

MESSAGE FROM CHAIRS

Welcome to the 2008 Villa and Virtual Conferences on Interaction Among Nanostructures (VC-IANs). The joint conferences will be held February 3rd-7th in Orlando, Florida. This conference aims to promote discussions and information exchange across the frontiers of research in the area of modern nanostructure development. International scientists with common professional interests in nanoscience will unite in a virtual, friendly and informal atmosphere to share both their knowledge of recent developments as well as their ideas about prospective directions and approaches to nano-scale advancements. The technical core of the meeting comprise of seven topics:

- Nanotubes
- Nanowires
- Quantum Dot Growth - Theory and Experiment
- Nanofabrication
- Properties of Quantum Dots
- Transport in Nanoscale
- Nanocrystal

This conference goes beyond a typical hotel setting, in an effort to foster intensive discussions around dining tables, swimming pools and spas. Juxtapose to the Gordon Research Conferences (GRCs), which restricts the transfer of information outside its walls, this conference encourages open-access to all of the information presented at the villa conference, regardless of whether given in a talk, a poster, or the following conference proceedings. The only constraint on reproduction and distribution, and the only role for copyright in this domain, should be to give conference attendees control over the integrity of their work and the right to be properly acknowledged and cited.

The joint virtual VC-IAN will run in real time, providing an advanced collaborative environment for participants from every corner of the world to share their knowledge while carrying on their regular scholarly duties and without the expense of physically traveling to the villas. By using the computers and phones in their offices or homes, through the Internet virtual VC-IAN participants will be able to present their research to the villa VC-IAN attendees by well-prepared topical sessions. Unlike a conventional conference, audiences are not limited to conference attendees alone.

The villa VC-IAN will not only be a time to enjoy the company of fellow researchers in the field, but also a time to have fun with friends and family! Therefore, we encourage you to give yourself some time for recreational pursuits and participate in many or all of the activities planned to SeaWorld, Walt Disney World and the Kennedy Space Center.

Our thanks are due to all those who have worked to make this such an exciting meeting, including the organizers and committee members. We hope that everyone attending has an enjoyable and productive week.

Kimberly A. Sablon
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VC-IAN 2008 General Chair

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	AM	PM	EVENING
MONDAY – FEB 4TH	9:00AM - 12:15PM	1:15PM - 2:45PM	7:00PM - 8:30PM
	NANOTUBES	NANOWIRES	VIRTUAL SESSION I
		2:45PM - 4:45PM	
		POSTER SESSION	
TUESDAY – FEB 5TH	8:00AM – 9:45AM	1:30PM – 4:45PM	7:00PM – 10:15PM
	QD GROWTH – THEORY & EXPERIMENT	PROPERTIES OF QUANTUM DOTS	TRANSPORT IN NANOSCALE
	10:00AM – 12:00PM		
	NANOFABRICATION		
WEDNESDAY – FEB 6TH	8:00AM – 9:00AM	UNTIL 5PM	7:30PM – 10:30PM
	VIRTUAL SESSION II		NANOCRYSTAL
	9:30AM – 9:45AM		
	TRANSPORTATION TO SEAWORLD	SEAWORLD	
THURSDAY – FEB 7TH	10:00AM – 10:15AM		
	TRANSPORTATION TO DISNEY WORLD	DISNEY WORLD	DISNEY WORLD
FRIDAY – FEB 8TH	10:00AM – 10:15AM		
	TRANS. TO KENNEDY SPACE CENTER	KENNEDY SPACE CENTER	

MAP OF CONFERENCE SITE

JOINT CONFERENCES ON INTERACTION AMONG NANOSTRUCTURES

February 3-7, 2008 Orlando, Florida, USA



16319 Magnolia Hill St
Clermont, FL 34714



1	16009 Hawk Hill Street	331	8	8	16144 Blossom Hill Loop	544	4
2	2918 Anhinga Hill Street	206	6	9	16021 Hawk Hill Street	328	4
3	16155 Palmette Hill Street	213	5	10	16319 Magnolia Hill Street	207	4
4	16037 Blossom Hill Loop	519	5	11	2801 Long Leaf Pine Street	40	4
5	16049 Magnolia Hill Street	27	4	12	2815 Sand Pine Street	55	4
6	16155 Egret Hill Street	315	4	13	16303 Magnolia Hill Street	210	4
7	16017 Blossom Hill Loop	524	4	14	16143 Magnolia Hill Street	74	3

9:00AM IAN018 (Invited)

Graphitic Nanotubes: Molecular Design and Functions

Takuzo Aida and Takanori Fukushima

JST ERATO-SORST Nanospace Project and Department of Chemistry and Biotechnology, School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan.

Understanding and utilization of π -electronic conjugation has become of increasing importance in materials sciences, particularly, for targeting molecular electronics, and a variety of molecules and substances, which show interesting optoelectronic properties have recently been reported. We recently found that bucky gels, prepared by grinding single-walled carbon nanotubes in imidazolium ion-based ionic liquids [1, 2], serve as highly powerful capacitors, and can be applicable to the fabrication of fully plastic actuators by layer-by-layer casting [3]. There are many other potential applications [4]. Graphitic nanotubes, prepared by self-assembly of an amphiphilic hexa-perihexabenzocoronene [5], are also interesting electronically active materials [6]. We also succeeded in obtaining a pseudo-crosslinked version of this graphitic nanotube by ADMET-triggered self-assembly of an allyl group-appended new amphiphilic hexa-*peri*-hexabenzocoronene [7]. On the other hand, we have developed photo and redox-mediated covalent stabilization of the graphitic nanotubes [8, 9]. Use of a chiral amphiphilic hexa-*perihexabenzocoronene* with stereogenic centers results in the formation of graphitic nanotubes with one-handed helical chirality [10, 11]. Water-dispersible graphitic nanotubes and surface-polymerized graphitic coils have also been fabricated [12, 13]. The most recent achievement includes the successful fabrication of a photoconductive graphitic nanotube with a coaxial architecture [14, 15].

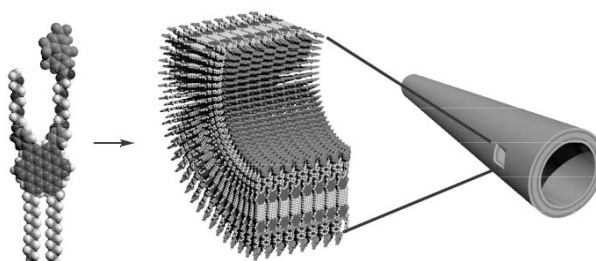


Fig.1 Schematic representation of a photoconductive graphite nanotube with a coaxial donor-acceptor heterojunction

Selected Publications:

(1) Hill et al., *Science* 2003, 300, 2072. (2) Fukushima et al., *Small* 2006, 2, 554. (3) Fukushima et al. *Angew. Chem., Int. Ed.* 2005, 44, 2410. (4) Fukushima et al. *Chem. Eur. J. (Concepts)* 2007, 13, 5048. (5) Müllen et al., *Chem. Rev.* 2007, 107, 718. (6) Fukushima et al., *Science* 2004, 304, 1481. (7) Jin et al., *J. Am. Chem. Soc.* 2005, 127, 10020. (8) Motoyanagi et al., *J. Am. Chem. Soc.* 2006, 128, 4220. (9)

Motoyanagi et al., *J. Polym. Sci., Part A, Polym. Chem. Ed.* 2006, 44, 5120. (10) Jin et al., *Proc. Natl. Acad. Sci., USA* 2005, 102, 10801. (11) Yamamoto et al., *Adv. Mater.* 2006, 18, 1297. (12) Zhang et al., *J. Am. Chem. Soc.* 2007, 129, 719. (13) Yamamoto et al., *J. Am. Chem. Soc.* 2006, 128, 14337. (14) Yamamoto et al., *Science* 2006, 314, 1761. (15) Yamamoto et al., *J. Am. Chem. Soc.* 2007, 129, 9276.

Figure 1. Schematic Representation of a Photoconductive Graphitic Nanotube with a Coaxial Donor–Acceptor Heterojunction.

9:30AM IAN020 (Invited)

STM on chemically functionalized carbon nanotubes and nanobuds

Abdou Hassanien

Nanotechnology Research institute, AIST, Tsukuba Ibaraki 305-8568 Japan, Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701

Carbon nanotubes (CNTs) represent an emerging new class of functional materials that hold great promise for future electronic nanodevices. The robust physical properties and structural integrity of single molecules has been utilized in building small circuits that work at room temperature. However, chemical inertness hampers research toward building realistic devices based on bottom up technology. In this talk I will address these issues by giving two examples of CNTs functionalization. In the first one I will present simple yet effective method to synthesize C_{60} - C_3NH_7 peapod. The second method uses floating catalyst technique in which the surface of CNTs has been decorated with chemical components, such as fullerenes, for further chemical derivitization. The interaction of fullerenes molecules with the sidewall of SWCNTs has been studied with high-resolution transmission electron microscopy (HRTEM), low temperature scanning tunneling microscopy (STM) and spectroscopy. Unlike physisorbed fullerenes, which are highly mobile under TEM observation, HRTEM images show stationary fullerenes indicating strong bonding with SWCNTs. Based on HRTEM images C_{60} molecules were identified as the predominant fullerenes species. Topographic STM images show also cage structure of fullerene molecules on SWCNTs that are stable against high bias imaging. Current tunneling imaging spectroscopy displays variation in the electronic properties in the vicinity of the fullerenes. The variation is strongly localized that SWCNT electronic states at 1.5 nm away are unaffected by the fullerenes attachment. . We take this as indication that the overall electronic properties of SWCNTs are unaltered by the presence of fullerenes and therefore nanobud material may offer an excellent opportunity to chemically activate SWCNTs without compromising their electrical behavior. We will also discuss possible functionalization routes to selectively decorate nanobud with active chemical groups to allow easily further chemical processing.

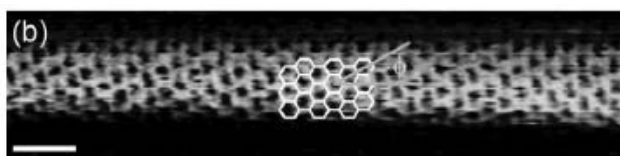


Fig. 1. Atomically-resolved topographic STM image of a zigzag nanotube in ambient conditions, the scale bar is 1 nm. The imaging parameters are 0.5 V and 0.2 nA for sample bias and tunneling current, respectively. The CNT diameter and chiral angle are 1.3 nm and 30° , respectively.

References:

1. A. Mrzel, A. Hassanien, Z. Liu c, K. Suenaga, Y. Miyata, K. Yanagi, H. Kataura, Surface Science 601 5116–5120 (2007)
2. Nasibulin *et. al.* Nature Nanotechnology 2(3), 156-161(2007)

10:00AM IAN015 (Invited)

A Novel Carbon Nanomaterial - Fullerene Functionalized CNT's: Synthesis, Structure and Field Emission Properties

Esko I. Kaupinen

NanoMaterials Group, Center for New Materials and Laboratory of Physics
Helsinki University of Technology, VTT Biotechnology, P.O. Box 1602, FIN-02044 VTT Espoo, Finland

We present synthesis, structure and field emission properties of a novel hybrid carbon nanomaterial, NanoBudsTM, combining fullerenes and single-walled carbon nanotubes (CNTs). NanoBuds consist of fullerenes attached to the *outside* surface of CNTs, i.e. nanotubes are functionalized with fullerenes (1). Two floating catalyst methods for their selective synthesis have been developed, using pre-made iron catalyst particles by a hot wire based PVD method or grown *in situ* via ferrocene vapour decomposition in the presence of CO and trace amounts of H₂O and CO₂. TEM images show spherical structures i.e. fullerenes at the surface of the tube. Their spherical nature was confirmed by tilting samples within a HR-TEM. Statistical size measurements on the basis of HR-TEM images revealed that the majority of fullerenes consists of C₄₂ and C₆₀. Interestingly, evidence of C₂₀ fullerenes, the smallest possible dodecahedra is found. Raman spectra show a pronounced G-band at 1600 cm⁻¹ associated with CNTs, and only a weak D-band at 1320-1350 cm⁻¹. The main peaks in MALDI-TOF spectrum are attributed to C₆₀ (C₆₀H₂, C₆₀H₂O) and C₄₂ (C₄₂COO) fullerenes. Accordingly, fullerenes are attached to CNTs via either oxygen (preferable for fullerenes larger than C₅₄) or carboxylic (for smaller fullerenes) bridges, which was confirmed by FT-IR measurements. EELS observations with TEM also showed the existence of oxygen. Scanning tunneling microscopy (STM) and spectroscopy (STS) measurements of samples deposited on Au(111) substrate confirmed the covalent nature of fullerene bonding to the tube. Atomistic density-functional-theory based calculations showed that systems composed of fullerenes and nanotubes with single vacancies covalently functionalized through ester groups can indeed exist. In-situ deposited i.e. non-purified planar NanoBud mats showed stable cold electron field emission with a current density of 189 μA/cm² at 1.26 V/μm. The threshold voltage was about 0.6 V/μm, compared to over 2 V/μm for similarly produced planar nanotube mats. In addition, we present novel method for direct integration of CNBs (and SWCNTs) into flexible thin film electronics structures, like transparent thin films to replace ITO. The electrical conductivity of as-produced thin CNB as well as SWCNT mats will be presented.

