruf.rice.edu/~dulab/

Research in the Quantum Transport Lab is centered on the experimental investigations on the physics of low dimensional electron systems, in particular on the fractional quantum Hall effect, and on quantum transport of nonequilibrium electronic systems. The research work focuses on fundamental understanding of quantum mechanical properties of electrons in low dimensional and nanoscale semiconductor structures and devices. Here is an outline of current research topics.

2D and 1D electron systems provide both a clean laboratory for many-particle physics and a unique platform addressing emerging issues in spintronics and solid-state quantum information devices. Our recent research has been centered on these two themes and has been supported by DOE, NSF, and DARPA. The materials used are mainly GaAs/AlGaAs heterostructures and quantum wells, but also include Si and GaN depending on the physics involved.

Kono Laboratory

Website: http://www.ece.rice.edu/~irlabs/

Our research is currently focused on the physics and applications of semiconductor nanostructures and carbon-based nanomaterials. We use state-of-the-art spectroscopic techniques to study charge, spin, and vibrational dynamics in a variety of nanostructures. The impact of our research includes: increased understanding of the quantum states and dynamics of interacting, confined, or strongly driven electrons in nanostructures; new spectroscopy techniques; novel device concepts and implementations (especially towards all-optical switches and spin-based devices); establishment of the quantum nature of semiconductor-light interaction; progress towards the solid-state realization of quantum information processing, computation and communications; and provision of a controlled environment in which to address unanswered questions in many-body physics.

Research areas include: Ultrafast and Nonlinear Optics in Carbon Nanotubes, Magneto-optics in Carbon Nanotubes, Terahertz Magneto-Spectroscopy of Semiconductor Nanostructures, Many-Body Processes of 2-D Excitons in High Magnetic Fields, Non-perturbative Nonlinear Optics in Semiconductors, Cyclotron Resonance in Ultrahigh Magnetic Fields, Magneto-optical Spectroscopy of Ferromagnetic III-V Semiconductors, Time-Resolved Far-Infrared Spectroscopy with Free Electron Lasers, and Armchair Quantum Wire Project.

Mittleman Laboratory

Website: http://www.ece.rice.edu/~daniel/

Our research interests are two-fold. Some of our work involves the generation and detection of single-cycle pulses of far-infrared radiation, which is accomplished with ultrafast laser pulses. This field, a subset of what is commonly known as ultrafast optoelectronics, is interesting because these far-IR (or terahertz) pulses access a range of the electromagnetic spectrum which is relatively unexplored.

Terahertz spectroscopy and imaging: Our current research involves the generation and detection of sub-picosecond pulses of far-infrared radiation, with central frequencies in the vicinity of 1 terahertz (THz). These pulses are generated by gating an optoelectronic switch with an ultrafast (visible or near-IR) laser pulse. Our first emitter setup looks like this. The THz radiation generated in this fashion consists of a single cycle of electromagnetic radiation, and as a result has an extremely broad bandwidth, extending (typically) from below 100 GHz to over 3 THz. Although the energy in each THz pulse is quite low, the coherent detection, in which the detector is gated with a second visible ultrafast pulse, permits extremely high signal-to-noise spectroscopic measurements. Because the THz pulses are measured using photoconductive sampling to map out the time-domain waveform, this technique has been called terahertz time-domain spectroscopy, or THz-TDS.

Photonic crystals and strongly scattering media: Photonic crystals are materials that strongly diffract light, due to an extended spatial dielectric periodicity. Our research in this area began as a collaborative effort with the Colvin Group, from the Chemistry Department. This collaboration was initially directed towards understanding the transmissive optical properties of thin films of colloidal crystals, close-packed arrays of spherical silica colloids. These films exhibit striking diffractive optical properties, resulting from the periodicity of the dielectric function in the medium. Peng Jiang, a student in the Colvin group, has recently invented a method for fabricating colloidal crystals which produces large (1 square centimeter) single crystal films, and which permits us to control the film thickness. Films grown with different colloid sizes appear colored in different hues due to the sensitivity of the diffraction process to the spacing between adjacent layers of spheres. Using this novel fabrication method, we were the first to study the evolution of the optical properties of a photonic crystal as a function of its thickness.

Arrival & Hotel Information

71

From Bush Intercontinetal Airport (IAH)

Taxi: Proceed to baggage claim to collect your luggage and then proceed out the doors indicated for taxis and ground transportation. You can request a credit card cab and ask for a receipt. Taxis from the airport are zoned and a ride to the Medical Center/Reliant Park area should cost $65 plus tip.

Super Shuttle: Either prior to arrival or upon arrival at the aiport you can purchase a ticket for a one-way or a roud-trip shared van/shuttle via Super Shuttle. After collecting your baggage proceed to the Super Shuttle counter and show your reservation or purchase your ticket. The cost will be approximately $25 each way. See http://www.supershuttle.com for online ticketing and reservations.

From Houston Hobby Airport (HOU)

Taxi: Proceed to baggage claim to collect your luggage and then proceed out the doors indicated for taxis and ground transportation. You can request a credit card cab and ask for a receipt. Taxis from the airport are zoned and a ride to the Medical Center/Reliant Park area should cost $27 plus tip.

Super Shuttle: Either prior to arrival or upon arrival at the aiport you can purchase a ticket for a one-way or a roud-trip shared van/shuttle via Super Shuttle. After collecting your baggage proceed to the Super Shuttle counter and show your reservation or purchase your ticket. The cost will be approximately $22 each way. See http://www.supershuttle.com for online ticketing and reservations.

From IRMMW-THz 2011 Conference to Crowne Plaza Reliant Park

The TeraNano PIRE program will arrange shuttle transportation from the Hyatt Regency Hotel (Downtown) to the Crowne Plaza Reliant Park Hotel for all attendeese who will already be in Houston for the IRMMW-THz 2011 Conference. Exact shuttle details will be sent to the appropriate inviduals via email by Wednesday, October 5.

From Hotel to Bush Intercontinental Airport (IAH)

The hotel provides a free airport shuttle for all guests leaving from the hotel each hour on the half hour (6:30, 7:30, 8:30, etc.). To book a seat on the airport shuttle speak with the concierge to determine what departure time would be best given your flight schedule.