1. A. G. Nasibulin, P. V. Pikhitsa, H. Jiang, D. P. Brown, A. V. Krasheninnikov, A. S. Anisimov, P. Queipo, A. Moisala, D. Gonzalez, G. Lientschnig, A. Hassanien, S. D. Shandakov, G. Lolli, D. E. Resasco, M. Choi, D. Tománek, and E. I. Kaupinen, (2007) A Novel Hybrid Nanomaterial, *Nature Nanotechnology* 2(3), 156-161.

Acknowledgements

Albert G. Nasibulin, Hua Jiang, David P. Brown, Sergey D. Shandakov, David Gonzales, Paula Queipo, Anton Anissimov, Andrei Ollikainen, Gunther Lientschnig, Abdou Hassanien, Peter V. Pikhitsa, Mansoo Choi, Guilio Lolli, Daniel E. Resasco, Arkady V. Krasheninnikov, David Tomanek, Jussi Heikkonen and Risto Nieminen are acknowledged for collaboration as well as Academy of Finland, TEKES and EU for funding.

10:30AM Break

10:45AM [IAN003](#) (Invited)

Growth mechanism, structural regulation and functionalization of carbon-based nanotubes

[Zheng Hu](#)

Key Laboratory of Mesoscopic Chemistry of MOE and Jiangsu Provincial Lab for NanoTechnology, School of Chemistry and Chemical Engineering, Nanjing University, Nanjing 210093, China

The growth mechanism is a long-standing and controversial issue in the CNT-related studies and has become a choke point for the development of this field. By using the in situ thermal analysis-mass spectroscopic technique, the CVD growth process of CNTs with benzene precursor has been clearly illuminated and the six-membered-ring-based growth mechanism through surface diffusion is deduced. Along this line, a synergism mechanism of C₅N-six-membered-ring-based growth through surface diffusion and vapor-liquid-solid growth through bulk diffusion was further inferred for the synthesis of CN_x nanotubes from pyridine precursor. Accordingly, the nitrogen content in CN_x nanotubes has been regulated within 3~8% and the so-synthesized CN_x nanotubes have quite uniform distribution of the nitrogen species which is beneficial for the surface functionalization. The platinum nanoparticles were then conveniently immobilized on the CN_x nanotubes due to the N-participation which shows promising electrocatalytic property for methanol oxidation.

11:15AM [IAN036](#) (Invited)

Helical Symmetry Breaking in DNA-NT Hybrids: Optical Signaling of the Wrap

[Slava V. Rotkin](#)^{1 2}

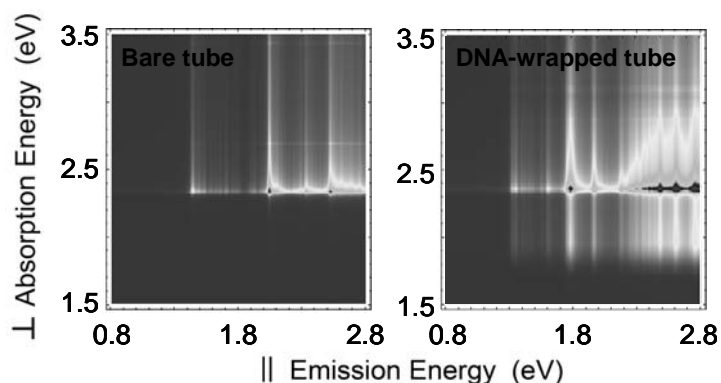
¹Physics Department, and ²Center for Advanced Materials and Nanotechnology, Lehigh University, Bethlehem, PA, USA

Functionalizing single-stranded DNA on a single-wall carbon nanotube (SWNT) [1] has allowed to isolate individual tubes, make them soluble, and separate SWNTs according to their symmetry. Such strong technological impact motivates us to study the optical properties of the DNA-SWNT hybrids, commonly used now for the solution-based fabrication and experiments. We demonstrated that symmetry-wise, the helicity of the DNA wrap may interfere with the electronic structure of the SWNT and result in various band gap modulations [2]. Thus a non-destructive characterization technique for detecting a specific binding is needed.

Theoretical modeling predicts a symmetry lowering in the SWNT band structure due to the Coulomb potential of the regular helical wrap of the ssDNA [2-4], followed by the qualitative changes in the cross- or circularly polarized SWNT absorption spectrum (with no or little change in the parallel polarization). In particular, we predict the appearance of a new peak in the cross-polarized absorption of the ssDNA-SWNT at a frequency lower than that of all allowed transitions in the bare tube. The Figure shows a dramatic difference in luminescence-absorption maps in the region of the first van Hove singularity of a (7,0) achiral zigzag SWNT wrapped with the ssDNA. Such effect can be used for optical identification of the wrap at sufficient ssDNA coverage. Wrap signaling happens also via another optical effect, a strong circular dichroism even in the complex with an achiral SWNT, resulted from the symmetry breaking [3].

Symmetry of the wrap is central to determine the circular dichroism and optical response of the hybrid. Having in mind that the exact geometry of a DNA wrap for an arbitrary tube is not precisely known yet [5], we put forward a general model [3] capable of modeling optical effects, varying the parameters of the wrap and/or tube diameters. For various ssDNA backbone helical angles and for various tubes we predict different absorption spectra, though we believe that a general qualitative feature of the helical symmetry breaking, the appearance of new van Hove singularities and circular dichroism, must be present.

Acknowledgement: The work was partially supported by NSF grant CMS-0609050, DoD-ARL under Cooperative



Agreement W911NF-07-2-0064 and ACS PRF-G grant. Fig. Calculated optical strength vs. \perp absorption energy and \parallel emission energy (absorption-luminescence map) for (Left) the bare (7,0) nanotube and (Right) the DNA-wrapped (7,0) nanotube.

1. M. Zheng, et al., *Science* 302, 1545 (2003). M. Zheng, et al., *Nature Mater.* 2, 338 (2003).
2. V. Puller, S.V. Rotkin, *Europhysics Letters* 77, 27006 (2007).
3. S.E. Snyder, S.V. Rotkin, submitted, (2007)
4. S.E. Snyder, S.V. Rotkin, *JETP Letters* 84, 348, (2006).
5. A. Jagota, et al., in S. V. Rotkin, S. Subramoney, (Eds.), *Applied Physics of Carbon Nanotubes* (Springer, Berlin), 253 (2005).

11:45AM IAN022 (Invited)

Application of carbon materials: bio-sensor and electronics

Wonbong Choi

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Florida International University Miami, FL 33174, USA

Carbon nanotubes (CNTs) have been studied rigorously due to their various unique properties, which is mostly driven by the wealth of possible bonding states of carbon atoms. In particular, the extreme electrical and mechanical property renders CNTs as the foremost nanomaterials in new paradigm of electronics.

In this talk, I will present our results on both multi-walled nanotube (MWNT) and single-walled nanotube (SWNT) aligned growth, vertically and laterally, and branched structure of Y-junctions, where we have demonstrated *unique* switching and transistor behavior without the need for an external gate. We show that such Y-junction switches have possibly higher efficiency of operation, compared to traditional semiconductor devices.

In conjunction with electrical functionality of aligned CNTs, I will present and discuss the charge transport of bio-molecular binding at the CNT-transducer, which is functionalized array of CNT for quantitative and selective detection of a range of metabolites including cholesterol, ascorbic acid and uric acid. In addition, a label-free detection scheme for DNA hybridization in single molecular-level will be presented.

12:15PM Lunch

1:15PM IAN014 (Invited)

LABEL-FREE SENSING WITH SILICON NANOWIRES

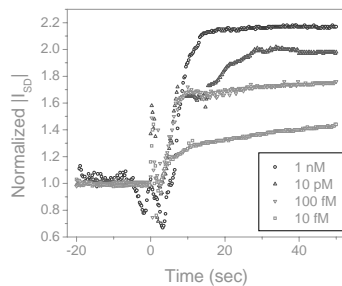
Eric Stern¹, David Routenberg², Erin Steenblock¹, Tarek Fahmy¹, & Mark Reed^{2,3}

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Nanoscale electronic devices have the potential to achieve exquisite sensitivity as sensors for the direct detection of molecular interactions, thereby decreasing diagnostics costs and enabling previously impossible sensing in disparate field environments. Semiconducting nanowire-field effect transistors (NW-FETs) hold particular promise, though contemporary NW approaches are inadequate for realistic applications. We present here a novel approach using complementary metal-oxide-semiconductor (CMOS) technology that has not only achieved unprecedented sensitivity, but simultaneously facilitates system-scale integration of nanosensors for the first time. This approach enables a wide range of label-free biochemical and macromolecule sensing applications, including cell type discrimination through the monitoring of live, stimulus-induced cellular response, and specific protein and complementary DNA recognition assays. An important achievement is the introduction of real-time, unlabeled detection capability, allowing for fundamental studies of cellular activation, and specific macromolecule interactions at <femtomolar concentrations. Important aspects of microfluidic integration and Debye screening will be discussed, along with the demonstration of live cell peptide-specific immunoresponse.



Strepavidin (in PBS) concentration dependence



Device micrograph, with ~50nm Si nanowire active region (bottom)

From quantum wire arrays to 2D superlattices through nanohole patterning

X. Cartoixà¹, R. Rurali¹, I. Fernández-Cuesta², F. Pérez-Murano² and J. Suñé¹

¹Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona (UAB), Campus de la UAB, 08193 Bellaterra (Barcelona), Spain and ²Centro Nacional de Microelectrónica - Institut de Barcelona, (CNM-IMB, CSIC) – Campus UAB, 08193 Bellaterra, Spain

We propose a method for the fabrication of one-dimensional nanostructures (both isolated and with finite electronic coupling) with no need of catalyst agents. The method is based on a lithography design of a pattern of channels onto a conveniently cleaved semiconductor surface.

Electronic structure calculations demonstrate that when the channel diameter is sufficiently larger than the interstitial space, the resulting pillars constitute an ordered array of electronically independent, though mechanically interconnected nanowires. We also show that a controlled coupling of the nanowires can be achieved, as long as one is capable to tune, at fabrication time, the thickness of the interconnections, which are ultimately responsible of the efficiency of the quantum confinement. This method, being based on a top-down approach, would yield an ensemble of identical nanowires, grown along the same crystallographic orientation and with similar properties concerning the length and the diameter.

We study [1] different templates, where the channels are distributed according to a square or a hexagonal network, discussing the case of Si and GaAs. The hexagonal distribution of channels proved to offer the best confining properties. Calculations have been performed with the Siesta ab-initio package and, for larger sizes, with the Effective Bond Orbital Model. For a Si substrate and holes in a square disposition, we observe that states remain in the wire section. However, after widening the interconnect, laterally propagating states appear. The dispersive behaviour is conclusively determined from the observation of the band width for the bands of interest.

We will also present our results of the first attempts at fabrication of this class of structures, based on TMAH wet etching of e-beam patterned Si [110] substrates.

This technique of nanohole patterning could be easily extended to quantum well or superlattice substrates, e.g. GaAs/InGaAs or GaAs/GaAsP, leading to the fabrication of 1D heterostructures or quantum dots with potential applications as light emitting devices.

[1] R. Rurali, J. Suñé and X. Cartoixà, *Appl. Phys. Lett.*, **90**, 083118 (2007).

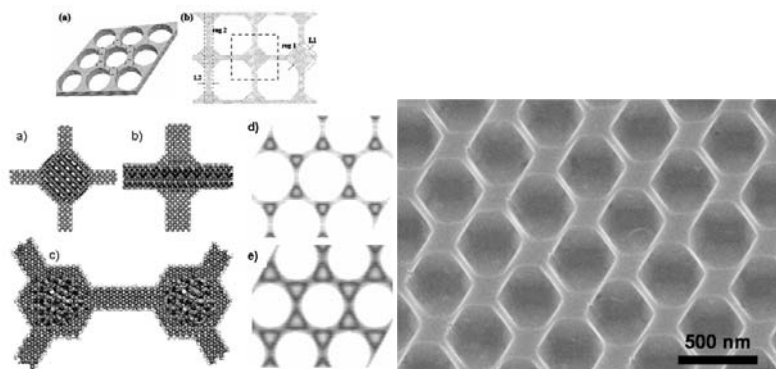


Fig. Top Panel: Schematic of the approach. Middle Panel: Wave-function of the lowest state of the conduction band in the case of square and hexagonal arrays of channels in silicon (a,b,c) and GaAs (d,e); showing nanowire (a,c,d) and 2D superlattice regimes (b,e). Bottom Panel: Preliminary test of a silicon substrate after etching with TMAH.

2:15PM IAN021 (Invited)

Nanogenerators for Self-Powered Nanotechnology

Zhong Lin (ZL) Wang

School of Materials Science and Engineering, Georgia Institute of Technology, Atlanta USA

Developing novel technologies for wireless nanodevices and nanosystems are of critical importance for in-situ, real-time and implantable biosensing, biomedical monitoring and biodetection. An implanted wireless biosensor requires a power source, which may be provided directly or indirectly by charging of a battery. It is highly desired for wireless devices and even required for implanted biomedical devices to be self-powered without using battery. Therefore, it is essential to explore innovative nanotechnologies for converting mechanical energy (such as body movement, muscle stretching), vibration energy (such as acoustic/ultrasonic wave), and hydraulic energy (such as body fluid and blood flow) into electric energy that will be used to power nanodevices without using battery. We have demonstrated an innovative approach for converting nano-scale mechanical energy into electric energy by piezoelectric zinc oxide nanowire (NW) arrays. By deflecting the aligned NWs using a conductive atomic force microscopy (AFM) tip in contact mode, the energy that was first created by the deflection force and later converted into electricity by piezoelectric effect has been measured for demonstrating nano-scale power generator. The operation mechanism of the electric generator relies on the unique coupling of piezoelectric and semiconducting dual properties of ZnO as well as the elegant rectifying function of the Schottky barrier formed between the metal tip and the NW. Based on this mechanism, we have recently developed DC nanogenerator driven by ultrasonic wave in bio-fluid, which is a gigantic step towards applications in practice. This presentation will introduce the fundamental principle of nanogenerator and its potential applications. Finally, a new field is introduced on *nano-piezotronics*, which uses piezoelectric-semiconducting coupled property for fabricating novel and unique electronic devices and components.

[1] Z.L. Wang and J.H. Song "Piezoelectric Nanogenerators Based on Zinc Oxide Nanowire Arrays", *Science*, 312 (2006) 242-246.

[2] P.X. Gao, J.H. Song, J. Liu and Z.L. Wang "Nanowire Nanogenerators on Plastic Substrates as Flexible Power Source", *Adv. Mater.*, 19(2007) 67-72.

[3] X.D. Wang, J.H. Song, J. Liu, and Z.L. Wang "Direct current nanogenerator driven by ultrasonic wave", *Science*, 316 (2007) 102-105.

[4] Z.L. Wang "Nano-piezotronics", *Adv. Mater.*, 19 (2007) 889.

[5] Research supported by NSF, DARPA, NASA and Emory-Georgia Tech CCNE from NIH.

Session: Poster (Villa)

2:45PM – 4:45 PM Monday, February 4th, 2008

IAN013V

Horizontally aligned carbon nanotube field emitters having a long term stability

Sung Mi Jung, Hyun Young Jung, Jung Sang Suh

Department of Chemistry, Seoul National University, Seoul, Republic of Korea

We have fabricated horizontally aligned multi- and single-walled CNT field emitters and studied their field emission properties. The horizontally aligned multiwalled carbon nanotube (MWNT) field emitters show an unusual very long-term

stability, much better stability than the singlewalled nanotube (SWNT) ones. The cause of degradation of horizontally aligned CNT field emitters is due to the heat generated by the resistance of CNTs during field emission. Less heat is generated from an MWNT field emitter than a SWNT field emitter, since the diameter of MWNTs is larger than that of SWNTs. We were able to effectively prevent the degradation of the horizontally aligned CNT field emitters by fabrication using MWNTs instead of SWNTs and by the deposition of aluminum, which becomes alumina during firing, on the SDS layer of the CNT films. The required time for 10% degradation is very long, 121 h. The horizontally aligned MWNT field emitters show good field emission properties such as high current density, low turn-on voltage and long-term stability. The fabrication processes are relatively simple and there is no intrinsic limit on the device size. Above all, no further treatment is needed for field emission. Therefore, the horizontally aligned MWNT field emitters could be used in practical applications such as the BLU (back light unit) for LCD (liquid crystal display).

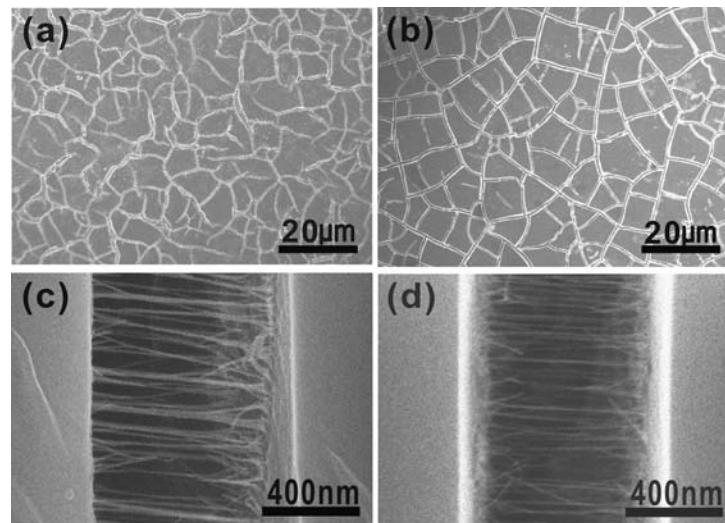


Fig1. SEM images of the SWNT (a, c) and MWNT (b, d) films deposited on Ti substrates after the firing process. A fissure is magnified in (c) and (d). The average fissure size in both films is approximately 900 nm.

1. J. Han, S. M. Jung, H. Y. Jung, S. B. Heo, J. H. Shin, J. S. Suh, *Appl. Phys. Lett* 88, 113101 (2006).
2. S. M. Jung, J. Han, H. Y. Jung, J. S. Suh, *Nano Let* 6, 1569 (2006).
3. B. Gao, G. Z. Yue, Q. Qiu, Y. Cheng, H. Shimoda, L. Fleming, O. Zhou, *Adv. Mater* 13, 1770 (2001).
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IAN044

Study on dynamical behavior of water within a carbon nanotube

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² Department of Mechanical Engineering, National Pingtung University of Science and Technology, No.1, Shuehfu Road, Neipu, Pingtung 91201, Taiwan

The molecular dynamics simulation method is used to investigate the relationship between temperature and vibrating behavior of water within a capped single-walled carbon nanotube (SWNT). The Tersoff potential [1] is used to simulate carbon atoms and the TIP3P or SPEC potential used to simulate water molecules. Moreover, the diffusion behavior of water molecules filled in a capped SWNT is also been studied. The key role of diffusion behavior for water molecules inside a capped SWNT is concentration. It is found that high concentration prompt water molecules to drift towards low concentration by the mechanism of the so-called diffusion. When a capped SWNT is fixed at the middle section, the amplitude of a SWNT's vibration is related with the chiral vector of a carbon nanotube. This finding is different from the previous results [2], whose a SWNT was fixed at one end. Also, the amplitude of a SWNT's vibration is nearly not affected by a few water molecules inside a SWNT. However, between 250~300K, the mean value, standard deviation, and variation of the amplitude of a capped SWNT fluctuate because of the phase change of water molecules, resulting in raising the collision between each other.

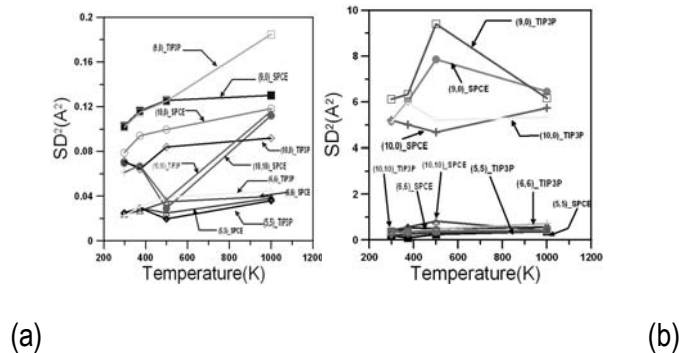


Fig1. The relationship between temperature and the vibration of a capped SWNT's end (a) water molecules inside the middle section of a SWNT in 25 nm length (b) water inside the bottom section of a SWNT in 100 nm length.

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IAN030V

The characterization of silicon quantum dots for nano floating gate memory

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The amorphous silicon (a-Si) nano-dots and the silicon quantum dots in silicon nitride (SiN_x) are widely studied because SiN_x is an attractive gate dielectric material for nanocrystal memory devices due to lower tunneling barrier height and higher dielectric constant than SiO₂[1]. In this study, silicon surface with nanostructure was fabricated by using polystyrene-block-polymethylmethacrylate (PS-b-PMMA) and reactive ion etching (RIE) system and SiN_x films with quantum dots were deposited by using plasma chemical vapor deposition on silicon substrate of nanostructures and planar structure. To study its effect on charge storage capacity of silicon quantum dots in SiN_x films and interface trap density between Si and SiN_x interface, C-V characteristics were studied.

The nanostructures of silicon substrate were fabricated using SF₆/O₂ plasma in RIE system. To demonstrate its effect on charge storage capacity, MIS devices with SiN_x films as insulator layer were fabricated using inductively coupled plasma chemical vapor deposition (ICP-CVD). The influence of nanostructure of silicon substrate on the charging effect in silicon quantum dots embedded in silicon nitride films was demonstrated. The flat-band voltage shift (ΔV_{FB}) of C-V characteristic

curve of MIS device with uniform silicon substrate such as nanostructures is wider than that of C-V characteristic curve of MIS device on planar structure. The MIS device with nanostructures exhibited a high charge storage capacity and low interface traps, compared to MIS device with planar structure. A non-volatile memory device with increased charge storage capacity over planar structure can be realized with the nanostructure.

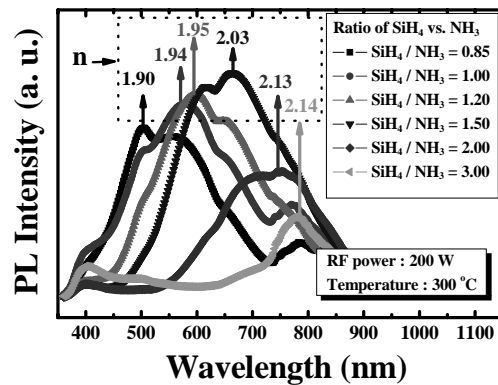


Fig1. The PL peak of SiN_x films deposited by the adjustment of the gas flow rates.