Crowne Plaza Houston on Kirby (Reliant Park)
8686 Kirby Drive • Houston, Texas 77054
Phone: (713) 748-3221 • Fax: (713) 796-9371

Houston Hotel Services and Amenities

The hotel is also located just one mile from the Reliant Park Metrorail Stop for convenient access to Downtown Houston. At the Crowne Plaza Houston near Reliant Park / Medical Center Hotel, enjoy complimentary wireless high-speed Internet access, complimentary weekday newspaper, unlimited access to our 24-hour Business Center and state-of-the-art 24-hour fitness center. The hotel also has two outdoor pools and a hot tub.

Crowne Plaza Houston Hotel Dining

Stetson's serves breakfast, lunch and dinner with a southwest flair and is located in the lobby of the main hotel tower. The Cattleman's Bar & Grill offers a large sitting area and comfortable bar area and serves favorite cocktails and light fare. Join us for Happy Hour daily from 4:30 pm until 10:30 pm.

Shuttle Transportation

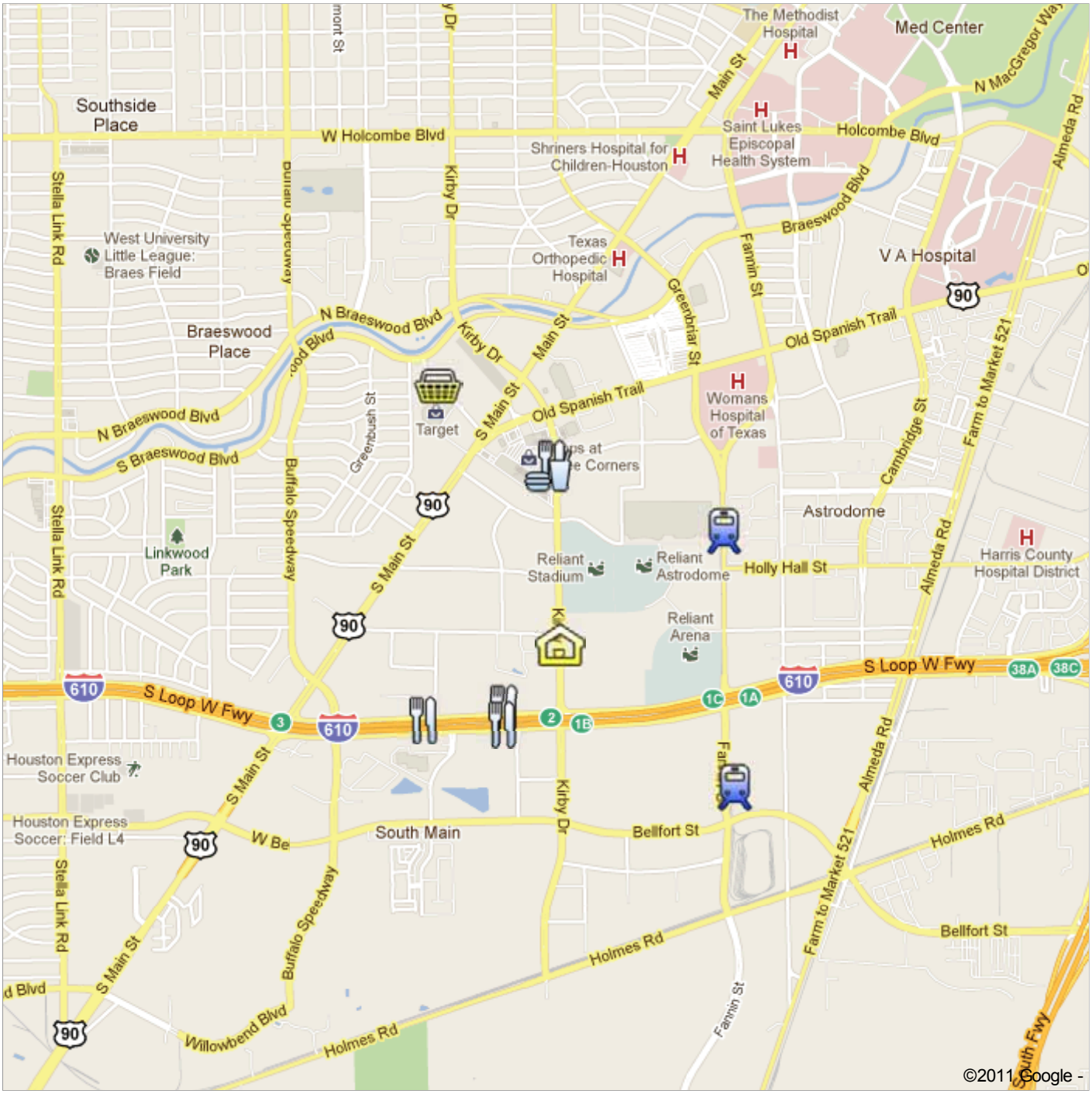
The Crowne Plaza Houston Medical Center Hotel is pleased to offer guests complimentary shuttle service within a 5-mile radius of the hotel. They also offer an airport shuttle to Bush IAH for hotel guests. Speak with the hotel front desk about shuttle arrangements. Scheduled shuttles have been arranged for meeting attendees for transport to/from Rice and our meeting events. See the detailed information in the meeting schedule.

Nearby Restaurants

There are a number of restaurants located quite close to the hotel including Olive Garden, Joe's Crab Shack, Pappadeaux Seafood Kitchen, and Pappasito's Cantina. Ask the hotel front desk for directions.

You can also utilize the hotel shuttle to take you to Rice Village (less than three miles away) which has dozens of highly rated, eclectic restaurants, bars and fine dining. With more than 300 shops and restaurants, Rice Village boasts of French, Japanese, Chinese, Italian, Turkish, Mexican, Spanish, Mediterranean, Vietnamese, Indian and Thai restaurants, one better than the next!

There are also many dining and entertainment options available in Downtown Houston which can be accessed via hotel shuttle, taxi, or Houston Metrorail (nerest stop 1 mile walk from hotel).