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IAN032V

Nano-needle structure using PS-*b*-PMMA nanomask in RIE for enhancement of charge storage of NVM

Jaehong Kim, Sungwook Jung, Junsin Yi

School of Information and Communication Engineering, Sungkyunkwan University, Suwon, Kyungki Do, Korea,

In this work, the fabrication of nanostructures applicable to nano floating gate memory is investigated by using a block co-polymer system composed of Polystyrene (PS) and Polymethylmethacrylate (PMMA). Block copolymer films have already been investigated in several nanolithographic etching process, where the block copolymer functions as a mask. Under suitable conditions the PS and PMMA self assembled into a honey comb lattice of PMMA in the matrix of PS. To utilize this self-assembled nanostructures of block co-polymer for nanoscale semiconductor devices, block copolymers were fabricated in the shape of thin films on the silicon substrate[1].

Needle-like silicon nanostructures were created using the block copolymer composed of PS and PMMA. The PMMA domains were selectively removed using UV irradiation. Silicon nanostructure was fabricated using reactive ion etching (RIE) in parallel plate reactors. In the SF₆ and O₂ plasma, SF₆ was the source of active fluorine that etches silicon and O₂ supplies oxygen radicals that eliminate the polymer on silicon surface. The formation of needle-like nanostructures on silicon surface using PS-*b*-PMMA as nanomask applicable to nonvolatile memory has also been reported in this paper. The uniform needle-like nanostructures of silicon surface were observed for the samples prepared under suitable condition. The process of creating needle-like nanostructures on silicon surface using RIE can be applied to increase the memory capacity[2].

In this paper, we have reported the formation of uniform needle-like nanostructures of silicon surface using PS-*b*-PMMA diblock co-polymer and a simple and compact RF parallel plate plasma system. Also the fabrication of needle-like silicon is described.

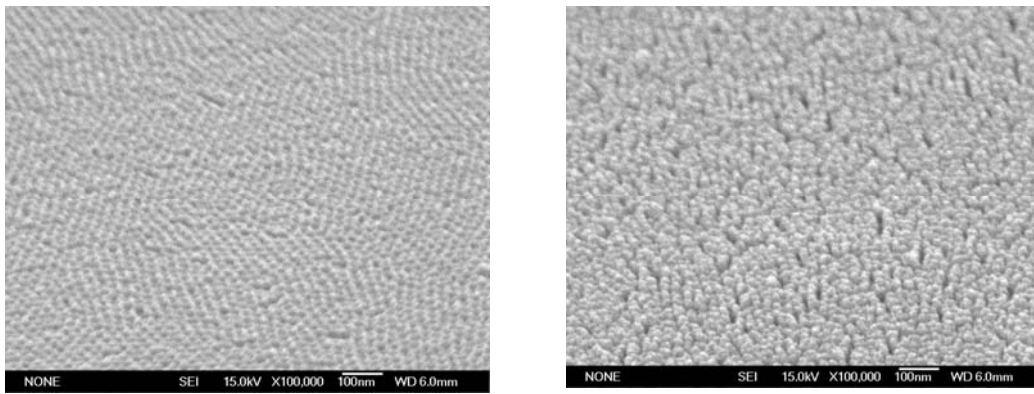


Fig1. Surface Morphologies of silicon surface etched by different SF₆ flow rate and RF power using PS-*b*-PMMA nanomask

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IAN023V

Properties and Application of LPCVD Grown Silicon Epitaxial Quantum Dots

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Low-temperature growth processes of crystalline Si have attracted great interest in thin-film technology. It is a quite general experience that low-temperature growth may lead to surface roughening, to the formation of amorphous inclusions, and often to a complete breakdown of epitaxial growth. This phenomenon seems to be an inherent property of low-temperature epitaxy. This phenomenon seems to be an inherent property of low-temperature epitaxy. Jorke et al.¹ and Eaglesham et al.² proved the existence of a critical epitaxial thickness, h_{epi} , beyond which the growth mode turns from crystalline to amorphous.

Silicon films were deposited by Low Pressure Chemical Vapor Deposition (LPCVD) onto crystalline silicon (100), (111) substrates and quartz at temperatures ranging from 500 to 700 °C. Si epitaxial thin films were grown from pure or hydrogen diluted Silane (SiH₄) and had been analyzed by Raman Spectroscopy, X-Ray Diffraction, UV-Vis, and SEM(Scanning Electron Microscope). The results showed that Si films can be grown in this reactor in a wide range of conditions, varying gas flow ratio (SiH₄, H₂, He) and temperature deposition between 500 to 700°C, with growth rates of some hundreds $\mu\text{m}/\text{min}$.

We report on the influence of channel length on transfer characteristics of Si epitaxial thin film transistors fabricated by nanoscale patterning. We study Threshold Voltage (V_{TH}), On/Off Current ratio($I_{\text{ON}}/I_{\text{OFF}}$), Saturation Current(I_{DSAT}) and transconductance(g_{m}) of Si epitaxial thin film transistors with various channel length and width.

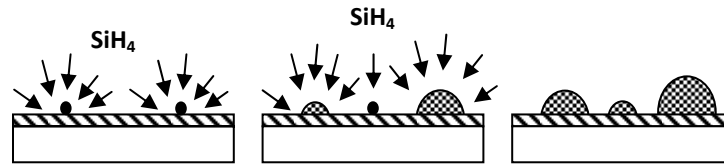
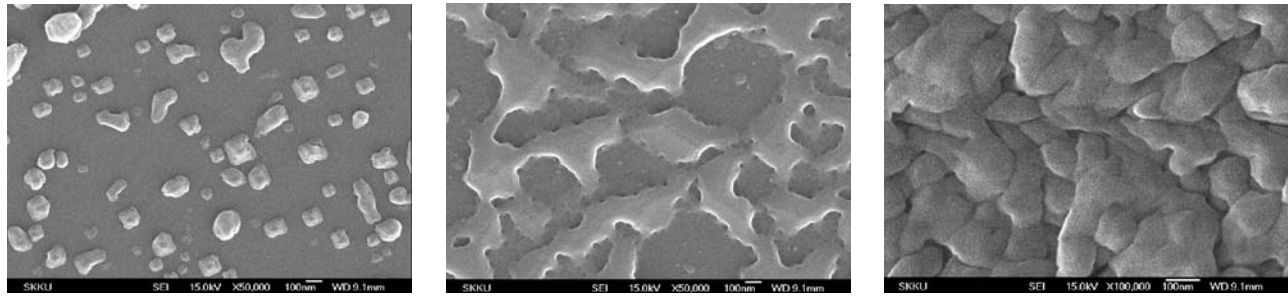


Fig1. The SEM Image of Si Epitaxial Quantum Dots deposited by LPCVD.

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2. D.J. Eaglesham, H.J. Gossmann, M. Cerullo, Phys. Rev. Lett.65, 1227-1230 (1990).

IAN048

Fabrication of Hierarchical Surfaces of Poly(caprolactone) (PCL) with Various Micro- and Nanostructures by Using Wet-chemical Etching and Polymer Imprinting Method and Their Tissue Engineering Application

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²Adult Stem Cell Research Center & Laboratory of Stem Cell and Tumor Biology, College of Veterinary Medicine, Seoul National University, Seoul, Korea

Recently, nanostructured surfaces have been attracting great attention as the means of controlling cell adhesion and growth because such an ability to control characteristics of cell on well-characterized surfaces is main goal in tissue engineering.[1] Poly(ϵ -caprolactone) (PCL) is a biodegradable polyester having good biocompatible characteristics and is known as a suitable scaffold for bone engineering.[2] On account of this there have been many studies on the mechanical property and tissue compatibility of PCL and functionalized PCL to control cell adhesion, proliferation and differentiation on it. It is also known that topographical bio-activity of PCL plays a critical role in fundamental biological studies as well as chemical modification for the development of tissue engineering. We have prepared hierarchical structures on PCL surface by using textured Al surface from Beck's dislocation etchant as a replication master for polymer imprinting method, and investigated the adhesion and proliferation of Mesenchymal stem cells (MSCs) on PCL replicas with micro and nanostructured morphology. PCL replicas formed the grassland-like morphology on their surface and MSCs exhibited the extremely different adhering property compared to the flat PCL surface. In this poster presentation, the details of preparation processes and the remarkable differences in bioactivity on the topographical variations of PCL surface by the simple replicating method will be discussed.

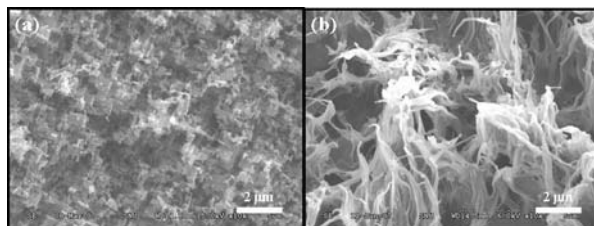


Fig1. FE-SEM images of (a) the Al surface having micro- and nanostructure after etched with Beck's dislocation etchant for 60s and (b) the surface of PCL replica with nanofibers.

1. H. Shin, S. Jo, AG. Mikos, *Biomaterials*, 24, 4354 (2003)
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IAN037

Preparation Method of Multifunctional Nanocomposite Particles, NP@SiO₂, by Employing Poly(vinylpyrrolidone) as A Mediator

Jin-Myoung Cha, Tae-Jong Paik, Jin-Kyu Lee

Materials Chemistry Laboratory, Department of Chemistry, Seoul National University, Seoul, Korea

The well-investigated method to prepare various nanoparticles with good size regularity is a thermolysis method in hot organic solutions. These nanoparticles are usually dispersible in nonpolar organic solvent such as hexane, CHCl₃, and toluene, which sometimes causes problem to overcoat them with silica or incorporate them into silica nanobeads due to the polar alcoholic solvent in silica forming process (modified Stöber process). We have developed a general procedure to incorporate of hydrophobically modified nanoparticles (organic dispersible as prepared in thermolysis methods) into silica colloids without any tedious surface modification. Hydrophobically modified nanoparticles do not form precipitates in alcoholic solution in the presence of amphiphilic poly(vinyl pyrrolidone) (PVP) which has been known to stabilize the various surfaces including nanoparticle and induce the silica formation onto it, and successive addition of TEOS with basic catalyst such as NH₄OH can generate thin layer of silica coating on nanoparticles or form silica nanobeads containing various numbers of nanoparticles depending on the concentrations. The PVP stabilized nanoparticles can also be easily adsorbed on the amino-funtionalized silica colloid surface to form interesting core-shell type nanocomposite structure. Many different organic-dispersible nanoparticles from the thermolysis can be used in our PVP mediated silica preparation method, and these multifunctional nanocomposite silicabeads are expected to be utilized in many applied fields where wettability, biocompatibility and easiness of surface modification are very critical.

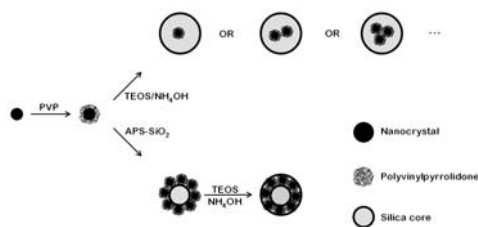


Fig. Schematic illustration of the overall synthetic procedure to incorporate nanoparticles into silica nanobead.

IAN053

Plasmon Resonance in Silver Nanoparticle Arrays Grown By ATLAS

Floriano Cuccureddu¹, S.Murphy¹, I.V.Shvets¹

¹Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN), School of Physics, Trinity College, Dublin 2, Ireland

The Atomic Terraces Low Angle Shadowing (ATLAS) device is a new instrument built to develop a novel method to grow planar arrays of linear nanowires regardless of the film and substrate materials. Top-down approaches, such as microfabrication techniques, can fabricate 30-40 nm nanostructures while with the ATLAS technique we are interested in 5-10nm wide nanowires. The ATLAS technique relies on the shadowing that vicinal treated substrates can provide at shallow angle deposition due to the terrace-and-step morphology. The ATLAS technique seems to be promising for the growth of a wide variety of nanostructures which could have important applications in various field of applied physics, such as photonics and electronics, as well as biotechnology and chemistry. Here the technique is demonstrated reporting the growth of silver nanodots on c-plane sapphire. Optical analysis has been performed showing plasmon resonances with peak positions depending on the polarization of the light. The light electric field triggers different kinds of interactions among the nanoparticles revealing the intrinsic anisotropy of the sample. Taking advantage of this the resonance peak wavelength can be tuned modifying the nanostructures size and morphology by regulating several parameters during the growth process. The study of these features is important for fundamental reasons as well as eventual applications.