Crowne Plaza Hotel Reliant Park Near Medical Ctr

Public · 0 views
Created on Sep 23 · By Sarah · Updated < 1 minute ago

View Interactive Map Online at http://tinyurl.com/CrownePlazaReliant

Rice Village Shopping & Dining District

Information Taken from Rice Village Website - Not Responsible for Incorrect Addresses or Closures

Rice Village is a collection of shops, restaurants and pubs, situated about a half-mile west of the center of Rice University's 300-acre (1.2 km2) campus. The core "Rice Village" extends over 10 city blocks, defined by University Boulevard, Kirby Drive, Rice Boulevard, and Morningside Drive

Dining Options

- Antone's Import Co., 2424 Dunstan Rd, Houston, TX 77005 (Po'boys, subs & deli)
- Bombay Brasserie, 2414 University Blvd., Suite 210, Houston, TX 77005 (Indian restaurant)
- Brown Bag Deli, 2523 Amherst St., Houston, TX 77005
- Cafe Rabelais, 2462 Bolsover, Houston, TX 77005 (French restaurant)
- Collina's Italian Cafe, 2400 Times Boulevard, Houston, TX 77005
- Croissant Brioche, 2435 Rice Blvd, Houston, TX 77005 (French Bakery & Cafe)
- D'Amico's Italian Market & Cafe, 5510 Morningside Drive, Houston, TX 77005
- El Meson, 2425 University Blvd, Houston, TX 77005 (Mexican, Cuban & Spanish restaurant)
- Fuzzy's Pizza Sports Cafe, 5925 Kirby Drive, Suite N., Houston, TX 77005
- Jason's Deli, 2530 University Blvd, Houston, TX 77005
- Jersey Mike's Subs, 5819 Kirby Dr, Houston, TX 77005
- Kahn's Delicatessen, 2429 Rice Blvd, Houston, TX 77005
- Kubo's Sushi Bar & Grill, 2414 University Blvd # 200, Houston, TX 77005 (Japanese)
- La Madeleine, 6205 Kirby Dr, Houston, TX 77005 (French bakery & cafe)
- Le Peep Restaurant, 6128 Village Parkway, Houston, TX 77005
- Miss Saigon's Cafe, 5503 Kelvin Drive, Houston, TX 77005 (Vietnamese)
- Prego, 2520 Amherst St., Houston, TX 77005 (Italian)
- Shiva Indian Restaurant, 2514 Times Blvd, Houston, TX 77005
- Texadelphia Sandwich Shop, 2420 Rice Blvd, Houston, TX 77005
- Thai Village Restaurant, 2512 Times Boulevard, Houston, TX 77005

Pubs, Bars, and Clubs (Bring your Passport as you will be asked to show ID)

- Baker St. Pub & Grill, 5510 Morningside Dr, Houston, TX 77005 (Draught beer, wine, and restaurant)
- Brian O'Neill's Restaurant & Irish Pub, 5555 Morningside Dr, Houston, TX 77005
- Bronx Bar, 5555 Morningside Dr # 105, Houston, TX 77005
- Buffalo Wild Wings Grill & Bar, 2525 Rice Blvd, Houston, TX 77005 (Buffalo wings, food, & sports)
- The Ginger Man, 5607 1/2 Morningside Drive, Houston, TX 77005 (Popular bar with huge selection of beers on tap)
- Little Woodrow's, 5611 Morningside Dr, Houston, TX 77005

Rice Village Map

Home

Shopping

Dining

Picture Tour

Maps & Directions

Houston Area Map & Directions

Map of Rice Village Stores

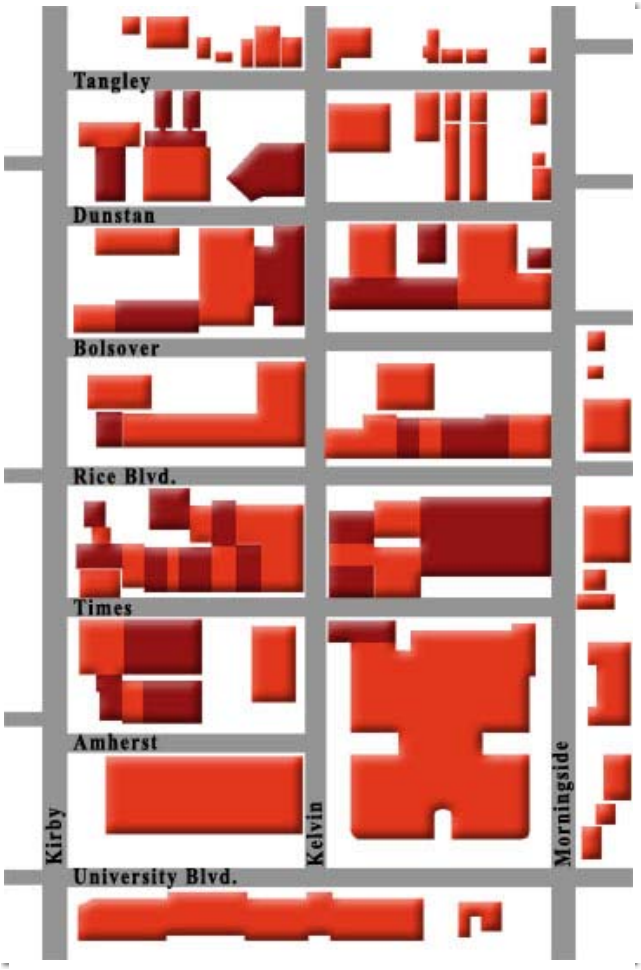
Online Forum

Ask a Question

Store Search:

Go

Rice University
RiceVillageOnline.com is not affiliated with Rice University.



A **map of Rice Village** is given to the left. Move your mouse across the map to see store & restaurant names throughout the Village.

*** Javascript required**

Interactive Map from MapQuest

Search Rice Village:

Go

Directions to Rice Village

Locations & Menus

Locations & Menus
MARKET SQUARE
THE CLOISTER
THE TUNNEL
AT THE SHOPS
TAKE-AWAY
TAKE OUT
Catering
News & Recipes
History
Treebeards Store
Contact Us
Links

When **Treebeards** outgrew its original location on Preston Street, we made the move to Travis Street in June of 1980. Known to historians as the Baker-Travis Building, circa 1861, our current location facing Market Square is the second oldest building in Houston. It was the original property of Rebecca Baker when she married Joseph F. Meyer, Sr., and is still owned by the family. Previous tenants have included a seed store, a tailor shop run by Rex Braun (a former state rep.), a toy store, and several lounges, including The Super Market, a popular psychedelic night club in the late 60's.

Come in for lunch and dine in our main hall downstairs, go upstairs for the comfortable atmosphere, or enjoy sitting outside on our balcony.

HOURS: Monday–Friday, Lunch 11am to 2:30pm

S O M U C H T O D O • S O L I T T L E T I M E

DESTINATION DOWNTOWN:

With a fusion of culture, lifestyles and commerce, life around here is anything but typical. Look up and discover soaring skyscrapers designed by icons like Philip Johnson and I.M. Pei. Turn a corner and bump into Houston's historic past or uncover a piece of contemporary public art. Major league sports, world-class theater, innovative chefs, funky hotspots, movies in the park, sidewalk cafes, outdoor festivals, pontoon boat tours and more. **Welcome to Downtown Houston!**

Attractions & Sights

1 Buffalo Bayou
2 Discovery Green
3 Downtown Aquarium
4 George Bush & James A. Baker, III Monuments
5 George R. Brown Convention Center
6 Historic District
7 JP Morgan Chase Tower Observation Deck
Monday - Friday, 8am - 5pm
8 Main Street Square
9 Southern Pacific Steam Engine 982
10 Saint Arnold Brewing Company
11 Union Station at Minute Maid Park
12 Wells Fargo Plaza Observation Deck
Monday - Friday, 8am - 5pm

Eat & Drink

13 Ballpark District
14 Bayou Place/Theater District
15 Discovery Green
16 Downtown Aquarium
17 Historic District/Market Square
18 Houston Pavilions
19 The Shops at Houston Center
20 Warehouse District

City, County & Federal

21 Bob Casey Federal Courthouse
22 City Hall/City Hall Annex
23 Harris County Court Complex

Institutions

Education

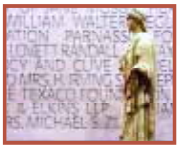
24 Incarnate Word Academy
25 South Texas College of Law
26 University of Houston Downtown

Medical

27 St. Joseph Medical Center

Religious

28 Antioch Baptist Church
29 Annunciation Catholic Church
30 Christ Church Cathedral
31 First Church of Christ Scientist
32 First United Methodist Church
33 Holy Cross Chapel
34 Islamic Dawah Center
35 Sacred Heart Co-Cathedral



Museums & Libraries

36 Houston Central Library
37 Julia Ideson Library
38 Heritage Society Museum
39 Museum District (via METRORail)

Music Venues

40 House of Blues
41 Verizon Wireless Theater

Recreation

54 Buffalo Bayou (hike, bike & jogging trail, canoe & kayak)
55 Discovery Green (jogging trail, bocce ball & putting green)
56 Lee & Joe Jamail Skatepark
57 Lucky Strike Bowling Lanes
58 Root Memorial Square (basketball court)

Sports

66 Minute Maid Park
67 Toyota Center

Transit

74 Downtown Transit Center
75 METRORail

Visitor Information

76 Explore Houston: GRBCC
77 Visitors Center: City Hall

Where to Stay

78 Alden Hotel
79 Athens Hotel Suites
80 Club Quarters
81 Courtyard by Marriott/ Marriott Residence Inn
82 Crowne Plaza Houston Downtown
83 Doubletree
84 Embassy Suites
85 Four Seasons
86 Hilton Americas - Houston
87 Holiday Inn Express
88 Hotel Icon
89 Hyatt Regency Downtown
90 Inn at the Ballpark
91 Lancaster Hotel
92 Magnolia Hotel

Shopping

59 Houston Pavilions
60 Macy's
61 The Shops at Houston Center

Grocery & Conveniences

62 Byrd's Market
63 CVS/Pharmacy
64 Phoenecia Specialty Foods
Coming Summer 2011
65 Wolfe's Cleaners

Theater

68 Alley Theatre
69 Hobby Center
70 Jones Hall
71 Jones Plaza
72 Wortham Theater Center

Film

73 Sundance Cinemas at Bayou Place
Coming Fall 2011

Parks

42 Allen's Landing
43 Discovery Green
44 Halliburton Plaza
45 Hermann Square
46 Pocket Park
47 Market Square Park
48 Root Memorial Square
49 Sabine Promenade
50 Sam Houston Park
51 Sesquicentennial Park
52 Sisters of Charity Park
53 Tranquillity Park

Tours

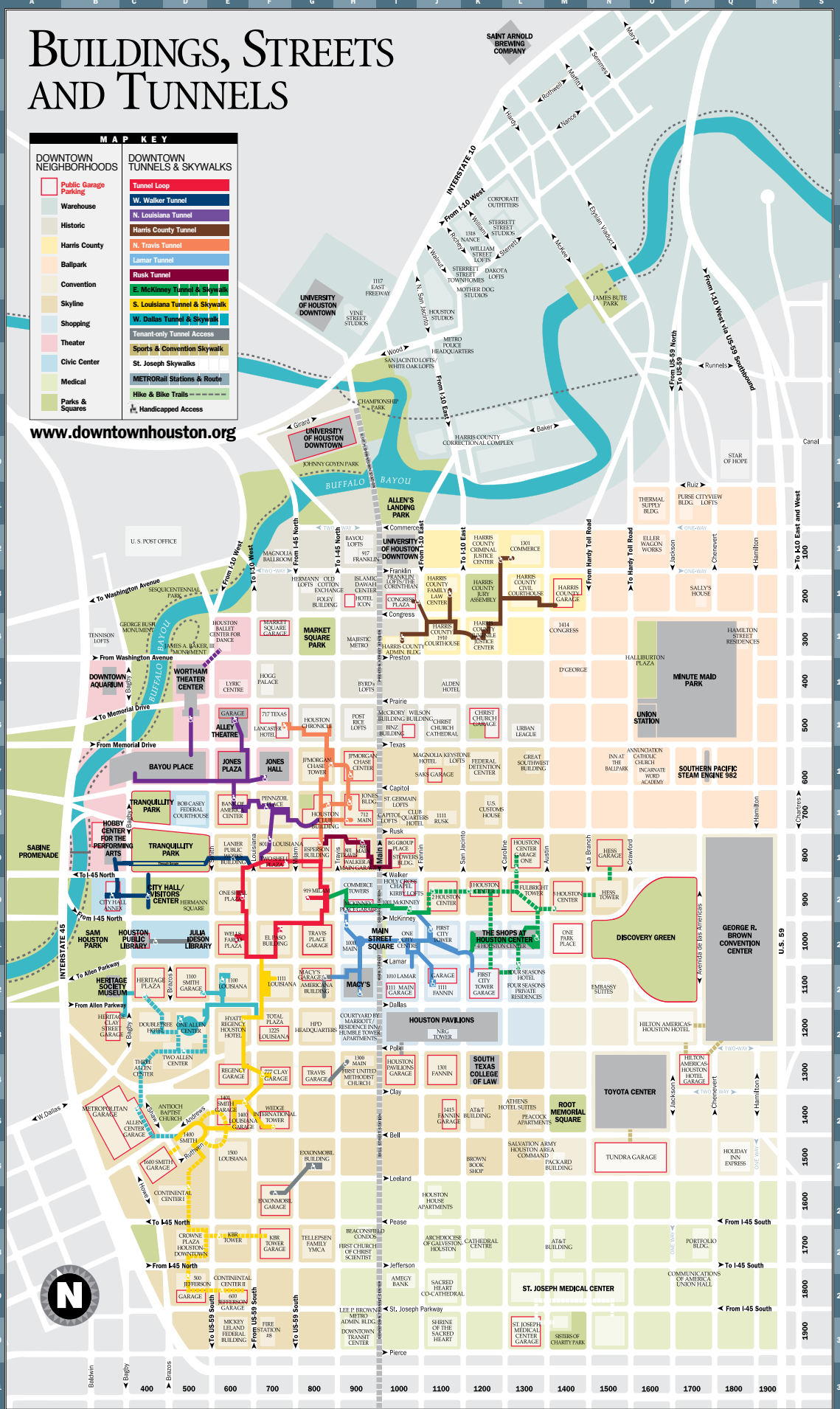
93	Buffalo Bayou Boat Tours	713-752-0314
94	Heritage Society Historic Homes Tour	713-655-1912
95	Minute Maid Park Tour	713-259-8687
96	Saint Arnold Brewery Tours	713-686-9494
97	Toyota Center Backstage Tour	713-758-7715