IAN002

Configuration Control of Quantum Dot Molecules by Droplet Epitaxy

Kimberly A. Sablon, Zh. M. Wang, J. H. Lee, and G. J. Salamo

MicroEP, University of Arkansas, AR 72701, USA

We demonstrate that by changing the substrate temperature at which Ga droplets form and varying the InAs deposition, we are able to control the configuration of quantum dots (QDs) per GaAs mound. In distinction from previous reports, we attained two structures, quad-molecules and quantum rod pairs. Quad-molecules are elongated along the [011] crystallographic direction due to strain-driven processes and formed directly at the edges of the GaAs mounds. On the other hand, quantum rod pairs (QRPs) formed along the [01-1] direction due to higher anisotropic diffusion.

Dinner 5:00PM

Session: Virtual VC-IAN Session One

Monday Evening, February 4th, 2008

7:00PM IAN003V (invited), (4:00PM, California)

Biomedicine and Nanoparticles, integrated hybrids and interactions

Gang L. Liu, Fanqing Frank Chen

Lawrence Berkley National Laboratory, MS 977R0225A, 1 Cyclotron Rd. Berkeley, CA 94720

With the rapid development of nanotechnology and its broad applications, a new wave of industrial revolution is underway. At nanoscale, the physico-chemical properties of matter change significantly from the bulk material. New properties emerge that are unimaginable for conventional bulk material, with dramatically enhanced mechanical, electrical, optical, magnetic, catalytic, and other desirable properties. The unique characteristics that make nanomaterials novel and could potentially be the properties that have huge benefit for human health, as well as profound adverse impacts on human health and environment. I will discuss the integrated nano-bio hybrid structure, their use in biomedicine, and the risk assessment strategy that should be employed for dealing with them, especially the molecular profiling techniques used for comprehensive nanotoxicological assessments for physical property dependent toxicogenomic markers. Topics of discussion include:

- proteomic nanosensors
- hypersensitive multimodality imaging solutions using nanoparticles
- nanobarcoding
- nanodelivery vehicles with multiple functions
- nanotoxicity

7:30PM [IAN005V](#) (6:30PM, Illinois)

A novel self-aligned and maskless process for formation of highly uniform arrays of nano-holes and nano-pillars
WEI WU¹, DIBYENDU DEY, ALEX KATSNELSON, OMER G. MEMIS, HOOMAN MOHSENI²

¹EECS Department, Northwestern University, Evanston, IL, USA

²EECS Department, Northwestern University, Evanston, IL, USA

Fabrication of a large area of periodic structures with deep subwavelength features is required in many applications such as solar cells [1], photonic crystals [2], and artificial kidneys [3]. We present a low-cost and high-throughput process for realization of two-dimensional arrays of deep sub-wavelength features using a self-assembled monolayer of hexagonally close packed (HCP) silica and polystyrene microspheres. This method utilizes the microspheres as super-lenses to fabricate nano-holes and nano-pillars arrays over large areas on conventional positive and negative photoresists, and with a high aspect ratio. The period and diameter of the holes and pillars formed with this technique can be controlled precisely and independently. We demonstrate that the method can produce HCP arrays of hole of sub-250 nm size using a conventional photolithography system with a broadband UV source centered at 400 nm. We also present our 3-D FDTD modeling, which shows a good agreement with the experimental results.

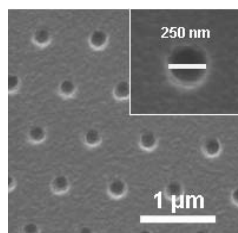


Fig1. Shows SEM images of AZ5214 photoresist nanoholes (inset shows enlarged image), after microspheres removal and photoresist development.

Spin splitting and polarisation in hole nanowires

Dan Csontos¹, Ulrich Zuelicke^{1,2}

¹Institute of Fundamental Sciences, Massey University, Palmerston North, New Zealand

²MacDiarmid Institute for Advanced Materials and Nanotechnology, Massey University, Palmerston North, New Zealand

Engineering spin splitting of charge carriers in semiconductors may open up intriguing possibilities for realizing a new spin-based electronics. Since g -factors have a strong dependence on band structure, it is expected that spatial confinement will have an important effect on Zeeman splitting. Furthermore, intriguing spin physics and possible mechanisms for spin-splitting manipulation arise due to the interplay between spin-orbit coupling and confinement. Valence-band charge carriers are especially interesting in this context due to the strong spin-orbit coupling that they are subjected to. The spin-3/2 character of states in the topmost valence band leads to intricate and sometimes counterintuitive quantum phenomena in hole nanostructures. For example, strong anisotropies of the effective g -factors with respect to the applied magnetic field were seen in p -type quantum wells [1], hole point contacts [2], nanowires [3], and localized acceptor levels [4].

We present a theoretical study of spin splittings of subband edges in hole nanowires subject to a magnetic field applied parallel to the wire axis. We find strong deviations of the subband-edge g -factors from values found in higher-dimensional systems. The interplay between spin splitting arising from the bulk-hole Zeeman effect and orbital contributions in a finite magnetic field is elucidated. Our findings suggest the possibility of versatile engineering of hole spin splittings in nanowires [5,6].

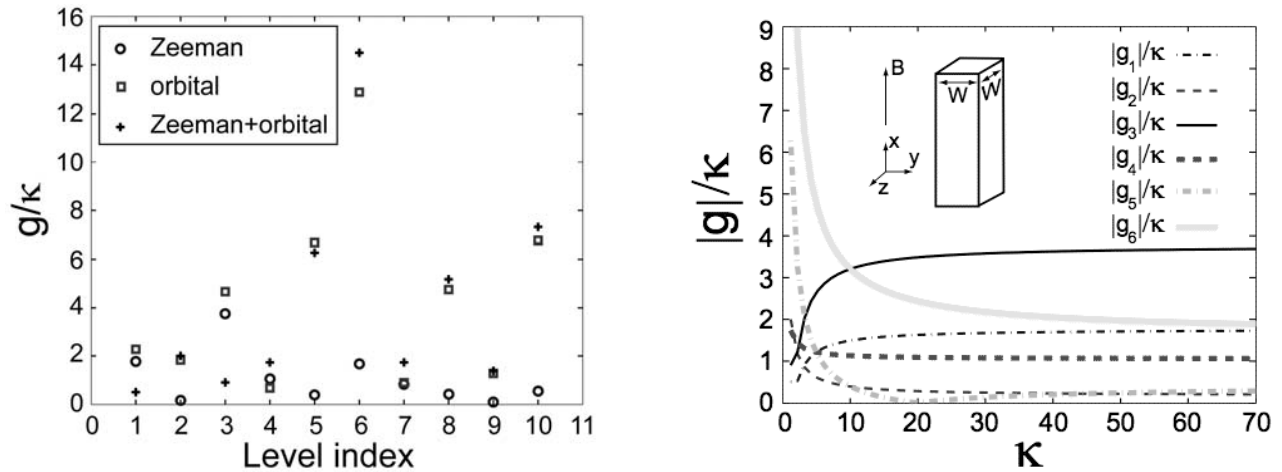


Fig1. Effective g -factors, normalized by the bulk-hole g -factor κ , for low-lying hole-wire subband edges in GaAs. Left panel: Comparison of contributions arising from the bulk-hole Zeeman effect and orbital magnetic-field effect. Right panel: Bulk-Zeeman contributions dominate for moderately p - d exchange-enhanced κ . Inset shows the wire geometry and magnetic-field direction.

1. R. Winkler, S. J. Papadakis, E. P. De Poortere, and M. Shayegan, *Phys. Rev. Lett.* **85**, 4574 (2000).
2. R. Danneau *et al.*, *Phys. Rev. Lett.* **97**, 026403 (2006).
3. S. Roddaro, A. Fuhrer, C. Fasth, L. Samuelson, J. Xiang, C. M. Lieber. *unpublished*, arXiv:0706.2883.
4. K. M. Haendel, R. Winkler, U. Denker, O. G. Schmidt, R. J. Haug, *Phys. Rev. Lett.* **96**, 086403 (2006).
5. D. Csontos and U. Zülicke, *Phys. Rev. B* **76**, 073313 (2007).

8:15PM IAN031V (10:15AM, Japan)

Band-Gap Modification by Radial Deformation in Semiconductor Single-Walled Carbon Nanotubes under Hydrostatic Pressure

M. Hasegawa¹ and K. Nishidate²

¹Department of Materials Science and Engineering, Iwate University, Morioka, Japan

²Department of Electric and Electronic Engineering, Iwate University, Morioka, Japan

In this report we elucidate electronic structure modification by radial deformation in single-walled carbon nanotubes (SWNTs). The radial deformation of an isolated SWNT under hydrostatic pressure is predicted using the method developed in the previous work [1]. In this method the deformation energy is calculated on the basis of a continuum elastic sheet model and by taking account of the interaction between opposing walls, which includes the van der Waals interaction missed in the density-functional theory (DFT) calculations in the standard approximations. The method is similar to that used in the semiempirical approach to the energetics of interlayer binding of graphite [2]. We performed *ab initio* DFT electronic structure calculations for deformed *zigzag* SWNTs and found that once the band gap at the Γ point starts to vary with radial deformation it decreases almost linearly with the fractional change in cross-sectional area S , $X = 1 - S/\pi R^2$, where R is the radius of the cross section of the undeformed SWNT (Fig. 1 (a)). It is also found that the band-gap modification is determined by the minimum curvature-radius, R_{\min} , along the circumference of the deformed cross-section perpendicular to the tube axis (Fig. 1 (b)): The band gap remains unchanged when $R_{\min} \geq 3.2 \text{ \AA}$ and closes at $R_{\min} \approx 2.4 \text{ \AA}$ irrespective of tube size.

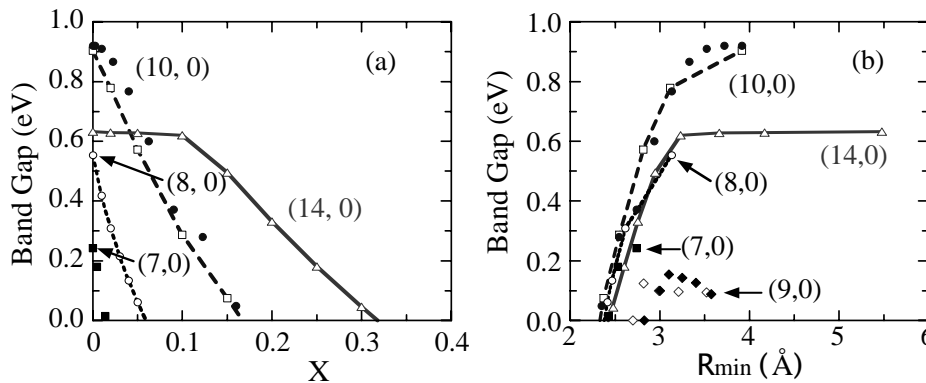


Fig1. Band gaps at the Γ point of the deformed zigzag (8,0) (dotted line), (10,0) (dashed line), and (14,0) (solid line) SWNTs as function of X and R_{\min} , both defined in the text. Also included are the previous results for the (7,0) tube (closed square, from Ref. 3), (9,0) tube (closed diamonds, from Ref. 4; open diamonds, from Ref. 3), and (10,0) tube (closed circles, from Ref. 5)

1. M. Hasegawa and K. Nishidate, *Phys. Rev. B* 74, 115401 (2006).
2. M. Hasegawa and K. Nishidate, *Phys. Rev. B* 70, 205431 (2004); *ibid* 76, 115424 (2007).
3. O. Gulseren *et al.*, *Phys. Rev. B* 65, 155410 (2002).
4. C.J. Park *et al.*, *Phys. Rev. B* 60, 10656 (1999).

Session: Quantum Dot Growth – Theory and Experiment (Villa)

Tuesday Morning, February 5th, 2008

8:00AM IAN017 (Invited)

Interactions between epitaxial quantum dots and substrate patterning

Jerry Tersoff¹

¹IBM Research Division, T. J. Watson Research Center, Yorktown Heights NY 10913 USA

Quantum dots can “self assemble” during heteroepitaxy, driven by misfit stress. This has been extensively studied for systems such as Ge on Si (001) and InAs on GaAs (001). Various strategies can be used to control the positions of the dots, in particular substrate patterning.

Quantum dots interact with each other even at relative large distances via coarsening [1,2], and more directly at short distances via stress [3,4]. These interactions can strongly influence the size distribution, which is central for most applications. The dots obviously also interact with any substrate patterning. In fact, they interact strongly even with a planar substrate, intermixing with the substrate (depending on temperature) and creating their own “patterning” by digging trenches into the substrate [4]. Recent work tests the limits of substrate patterning and position control [5].

This talk will discuss these interactions and how they influence the positions, shape, and compositions of the quantum dots.

1. F. M. Ross, J. Tersoff, and R. M. Tromp, Phys. Rev. Lett. 80, 984 (1998).
1. A. Rastelli, M. Stoffel, J. Tersoff, G. S. Kar, and O. G. Schmidt, Phys. Rev. Lett. 95, 026103 (2005).
2. J. A. Floro, E. Chason, L. B. Freund, R. D. Twisten, R. Q. Hwang, G. A. Lucadamo, Phys. Rev. B 59, 1990 (1999).
3. Y. Tu and J. Tersoff, Phys. Phys. Lett. 98, 096103 (2007).
4. G. Katsaros, J. Tersoff, A. Rastelli, M. Stoffel, P. Acosta-Diaz, O. G. Schmidt, K. Kern (unpublished).

8:30AM IAN010 (Invited)

Progress in Size Uniformity and Density Control of Self-Assembled InAs Quantum Dots

K. Yamaguchi, T. Kanto, N. Kakuda, N. Tsukiji, P. Ponlachat

Department of Electronic Engineering, The University of Electro-Communications, Tokyo, Japan

Self-assembled semiconductor quantum dots (QDs) have attracted considerable interests for many applications of opto-electronic and quantum information devices. A Stranski-Krastanov (SK) growth of self-assembled QDs has been actively studied for more than about seventeen years. The conventional SK growth is not yet enough technology to control precisely the QD structures, but various QD devices have been tried to develop at present. In this conference, we will focus on recent progress in size uniformity and density control of the self-assembled InAs QDs grown on the GaAs by using the SK mode.

Size uniformity and density of the self-assembled QDs strongly depend on the SK growth conditions. In particular, low-growth rate and low-arsenic pressure conditions effectively suppressed size fluctuation of the InAs QDs. Such growth conditions frequently formed the stable facets on the QD sidewalls and induced a self-size limiting effect, which is very

important phenomenon for realization of the uniform QD structure. As the result, the uniform InAs-QDs ensemble revealed a narrow photoluminescence (PL) linewidth of about 18 meV [1]. The stacking growth is also an attractive technique for getting uniform and high-density QDs. Recently, we found the self-formation of nanoholes on the thin GaAs capping layer embedding the uniform InAs QDs [2] and fabricated the closely stacked InAs-QDs on those GaAs nanoholes [3]. Since the electron wave function coupled strongly between the closely stacked QDs, optical polarization anisotropy in edge emitting luminescence of those QDs was effectively suppressed. In addition, the high-aspect QD structure due to the vertical coupling reduced fluctuation in QD height, and the macroscopic PL spectra of those stacked QDs revealed extremely narrow linewidth of about 14 meV (Fig.1).

High-uniformity and high-density QDs have been needed for development of the QD lasers with high performance. Unfortunately, the low growth rate and low arsenic pressure conditions for getting the high uniformity QDs, mentioned above, led to low QD density of about $2 \times 10^{10} \text{ cm}^{-2}$ because of the enhanced surface migration. That is, there is a trade-off relation between uniformity and density of the QDs in the conventional SK growth. Also, it should be noted that high-density formation of the QDs frequently brings about coalescence of the neighboring QDs, which induces dislocations. Recently, we have demonstrated high-density ($5\text{-}10 \times 10^{10} \text{ cm}^{-2}$) and high-uniformity InAs/GaAs QDs by Sb initiation (Fig.2) [4,5]. In this Sb-mediated SK growth, coalescence of the QDs was effectively suppressed, in spite of high density, because of the Sb surfactant effect. Another topic is control of low density QDs for fabrication of the single QD structures. We will also discuss here our new method for fabrication of low density InAs QDs with less than 10^8 cm^{-2} ; intermittent supply and annealing method [6].

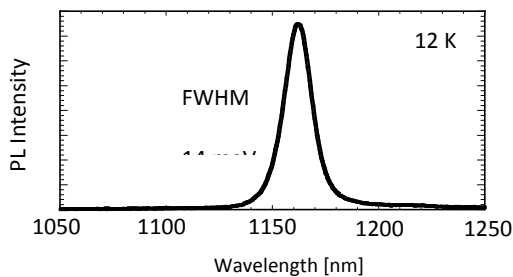


Fig.1. PL spectrum of closely stacked InAs QDs grown on GaAs nanoholes combined with embedding QDs.

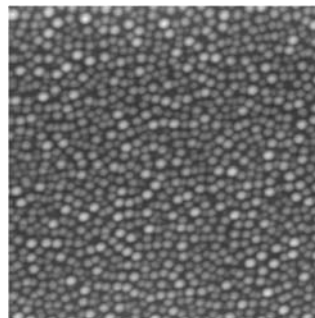


Fig.2. An AFM image of high density InAs QDs grown on GaAs(001) by Sb-mediated MBE. QD density was $1 \times 10^{11} \text{ cm}^{-2}$.

200 nm

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9:00AM IAN012 (Invited)

Multiscale Simulation of Three-Dimensional Self-Assembled Quantum Dots

Ernie Pan

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In this talk, growth of self-organized quantum dots on strained semiconductors in the Stranski-Krastanov mode is studied based on a newly developed multiscale fast kinetic Monte Carlo. In the growth plan, the four nearest and four next

nearest neighbors of each atom in the square lattice grid with periodic boundary condition are considered in the calculation of the binding energy among atoms. The long-range elastic strain energy is accurately evaluated by the rigorous point-eigenstrain half-space Green's function and is incorporated for the first time into the kinetic Monte Carlo model. The set of relevant growth parameters such as growth temperature, surface coverage, flux rate, and growth-interruption time, are investigated and optimal values are identified. It is shown clearly that when the long-range elastic strain energy is included in the simulation, uniform size and ordered spatial distribution can be achieved.

Furthermore, by incorporating the anisotropic strain energy field into a kinetic Monte Carlo algorithm for adatom diffusion, we show that the self-organized island pattern on the surface of an anisotropic substrate is closely correlated to the elastic energy distribution on the surface. This is demonstrated for GaAs substrate with growth orientations (001), (111), and (113), where the strain energy field in the substrate is shown to be the key factor that controls the island pattern. Our simulated patterns are also in qualitative agreement with recent experimental growth results.

A special pre patterning method is also proposed for spatially ordered self-organizing quantum dots on anisotropic semiconductor substrates. Using the developed kinetic Monte Carlo simulation model, atoms are deposited with varying intermediate interruption times. We demonstrate the effect of interruption time and long-range anisotropic strain energy on island size uniformity and lateral alignment.

Selected References:

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9:30AM IAN055

Fabrication of Noble Nanostructures and Preservation of Self-Assembled InAs Quantum Dots during GaAs Capping

J. H. Lee, Zh. M. Wang, V. G. Dorogan, Yu. I. Mazur, Morgan. E. Ware and G. J. Salamo

Materials Research Science and Engineering Center (MRSEC), University of Arkansas, Fayetteville AR 72701, USA

The research and advancement in the fabrication of nanostructures are expected to provide pioneering perspective into the next generation device applications. The anticipated impact of nanoscale device applications is expected to be enormous, and thus, the designing, synthesis and fabrication of nanostructures are extremely important. We, therefore, demonstrate the fabrication of noble nanostructures such as quantum rods (QRDs), quantum dot pairs (QDPs), bridged QDPs, and dimpled QDs by using solid molecular beam epitaxy (MBE). We execute the synthesis of noble nanostructures by an application of a shallow GaAs layer (10ML) on InAs QDs. In this report, the shape transition and evolution process of InAs QDs into InGaAs nanostructures are studied during the capping of GaAs layers in terms of morphology and optical property. At relative higher surface temperatures between 500 – 400 °C, QDs go through significant shape transition and eventually evolve into nanostructures. The shape evolution is mostly driven by surface diffusion process induced by the change in surface energy distribution. As QDs are required to be capped for their applications and optical characterizations, it is important to understand the mechanism during the capping process. We, therefore, also demonstrate the preservation of original shape of self-assembled InAs QDs during the capping of GaAs in terms of morphology and optical property. At relatively lower temperatures, below 360 °C, the original dome shape can be preserved due to limited surface diffusion for a

fixed shallow capping of GaAs. Photoluminescence results show a red-shift with decreasing capping temperature, which satisfactorily matches with morphological evolution, indicating taller height with decreasing capping temperature.

9:45AM Break

Session: Nanofabrication (Villa)

Tuesday Morning, February 5th, 2008

10:00AM IAN052

Optical and electrical study of spin-coated ZnO:Sb nanorod thin films

Mujdat Caglar¹, Yasemin Caglar¹, Saliha Ilcan¹, Fahrettin Yakuphanoglu², Jingbiao Cui³

¹Physics Department, Anadolu University, Eskisehir, TURKEY

²Physics Department, Firat University, Elazig, TURKEY

³Physics Department, Arkansas University at Little Rock, Little Rock, AR, USA

Zinc oxide (ZnO) nanostructured material has gained much interest due to its potential applications in various devices such as light emission diodes, solar cells, varistors, transducers, transparent conducting electrodes, sensors, and catalysts. The as-grown ZnO nanomaterials with a wurtzite structure often exhibit an n-type semiconducting property. It is still very challenge to dope ZnO with p-type behavior although various p-type dopant materials have been investigated so far. In this study, ZnO:Sb nanorod thin films were deposited onto glass substrate by a sol-gel spin-coating method. Optical and electrical properties of spin-coated ZnO:Sb nanorod thin films were investigated. SEM studies revealed that uniformly distributed nanorod arrays were deposited on the substrate. The surface morphology was found to depend on the concentration of antimony in the source materials. The optical band gap and Urbach energy of the films, calculated from the optical absorption measurements, were affected by the dopant concentration. Both band edge emission and defect emission associated with oxygen vacancies and interstitial Zn in ZnO were observed in photoluminescence spectra. The current-voltage curves of the films showed a non-linear behavior, which suggests of semiconducting characteristics of the doped thin films. The p-type characteristics of the Sb-doped ZnO films were confirmed by a hot probe measurement.

10:15AM IAN008

Investigation of the magnetic field effect on ultrasound synthesis of magnetic nanoparticles

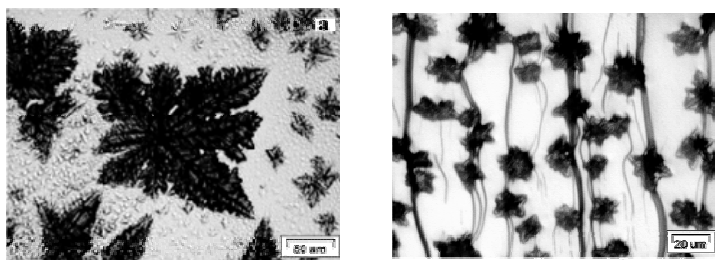
Riam Qasem^a, Shirly Ben -David Makhlu^f, Aharon Gedanken.