Free Self-Guided Audio Walking Tours download at downtownhouston.org
The Ultimate Downtown Walking Tour
The Museum District Walking Tour
Discovery Green Walking Tour

MAP KEY

Public Parking Garages · Bayou Trail Access · Historic District · 24-Hour Accessible ATM · Dog Park

Downtown Houston Map / 79



Locator

Buildings

1 Houston Center	K-20
2 Houston Center	J-20
4 Houston Center	K-21
5 Houston Center	M-20
500 Jefferson	D-29
712 Main	H-18
717 Texas	F-16
801 Louisiana	F-19
801 Travis	H-19
806 Main	H-19
917 Franklin	H-12
919 Milam	G-20
1000 Main	H-21
1001 McKinney	I-20
1010 Lamar	I-22
1100 Louisiana	E-22
1111 Louisiana	F-22
1111 Fannin	J-22
1111 Rusk	J-18
1117 East Freeway	I-6
1300 Main	H-24
1301 Fannin	J-24
1301 Commerce	L-12
1318 Nance	K-5
1400 Smith	D-26
1500 Louisiana	E-26
Amegy Bank	I-29
Americana Building	G-22
Archdiocese of Galveston-Houston	J-28
AT&T Building	K-25
AT&T Building	M-28
Bank of America Center	E-18
BG Group Place	I-19
Binz Building	I-16
Communication Workers of America Union Hall	P-29
Continental Center I	D-27
Continental Center II	E-29
The Corinthian	I-13
Corporate Outfitters	L-5
Eller Wagon Works	O-12
El Paso Building	F-21
Esperson Buildings	G-19
ExxonMobil Building	G-26
Fire Station No. 8	F-30
First City Tower	J-21
Fulbright Tower	L-20
Great Southwest Building	L-17
Heritage Plaza	C-22
Hess Tower	N-20
Houston Ballet Center for Dance	E-14
Houston Chronicle	G-16
Houston Club Building	G-18
Houston Studios	J-7
Jones Building	H-18
JPMorgan Chase Center	H-17
JPMorgan Chase Tower	G-17
KBR Tower	E-28
Lee P. Brown METRO Administration Bldg.	H-30
Lyric Centre	E-15
Magnolia Ballroom	F-12
Majestic Metro	H-14
McCrory Building	I-16
METRO Downtown Transit Center	H-30
METRO Police Headquarters	J-7
Mother Dog Studios	K-6
NRG Tower	J-23
Old Cotton Exchange	G-13
One Allen Center	D-23
One City Centre	I-21
One Shell Plaza	E-20
Portfolio Building	P-28
Pennzoil Place	F-18
Purse Building	P-11
Sterrett Street Studios	L-5
St. Joseph Medical Center	N-29
Stowers Building	I-19
TOTAL Plaza	F-23
Thermal Supply Building	O-11
Three Allen Center	C-24
Two Allen Center	D-24
Two Shell Plaza	F-19
Urban League Building	L-16
Vine Street Studios	H-7
Wedge International Tower	F-25
Wells Fargo Plaza	E-21
Wilson Building	I-16

Government

Bob Casey Federal Courthouse	D-18
City Hall	C-20
City Hall Annex	B-20
Congress Plaza	I-13
Federal Detention Center	K-17
Harris County Administration Building	I-14
Harris County 1910 Courthouse	J-14
Harris County Civil Courthouse	L-13
Harris County Criminal Justice Center	K-12
Harris County Family Law Cntr.	J-13
Harris County Correctional Complex	J-9
Harris County Jury Assembly	L-10
Harris County Juvenile Justice Center	K-13
Houston Police Department	K-14
Lanier Public Works Bldg.	G-23
Mickey Leland Federal Bldg.	E-19
U.S. Customs House	E-30
U.S. Post Office	K-18

Hotels

Alden Hotel	J-15
Athens Hotel Suites	L-25

(Hotels, continued)

Club Quarters Hotel	I-18
Courtyard by Marriott/ Residence Inn	H-23
Crowne Plaza Houston - Downtown	D-28
Doubletree Hotel	C-23
Embassy Suites	N-22
Four Seasons Hotel	L-22
Hilton Americas-Houston	O-23
Holiday Inn Express	Q-26
Hotel Icon	H-13
Hyatt Regency Hotel	E-23
Inn at the Ballpark	N-17
Lancaster Hotel	F-16
Magnolia Hotel	J-17

Residential

Bayou Lofts	H-12
Beaconsfield Condos	H-28
Byrd's Lofts	H-15
Capitol Lofts	I-18
CityView Lofts	P-11
Commerce Towers	H-20
Dakota Lofts	K-6
Eller Wagon Works	O-12
Foley Building	G-13
Four Seasons Private Residences	L-22
Franklin Lofts	I-13
Hermann Lofts	G-13
Hogg Palace	F-15
Houston House Apartments	J-27
Humble Tower Apartments	H-23
Keystone Lofts	J-17
Kirby Lofts	I-20
One Park Place	M-21
Peacock Apartments	L-25
Post Rice Lofts	H-16
San Jacinto Lofts	I-8
Sterrett Street Townhomes	K-6
St. Germain Lofts	I-18
Tennison Lofts	B-14
White Oak Lofts	I-8
William Street Lofts	K-6

Shopping

Brown Book Shop	K-26
Houston Pavilions	J-23
Macy's	H-22
The Shops at Houston Center	K-21

Theater District/ Sports & Conventions

Alley Theatre	E-16
Bayou Place	D-17
·Sundance Cinemas	
·Verizon Wireless Theater	
George R. Brown Convention Center	Q-21
Hobby Center for the Performing Arts	B-19
Jones Hall	F-17
Jones Plaza	E-17
Minute Maid Park	P-15
Toyota Center	N-24
Wortham Theater Center	D-15

Places of Interest

Allen's Landing Park	I-11
Antioch Baptist Church	D-25
Annunciation Catholic Church	O-17
Buffalo Bayou Hike & Bike Trail	I-11
Championship Park	H-9
Christ Church Cathedral	J-16
Discovery Green	O-21
Downtown Aquarium	B-15
First Church of Christ Scientist	H-28
First United Methodist Church	H-24
George Bush Monument	C-13
Heritage Society Museum	B-22
Halliburton Plaza	O-15
Hermann Square	D-20
Holy Cross Chapel	I-20
Houston Pavilions	J-23
Houston Public Library	C-21
Incarnate Word Academy	O-17
Islamic Dawah Center	H-13
James A. Baker, III Monument	D-14
James Bute Park	N-6
Johnny Goyen Park	G-10
JP Morgan Chase Tower Observation Deck	G-17
Julia Ideson Library	D-21
Main Street Square	H-21
Market Square Park	G-14
Root Memorial Square	M-25
Sabine Promenade	A-19
Sacred Heart Co-Cathedral Cathedral Centre	J-29
Shrine of the Sacred Heart	K-28
Saint Arnold Brewing Company	J-30
Sam Houston Park	L-1
Sesquicentennial Park	B-21
Sisters of Charity Park	C-16
Southern Pacific Steam Engine 982	M-30
South Texas College of Law	P-17
Tellepsen Family YMCA	K-24
Tranquility Park	G-28
Univ. of Houston Downtown	C-19
Univ. of Houston Downtown	G-9
Visitors Center	I-12
Wells Fargo Plaza Observation Deck	C-20

For more information about Downtown go to:
www.downtownhouston.org

80 / Historic District Restaurants

All located in within easy walking distance of Treebeard's in Downtown Houston's Historic District.

17 Restaurant - $$$$ - American
1117 Prairie, 832-200-8800
Found in the lobby of the luxurious Alden Hotel, this lush and lavish destination screams elegance. Detailed American cuisine and intelligent service make this a restaurant of note in the Historic District.

Azuma Sushi & Robata Bar - $$ - Asian
909 Texas, 713-223-0909
Voted for having the "Best sushi in Houston" by Citysearch.com, this new-age Japanese restaurants anything but typical.

Cabo - $$ - Mexican/Latin
419 Travis, 713-225-2060
Enjoy your favorite drink downstairs at the bar, or dine for a meal upstairs at the restaurant. This hip Mix-Mex spot offers outdoor balcony seating on the second floor that overlooks the streets of downtown.

Cafe Luz - $ - American
907 Franklin, 281-912-3589
A bakery café named after the hand-crafted copper lighting that illuminates the historical space near Market Square Park. Diners will find seasonal dishes and baked goods from chefs all over the city.

Convey Sushi - $ - Asian
803 Congress Street, 713-518-7219
A very cool new sushi spot located at Market Square. The same owner as next door neighbor, Les Givral's Kahve, Convey is affordable sushi. A conveyer belt, thus the name, runs down the center of the bar.

El Rey Taqueria - $ - Mexican/Latin
233 Main, 713-225-1895
This Cuban and Mexican eatery offers traditional food that can't be found elsewhere downtown. Home of the tasty plantains and juicy roasted chicken, El Rey will leave dining guests satisfied.

ERA - $ - Italian
809 Congress, 713-225-1066
ERA is Market Square's newest addition, offering sandwiches and personlized pizzas. The menu is creative and goes beyond typical Italian fare with internationaly-inspired flavors. With names like Thai Thai and Chupacabra, you'll find a pizza to satisy your cravings.

Falafel Frenzy - $ - Mediterranean
914 Prairie, 713-237-8987
This quaint spot serves up all your Mediterranean favorites, including beef and chicken kabobs, hummus and of course falafels.

Frank's Pizzeria - $ - Italian
417 Travis, 713-225-5656
Serving the downtown area since 1997 and home of the "Late Night Slice." Frank's Pizzeria has built a quality reputation for itself serving up delicious food in a great atmosphere.

Hearsay Gastro Lounge - $$ - American
218 Travis, 713-225-8079
Located in a beautifully refurnished historic building, this upscale restaurant and lounge serves up delicious French inspired sandwiches, salads, and entrees. Theat feature an extensive wine list, numerous beers on draft and in bottle and premium liquors.

Hubcap Grill - $ - American
1111 Prairie, 713-223-5885
Freestanding gray building adorned with hubcaps featuring the best burgers in Downtown! Everything made from scratch, all the meat is fresh - never frozen, even the buns are homemade!

Irma's New Southwest Grill - $$ - Mexican/Latin
1314 Texas Avenue, 713-247-9651
A hip spot to quench a Mexican food craving! Enjoy tasty foods and great drinks for lunch or dinner, while being only a few blocks from Minute Maid Park.

Les Givral's Kahve - $ - Vietnamese
801 Congress, 713-547-0444
Winner of the 2006 "City's Best" award for Vietnamese restaurants in Houston, Les Givral's offers a dynamic menu and great service for dining guests. Les Givral's Kahve prides itself on serving quality foods and listening to the customer.

Little Napoli - $$ - Italian
1001 Texas @ Main, 713-225-3900
In the mood for Italian? This bistro has exactly what you need. Offering its guests casual Italian items, and the option to enjoy their meal inside or outside on the patio, Little Napoli brings Italian eating to downtown.

Macondo Latin Bistro - $ - Mexican/Latin
208 Travis, 713-228-3560
Open seven days a week for breakfast, lunch, and dinner, this quaint neighborhood spot features Columbian breakfast specials served with plantains and rice. They have 100 wines by the bottle - all under $20.

Market Square Bar & Grill - $ - American
311 Travis, 713-224-6133
This Chicago-style hangout has turned completely Texan. Boasting a handful of "fire-powered" burgers, Market Square offers plenty of reasons to stop by for a meal. The backyard patio, friendly staff, and full bar add flavor to this bar and grill.