^aDepartment of Chemistry and Kanbar Laboratory for Nanomaterials at the Bar-Ilan University Center for Advanced Materials and Nanotechnology, Bar-Ilan University, Ramat-Gan, 52900, Israel, and Department of Physics, Bar-Ilan University, Ramat-Gan 52900, Israel.

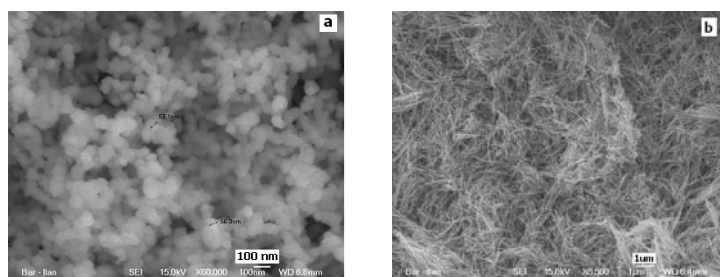
One of the very basic results of the physics and chemistry of solids is the understanding that most properties of solids depend significantly on the size of a solid particle in one, two, or three dimensions. Whether it can be called a

revolution or simply a continues evolution, it is clear that the development of new materials and their understanding on an increasingly smaller length scale is at the root of progress in many areas of materials science. Considering the importance of magnetite hydrosol especially bio-compatible hydrosol in technological and biological applications, its preparation is very restricted. A new facile, one-step and direct synthetic method is developed, based on the extreme conditions of temperature and pressure produced by ultrasound energy, using a stabilizing agent that is bio-compatible and facing the extreme conditions of sonication without decomposition. In addition, the investigation of applying external magnetic field at different situations is resulted to the formation of interesting three-dimensional microstructures with different physical and magnetic properties. Our investigation revealed that the extreme conditions resulting from the sonication cannot act as a barrier against the effect of a magnetic field on the growth process of the magnetite particles. The magnetic field led to the formation of rod-like, rather than spherically shaped particles. The more dramatic effect of the external magnetic field is seen in the interaction of the stabilized magnetite nanoparticles, when no colloidal solution is obtained, and the external magnetic field causes to the destabilization of the colloidal solution

Beside the magnetite particles, I have investigated the sonochemical synthesis of both cobalt and nickel particles, as both an aggregated ones and as a stable organosol, PEG was used as both a dispersive medium and also as a stabilizer. In addition, investigating the effect of the application of external magnetic field revealed a different morphology and magnetic properties. By this part of work, we conclude that the viscosity of the PEG solvent plays an important role in the stabilization mechanism. It restricts the diffusion of the particles through the dispersion medium, and hence reduces the probability of collision. We based our assumption on the Einstein Theory (1905) that deals with a mathematical expression for the diffusivity of colloid particles into solvents.



Optical microscope images of three-dimensional magnetite structures obtained by the evaporation of its hydrosol on a glass microscop both, in the absence and under the application of magnetic field..



Nickel particles obtained by sonochemistry, a: in the absence of magnetic field, b: under external magnetic field

Fabrication of Biomimetic Superhydrophobic Polymer Surfaces Having Hierarchical Structures in Micro and Nano Dimensions

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¹School of Chemistry, Seoul National University, Seoul, Korea

²School of Materials Science and Engineering, Seoul National University, Seoul, Korea

There has been a great deal of research interests in generating superhydrophobic surfaces because of their importance in fundamental research [1], practical applications and the inspired biomimetic attempts.[2] The superhydrophobic property in natural system was known to be governed by a cooperative effect of nanostructured materials within the micron scale patterned areas.[3] These hierarchical structures have been usually fabricated by tailoring surface topography through plasma etching, sol-gel processing, and so on.

The present study demonstrates a simple, efficient, and highly reproducible method to fabricate biomimetic superhydrophobic surfaces with aligned micron-sized papillae that have nanoembosses or nanofibers of controllable lengths. This was achieved by employing patterned anodic aluminum oxides (AAO) with hierarchical structures as a replication master that was fabricated from electrochemical method and photolithography method. It was revealed on the basis of the water contact angle measurement that both nanostructures and microstructures have a cooperative effect on the hydrophobicity of polymer surface (see figure 1). From the hierarchically structured replication masters, many polymer surfaces could be duplicated, and all of them possessed almost the same contact angles of superhydrophobicity (averaged contact angle of $158.6 \pm 1.4^\circ$) that could be sustained for more than three months. This replication method is expected to provide a good basis for designing many other functional surfaces such as anti-reflecting, optically transparent superhydrophobic, or biologically compatible surfaces.

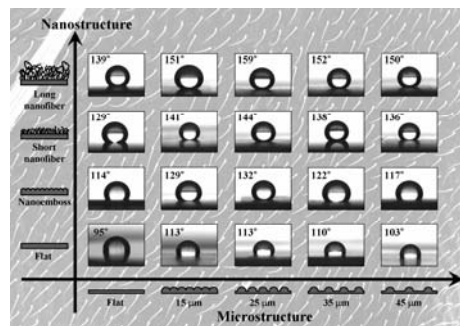


Fig. Water contact angles of the HDPE (high density polyethylene) replica having various hierarchically structured surfaces in comparison to a flat HDPE surface. (x-axis shows the pitch sizes of micron-size patterns and y-axis shows the shape and length of nanostructures)

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Deposition and characterization of Al doped CdO nanostructured thin film prepared by sol-gel spin coating method

Salih Ilcan¹, Yasemin Caglar¹, Mujdat Caglar¹, Fahrettin Yakuphanoglu²

¹Physics Department, Anadolu University, Eskisehir, TURKEY

²Physics Department, Firat University, Elazig, TURKEY

Metal oxide thin films have a variety of uses in optical, thermal, electronic and solar energy devices. In particular, transparent conducting oxides (TCOs) CdO, ZnO, SnO₂, CuAlO₂, etc. are very important materials due to their high transparency in the visible region and also for having a very high conductivity. We have synthesized aluminum-doped cadmium oxide thin films on glass substrates by sol-gel spin coating method, taking the precursor materials cadmium acetate dihydrate and aluminum nitrate. XRD pattern reveals the good crystallinity of CdO thin films. Surface morphology of the film has been studied by a scanning electron microscope. SEM micrograph showed the presence of nanostructure. The crystal structure and orientation of the thin films were investigated by X-ray diffraction patterns. The grain size of the film was calculated using the Debye-Scherrer formula. Texture coefficient and lattice constants were also calculated. Optical reflectance and transmittance were recorded with a double beam Shimadzu UV 2450 spectrophotometer with specular reflectance attachment at an incident angle of 5. The CdO:Al thin films obtained, showed high polycrystalline quality and high transmission in the visible region. The optical constants, width of localized states in the optical band gap and optical band gap of deposited aluminum-doped CdO thin films were determined by optical method.

Acknowledgement

This work was supported by Anadolu University Commission of Scientific Research Projects under Grant No. 061039.

11:15AM IAN043

The structural and optical studies of CdO nanostructured thin film prepared by sol-gel spin coating method

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¹Physics Department, Anadolu University, Eskisehir, TURKEY

²Physics Department, Firat University, Elazig, TURKEY

Thin films of transparent conductive oxides (TCO) such as zinc oxide, indium-tin oxide, tin oxide and cadmium oxide (CdO) have been extensively studied because of their use in semiconductor optoelectronic device technology. The effect of the annealing temperature on the structural and optical properties of the undoped cadmium oxide (CdO) thin films obtained by the sol gel spin coating method, using a simple precursor solution, was studied. The films were characterized by X-ray diffraction, scanning electron microscopy and ultraviolet-visible spectroscopy. The crystal structure and orientation of the thin films were investigated by X-ray diffraction patterns. All the CdO films are polycrystalline with (111) preferential orientation and present high optical transmission >85% for visible region. The grain size of the film was calculated using the Debye-Scherrer formula. Surface morphology of the film has been studied by a scanning electron microscope. Optical reflectance and transmittance were recorded with a double beam Shimadzu UV 2450 spectrophotometer with specular reflectance attachment at an incident angle of 5. The optical constants such as refractive index, extinction coefficient, real and imaginary parts of the dielectric constant of this film were determined. The important changes in absorption edge, refractive index and the dielectric constant were observed due to the annealing temperatures.

Acknowledgement

This work was supported by Anadolu University Commission of Scientific Research Projects under Grant No. 061039.

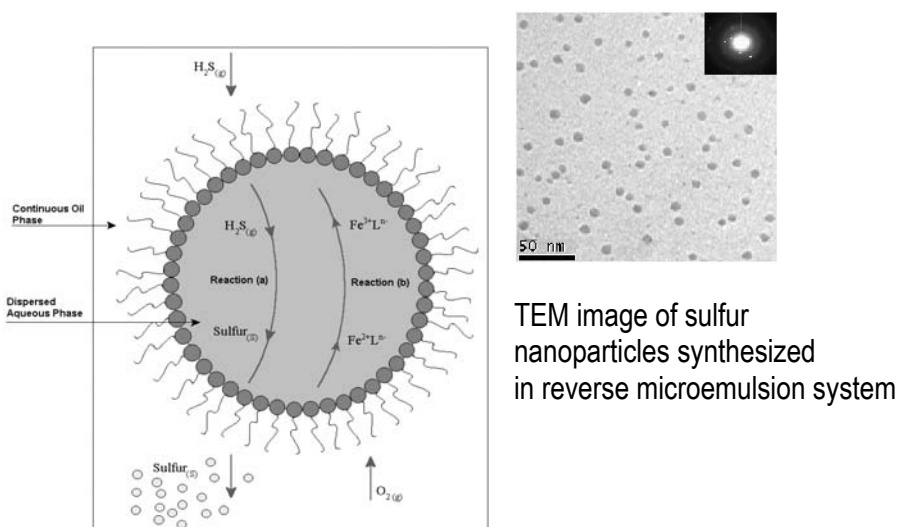
Sulfur Nanoparticles Synthesis and Characterization from H₂S gas, using Novel Biodegradable Iron Chelates in Reverse Microemulsion.

A. S. Deshpande^a, R. B. Khomane^a, B.K. Vaidya^a, R. M. Joshi^a, A. S. Harle^b, B. D. Kulkarni*^a.

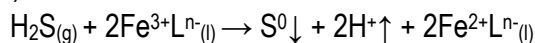
^a Chemical Engineering & Process Development Division, ^b Center for Material Characterization Division, National Chemical Laboratory, Dr. Homi Bhabha Road, Pune 411 008, India.

Sulfur nanoparticles were synthesized from hazardous H₂S gas by desulfurization based on liquid redox process (1). The use of novel biodegradable iron chelates, in particular, FeCl₃-malic acid chelate system has been extensively studied in reverse microemulsion (cyclohexane-n-hexanol/TritonX-100/water) for catalytic oxidation of H₂S gas at ambient conditions of temperature, pressure and neutral pH.

The structural features of sulfur nanoparticles have been characterized by XRD, TEM, DRIFT-IR and BET surface area measurements. XRD analysis indicates the presence of α-sulfur (JCPDS-08247). TEM analysis shows that the morphology of sulfur nanoparticles synthesized in reverse microemulsion system is nearly uniform in size (average particle size 10 nm) and narrow particle size distribution (in range of 5-15 nm) as compared to that in aqueous systems.



Reaction – (a)



Reaction – (b)

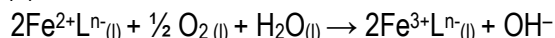


Fig 1. Synthesis of Sulfur Nanoparticles in Reverse Microemulsion System from H₂S gas

The sulfur element is known to possess potent antimicrobial activity [2]. Due to their smaller particle size (~10 nm), sulfur nanoparticles are expected to exhibit antimicrobial action at lower concentrations than sulfur particles synthesized in

aqueous phase (80-100 nm). Sulfur nanoparticles synthesized in reverse microemulsion system exhibit higher antimicrobial activity (against bacteria, yeast and fungi) than that of sulfur synthesized in aqueous phase only.

The described process serves mainly two objectives; (a) waste utilization for preparation of commercially important nano-sulfur product and (b) reduction in environmental pollution.