Mia Bella Trattoria - $$ - Italian
320 Main, 713-237-0505
Dining guests will enjoy an eclectic variety of Italian cuisine, blended with a Mediterranean feel. The dining area offers a comfortable ambience.

Minuti Coffee - $ - Coffee/Dessert
909 Texas, 713-226-7500
The coffee is created by a 'roast master' in Italy, before making its way into the hands of talented baristas. This is the perfect place to bring the laptop and take advantage of Minuti's free wifi. They also have beer.

Niko Niko's Market Square - $ - Mediterranean
301 Milam @ Congress, Market Square Park, 713-528-4976
A Houston staple serving up Greek food since 1977, Niko Niko's at Market Square Park offers a pared down menu from their flagship Montrose location.

Sambuca Jazz Cafe - $$$ - American
909 Texas Ave., 713-224-5299
A hip, trendy and upscale restaurant right in the mix of Main Street. The menu includes a wide variety of favorites and combined with the live music, Sambuca's is Houston's ultimate supper club.

Spaghetti Warehouse - $$ - Italian
901 Commerce, 713-229-0009
Making its home in an old warehouse downtown, this Italian-American eatery offers up large portions for lunch and dinner. Serving traditional cuisines such as spaghetti and meatballs, lasagna, and pizza, the Spaghetti Warehouse caters to all ages and appetites.

Warren's Inn - $ - American
307 Travis, 713-247-9207
This downtown hangout is a very popular spot in the Historic District. The goods times will roll with a song-filled jukebox, excellent drinks, and a fun and hip environment. Quick sandwiches are served during the day.

Bars and clubs in the Historic District are located near Treebeard's. You may be required to show ID (passport or driver's license) to enter or order alcoholic beverages.

Brewery Tap - Historic
717 Franklin, 713-237-1537
This downtown brewery has been around for a while, but doesn't show any signs of aging. This brewery offers a vast selection with its 35 beers on tap. Laid-back and friendly, a great place to catch a game of darts.

Cabo Bar - Historic
419 Travis, 713-225-2060
A great restaurant/bar for lunch, dinner or happy hour! Guests can catch the game on the tube, or can look onto the city streets through the restaurant windows.

Char Bar - Historic
305 Travis, 713-227-5867
Operating since 1930, Char Bar is extremely unique. Sharing places with an in-house tailor, the bar area serves infamous martinis that pack quite a punch. Two full-service bars cater to the needs of the guests.

Club Curve - Historic
410 Main, 832-460-0150
Club Curve offers a historical brick, loft-like atmosphere and features large screens where you can watch the town's most impressive Video Jockeys mix today's hottest music. The atmosphere is elegant and sexy, the service slick and professional.

Dean's Credit Clothing - Historic
316 Main, 713-227-3326
Located in the Historic District, this location is a clothing store by day and a bar by night. The wood floors and variety of clothing items hung all around, give Dean's a distinctive look and feel.

Dive Lounge - Theater
410 Bagby, Downtown Aquarium, 713-223-3474
A gallery-styled lounge with rippling water walls, and a low-lit, mellow ambiance allows guests to unwind and relax.

Eighteen Twenty Bar - Ballpark
1820 Franklin, 713-224-5535
Located just one block north of Minute Maid Park, Eighteen Twenty Bar is your quaint neighborhood spot serving up a cozy atmosphere along with your favorite spirits and some yummy munchies: pizzas, white castle cheese burgers and popcorn.

Flying Saucer - Historic
705 Main, 713-228-7468
This spot is a definite standout among downtown bars. Offering over 200 beers, with almost half on draft, Flying Saucer is a great place to hang out. A cool and relaxed atmosphere along with a hip crowd.

Hearsay Gastro Lounge - Historic
218 Travis, 713-225-8079
Hearsay Restaurant and Gastro Lounge New American Located in a beautifully refurnished historic building, this upscale restaurant and lounge serves up delicious French inspired sandwiches, salads and entrees. They feature an extensive wine list and numerous beers on draft.

Home Plate Bar & Grill - Ballpark
1800 Texas, 713-222-1993
Located across the street from Minute-Maid Park, Home Plate offers fun and excitement for local sports fans. Before or after an Astros game, fans can enjoy a drink or meal at this sporty hangout.

Kryptonite - Historic
717 Franklin St.
Located in the basement of the Manolia Brewery Building.

Downtown Bars & Clubs / 83

Bars and clubs in the Historic District are located near Treebeard's

La Carafe - Historic
813 Congress, 713-229-9399
The oldest bar in Houston, this little wine and beer getaway is a downtown treasure. Boasting a great jukebox, romantic atmosphere, and an extensive wine selection, this quaint bar offers an unforgettable experience to visitors.

Last Concert Cafe - Warehouse
1403 Nance, 713-226-8563
This warehouse location is a true downtown jewel. Come catch live music every night at Last Concert. The backyard is a great place to enjoy a drink, socialize, or sit back and relax.

Lone Star Saloon - Skyline
1900 Travis , 713-757-1616
This laid back location caters to the after-work and late-night crowds. One of the older locations downtown, this saloon has a come-as-you-are attitude. A big screen TV and classic jukebox entertains.

Lucie's Liquors - Theater
534 Texas, 713-836-2276
Go to Lucie's for a taste of vintage Vegas, quality drinks and a night to remember. The attitude at this place is to remember a time when the Rat Pack was at the top and the ladies called the shots.

Lucky Strike Lanes & Lounge - Shopping
1201 San Jacinto, Houston Pavilions, Level 3, 713-343-3300
American Upscale bowling alley with a separate restaurant/lounge area. Bowlers and patrons relax on sleek leather couches and enjoy floor-to-ceiling video screens that flash movie clips and music videos as DJs deliver danceable grooves.

Market Square Bar & Grill - Historic
311 Travis, 713-224-6133
This Chicago-styled hangout offers excellent martinis from its full bar. MSB&G is known for their friendly service, and the laid-back atmosphere is conducive to conversation. A local favorite!

Molly's Pub - Historic
509 Main, 713-222-1033
This classic Irish pub offers a variety of Irish whiskeys and international beers.

Notsuoh - Historic
314 Main
And for those who have missed James Pirtle's Notsuoh, mourn no longer; this funky spot is open again. Patrons can enjoy art, music, games and more along with its simple menu.

PBR Houston - Theater
534 Texas, 713-229-8499
Cowboy cool meets urban chic in this country bar in the city. Grab a cold beer, hard drinks and try your hand at a little bull riding. This is place is you want to two-step or hang low.

Reserve 101 Martini & Scotch Bar - Convention
1201 Caroline, 713-655-7101
Stop in this comfortable, classy bar for an exotic martini, glass of their monthly featured wine, or a glass of scotch from one of the most impressive scotch lists in Houston.

Sambuca - Historic
909 Texas, 713-224-5299
This upscale spot is located right in the mix of Main Street in the historic Post Rice Lofts, formerly the Rice Hotel. Guests can enjoy live music every night of the week in this unique and eclectic environment.

Bars and clubs in the Historic District are located near Treebeard's

Shark Bar - Theater
534 Texas, 713-229-8499
No need to drive to Galveston to get to the Beach. This surf bar is an endless party with pail punch, pina coladas and retro dance music that will take you to the North Shore.

Shay McElroy's Pub - Historic
909 Texas, Suite A, 713-223-2444
Located on Main St., this Irish pub has found a new home in downtown Houston. Imported Irish décor and a friendly staff greet visitors upon entrance. The atmosphere is very authentic, and the spirits are quite tasty as well.

State Bar - Historic
909 Texas, Ste 2A, 713-229-8888
Located on the second floor of the Rice Lofts, this upscale bar presents a classical richness all its own. Guests are greeted by a mahogany bar and high-arched windows as they enter.

The Dirt - Shopping
1209 Caroline St., 713-651-3988
The Dirt has been a Houston landmark for over six years, serving as a favorite home away from home for Houstonians and international musicians alike.

The Sam Bar @ Alden Hotel - Historic
1117 Prairie, Alden Hotel, 832-200-8800
Accompanying the popular 17 Restaurant, The Sam Bar is stylish and sleek. The atmosphere exudes a new modern feel. The Sam Bar offers guests a refreshing experience in the distinguished Alden Hotel of Houston.

Voice @ Hotel Icon - Historic
220 Main, 713-224-4266
At VOICE, Hotel ICON's restaurant and lounge, guests are invited to Savor - Sip - Socialize. The grand yet intimate bar and lounge offer patrons a unique, comfortable enviroment surrounded by towering columns and irreplaceable historic elements.

Warren's Inn - Historic
307 Travis, 713-247-9207
It may not be fancy, but this downtown hangout is a favorite of the locals. The good times will roll with a killer jukebox, excellent drinks, and a fun, no-cares attitude.

Alley Theatre - Downtown - Theater District
Saturday - 2:30 PM OR 8:00 PM
Admission: Ticket Prices Vary
Website: http://www.alleytheatre.org/
Dividing the Estate: Deeply funny. Richly drawn. Recommended for mature audiences. Horton Foote, the award-winning writer of The Trip to Bountiful and The Day Emily Married, returns to the town of Harrison, Texas, with this sharp satire about a Southern dynasty in crisis. At odds over the fate of their dwindling inheritance, several generations of the well-to-do Gordon family must confront their disreputable past as they grapple with an uncertain future. Will they face possible ruin and indignity together or take their chances and go their separate ways? **Ether Dome :** Discovery. Deception. Betrayal. Recommended for mature audiences. About love, deception and betrayal, Ether Dome tells the story of the discovery of anesthesia and focuses on the relationship between two of the greatest medical innovators in Western history, Horace Wells and his student, William Morton. Highlighting the inherent contradiction of profiting from people's illnesses, Ether Dome challenges our understanding of God, pain and what it means to be truly human.

Bayou City Art Festival - Downtown Houston
Saturday & Sunday - 10:00 AM to 6:00 PM
Admission: $10 - $15, Kids under 12 are free
Website: http://www.bayoucityartfestival.com/
The annual, juried, fine art event boasts a stress-free outdoor gallery brimming with 300 artists working in 19 artistic media. Adding to the festive outdoor gallery are wine cafés, the interactive Gexa Energy Creative Zone for children, restaurants, and a performing arts stage with ongoing multicultural musical and dance entertainment presented by The Houston Arts Alliance.

Greek Festival - Museum District - Near University of St. Thomas
Saturday - 11:00 AM to 10:00 PM
Admission: $5 Admission Only Ticket or $20 Pre-Order Tickets on Website (includes food plate)
Website: http://www.greekfestival.org/
The Original Greek Festival Houston, Texas - October 6 - 9, 2011
Come and join The Original Greek Festival, now in its 45th year, and be Greek for a day! Growing attendance over the years continues to create excitement as the word gets around, so bring your family, friends and co-workers to enjoy the festive atmosphere and our new expanded festival site. Facilities, children's activities, Athenian playground & seating capacity have also been expanded. OPA!!

Historic Pub Crawl - Downtown
Saturday - 5:45 PM
Admission: $30
Website: http://www.discoverhoustontours.com/
Stroll through Houston's Downtown Historic District and learn about the origins of the nation's fourth-largest city while you pop into five pubs or cafes for Dutch-treat happy-hour fare. Each tour features a stop inside the Spaghetti Warehouse (the most haunted building in Downtown Houston) and an exclusive opportunty to explore the basement of the 1926 Lancaster Hotel, where local socialites and actors entertained soldiers during World War II. Is this a ghost tour?

IKEA Houston Screen on the Green "RIO" - Downtown - Discovery Green Park
Saturday - 7:00 PM
Admission: Free
Website: http://www.discoverygreen.com/

Live Music - House of Blues - Who's Bad - Downtown
Saturday - 9:00 PM
Admission: Ticket Prices Vary
Website: http://www.hob.com/
Join the House of Blues Houston as they welcome Who's Bad to the stage!

Nightmare on the Bayou - Haunted House - Near Downtown
Saturday - Doors open at 7:30
Location: Nightmare on the Bayou is located next to Party Boy at 1515 Studemont St Houston, TX 77007-3823 (take taxi or drive)
Admission: $30 - $40
Website: http://www.nightmareonthebayou.com/
Nightmare on the Bayou (Next to the Graveyard!) is located at I-10 & Studemont near the Heights in the shadow of downtown Houston. And when we say "Next to the Graveyard", we mean it! Nightmare on the Bayou is located directly next to Houston's oldest graveyard. Nightmare on the Bayou is Houston's only haunted house THAT IS REALLY HAUNTED! We love our Ghosts, and are proud to be the only Haunted House in Houston that is REALLY HAUNTED!!! Don't believe it? Ask our employees! Actual hauntings abound in and around our multiple haunted attractions and property! Nightmare on the Bayou has over 15,000 sq. feet of Hauntedness!

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