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11:45AM IAN029V

Studies on Novel Nanoceramic Coating for Industrial Applications

S.Balasubramanian and E.Ramanathan

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The coatings on different materials can be classified as :a)protective b) decorative and c) functional coating depending on their end use. The pretreatment of metal surface is necessary since it provides better anchoring for the top coat and also prevents the creeping corrosion to a large extent. Phosphating and sand blasting are conventional method for pretreatment .The formation of zinc and iron phosphate crystal lattice in a phosphating bath results in the deposition of phosphophyllite [$Zn_2 Fe(PO_4)_2 \cdot 4H_2O$] and hoepite[$Zn_3(PO_4)_2 \cdot H_2O$]over the metal surface. The base coating for mild steel is an important process since the efficacy of the top coat depends on the nature of the underlying coat.

The nanoparticle coating over different surfaces has been reported in the literature. The conventional zinc phosphate coating and nanoceramic coating which is essentially obtained from nano ZrO_2 particle over mild steel surface has been investigated in the present study and the efficacy of the epoxy top coat over these base coats have been compared .The average particle size of the nanoparticle has been found to be 52 nm. Several tests like salt spray resistance; humidity resistance, impact resistance, pencil hardness, cross hatch, dry film thickness, acid resistance, alkali resistance, fuel resistance etc have been carried out as recommended by ASTM. The test results demonstrate the supremacy of the nanocoated surface over the phosphated surface. The AFM studies of both zinc phosphate coated surface and the nanoceramic coated surface clearly indicates the nature of the coatings. The spherical shaped nanoparticles have been observed in the latter case while the former indicated bands in the AFM image. The size of the nano particles has been determined by XRD.A probable mechanism for the behavior of nanoceramic ZrO_2 particle and the zinc phosphate on the metal surface will be discussed.

References:

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- Painting scheme for Liquid epoxy paint

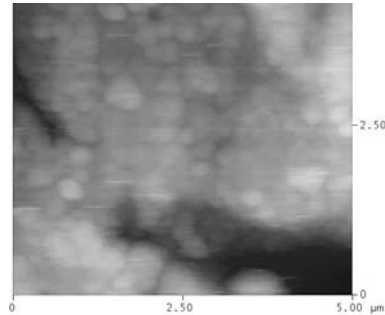


Epoxy paint – top coat

Epoxy primer – undercoat

Phosphating or Nanocoating
– Metal pretreatment

AFM image of Nanocoat - High resolution



12:30PM Lunch

Session: Properties of Quantum Dots (Villa)

Tuesday Afternoon, February 5th, 2008

1:30 PM IAN009 (Invited)

Optical properties of quantum dots coupled with a continuum of states: Spin and nonlinear effects

Alexander O. Govorov

Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701, USA

This talk will describe optical properties of excitons in quantum dots interacting with the continuum of external states. Voltage-tunable self-assembled dots interact with the continuum of external states via tunneling [1,2] or Auger processes [3]. When the interaction involves the Fermi sea in the back contact, photoluminescence has peculiar line shapes with a linewidth determined by the Kondo temperature [1]. Since the coupling between a quantum dot and the Fermi sea in the metal contact is voltage-tunable, the spin state and spin relaxation of exciton can be controlled by the applied voltage utilizing the Kondo effect. Using this method, it is possible to control the spin flip rate of excitons by more than an order of magnitude [2]. In this scheme of electrical manipulation, dark excitons (spin=2) turn into bright excitons (spin=1) and vice versa. When a self-assembled quantum dot interacts with an empty continuum, the absorption spectra demonstrate asymmetric lines (Fano effect). Interestingly, the degree of asymmetry is strongly increased in the nonlinear regime [4]. In

the nonlinear regime, even very weak coupling to external states becomes apparent. Colloidal semiconductor dots can strongly interact with metallic nanoparticles via Coulomb coupling [5,6]. Since plasmon excitations in metal nanoparticles represent a continuum of states, this problem is again reduced to the Fano/Anderson model with several important modifications. The effects described in our papers can be utilized for manipulation of quantum states in nanostructures.

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2:00PM IAN023 (Invited)

Controlled interactions of quantum dots and cavity modes for efficient nanophotonic devices

Stefan Strauf^{1,2}, Matthew T. Rakher¹, Nick G. Stoltz³, Kevin Hennessy⁴, Yong-Seok Choi⁴, Evelyn L. Hu^{3,4}, Larry A. Coldren^{3,4}, Pierre M. Petroff^{3,4}, and Dirk Bouwmeester^{1,5}

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²Department of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ 07030, USA

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⁵Huygens Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands

Controlled engineering of radiative exciton transitions from semiconductor quantum dots (QDs) and high-quality optical modes provided by micro- and nanocavities creates novel optoelectronic devices emitting classical and non-classical light states with unprecedented photon emission efficiency. In this talk we will review our recent work on ultra-low threshold photonic crystal nanolasers [1,2] and ultra-high frequency single photon sources (SPS) [3].

Extremely low-threshold lasers can result from the appropriate match of small mode-volume photonic-crystal cavities to optically active material. We will demonstrate that very few (1 to 3) QDs as a gain medium are sufficient to realize a photonic-crystal laser with ultra-low lasing thresholds. The nanocavities are based on a lattices of airholes etched out of a thin GaAs membrane, confining the optical mode down to the fundamental limit of a standing half-wave in all three dimensions. This drastically reduces losses, since virtually all spontaneous emission is directed into the lasing mode, corresponding to a beta factor close to unity. Ultra low lasing thresholds of a few nW are confirmed by observing the characteristic nonlinearities in the light-light curves, the cavity mode linewidth narrowing, and by mapping the transition from a thermal to a coherent light state using photon statistics measurements. Moreover, we observed that lasing does not require a direct exciton-mode resonance implying a unique quantum dot gain mechanism provided by the interplay of the QD surrounding and the inhibition of spontaneous emission at the sharp exciton transitions. This has clear implications for the future design of ultra efficient nanoscale lasers, which may now be formed with only a few, or even single, QDs that, with cooperation from the surrounding matrix, self-tune their emission into the lasing mode with nearly perfect efficiency [1,2].

If the optical cavity mode couples only to a single QD one can create a photon source which provides single photons on demand. Here we report on QD based SPS with measured single photon emission rates of 4.0 MHz (31 MHz into the first lens). These results were achieved using a novel type of GaAs/AlGaAs-microcavities based on two distributed Bragg reflectors with etched trenches and an embedded oxide-tapered aperture to provide mode confinement while maintaining high quality factor up to 50,000. Embedded electrical gates provide tuning of exciton transitions into resonance with the cavity mode and thus to benefit by the Purcell enhancement of the QD emission rate. Moreover, we demonstrate that the limitations of photon emission due to formation of exciton dark-states typically occurring in self-assembled QDs can be overcome by utilizing charged QD transitions. As a result, these SPS emit at record high emission rates making them of interest for a broad range of applications in quantum information science.

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2:30PM IAN007 (Invited)

Some aspects of exciton thermal exchange in InAs QD DWELL laser structures

T. V. Torchynska

ESFM- National Polytechnic Institute, U.P.A.L.M., Mexico D.F., 07738, Mexico,

The photoluminescence (PL) spectra, their temperature and power dependences, as well as PL excitation spectra, have been investigated for ground (GS) and excited (ES) states of InAs quantum dots (QDs) in: a) symmetric $\text{In}_{0.15}\text{Ga}_{0.85}\text{As}/\text{GaAs}$ quantum well (DWELL) structures (the same composition of capping and buffer layers) with QDs prepared at different temperatures, and b) asymmetric $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ DWELL structures (different composition of capping and buffer layers).

The set of rate equations for exciton capture (relaxation into QWs or QDs) and thermal escape are solved with the aim to analyze the nature of thermal activation energies of PL quenching processes for ground and excited state PL bands in studied DWELL structures. It is revealed three different stages for thermally activated quenching of the QD PL intensity in the temperature range 80-300K. These stages and the reason for the variety of activation energies of PL thermal quenching in DWELL structures are discussed as well.

The fitting procedure has confirmed three stages of PL thermal quenching and has allowed estimating the variation of recombination parameters in QWs and GaAs barriers in dependence on technological parameters. The theoretically predicted results were compared with experimental one and the mechanisms for PL thermal quenching are revealed.

It is shown that structures investigated exhibit a spatial long range variation of the average QD size in the QD ensemble across the sample. This long range QD size in homogeneity was used for an investigation of the multi excited state energy trend versus ground state energy (or QD sizes). Experimental results were compared with the electron-hole level energy trend versus QD sizes predicted theoretically on the base of the 8-band k-p approach. Some anti correlation between experimental and theoretical results has been revealed and discussed.

The work was supported by CONACYT Mexico (project N58358).

Deep level transient spectroscopy in quantum dot characterization

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Beside photoluminescence, deep level transient spectroscopy (DLTS) has become a powerful method for investigating the electronic properties of quantum dots (QDs). Due to the complex charge carrier statistics often associated with quantum dots, this method offers a less straight forward interpretation scheme than that normally available for deep level impurities in crystalline semiconductors. For QDs prepared by the Stranski-Krastanov technique, a spread in the electronic energy levels occur due to varying QD size. Furthermore, this kind of QD systems are influenced by factors such as the existence of multiple emission paths (tunneling and thermal) and multiple particle emission statistics. Recent experimental results interpreted by theoretical treatments have elucidated these properties [1, 2].

A frequently used benefit of DLTS is the possibility to estimate charge carrier energy levels by extracting activation energies from thermal emission rate data. For QDs such a procedure requires additional considerations for the influence of energy level distributions, charging and tunneling emission. Fig. 1 shows a contour plot of the DLTS signal from an ensemble of InAs/GaAs QDs with two energy levels of s and p character, respectively. The measurement was done as a function of temperature and reverse voltage across the depletion region of a Schottky diode, embedding the QDs. In such a representation, it can be demonstrated that vertical contours occur for pure thermal emission processes while horizontal contours occur for pure tunneling processes. Deviations from these rules reflect a mix of the two processes. In addition, the contours are influenced by the temperature dependence of the Fermi level the distribution of the energy levels and the charging of the QDs with increasing reverse voltage. Therefore, in order to obtain activation energies from DLTS, the data must be collected along a route on the T,V plane corresponding to well defined emission conditions with respect to voltage and temperature ranges. In order to study the tunneling properties correctly, the data must be collected from a region where the gradient is vertical in this diagram. Experimental and theoretical details confirming these rules are presented in our paper.

1. O. Engstrom, M. Kaniewska, W. Jung and M. Kaczmarczyk, *Appl. Phys. Lett.* **91**, 033110 (2007)

2. O. Engstrom, M. Kaniewska, M. Kaczmarczyk and W. Jung, *Appl. Phys. Lett.* **91**, 133117 (2007)

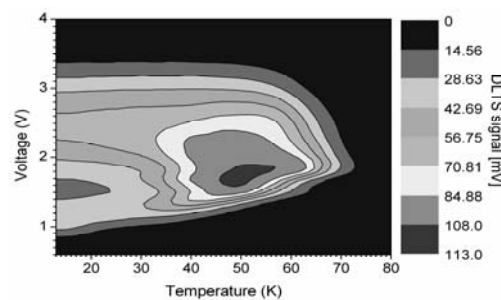


Fig. 1 Contour plot of DLTS signal as a function of temperature and reverse voltage for InAs/GaAs quantum dots embedded in the depletion region of a Schottky diode.

3:15PM IAN056 (Invited)

Coherently controlled light emission of quantum dots in cavities*

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Semiconductor quantum dots (QDs) possess similar optical properties to that of real atoms and are thus being called “artificial” atoms. In addition to a much larger transition dipole moment compared to their natural counterpart due to their mesoscopic size, QDs be fully tailored, to give rise to the desired electronic properties. These developments bring about new possibilities to explore “quantum optical control” in such nanostructures and to harness these quantum optical properties for novel optical device applications, including the current topic of quantum information technology. Indeed, the realization of driven Rabi oscillations in two level system and multi-level QD systems, demonstrated fundamental single-qubit and two-qubit quantum operations. These demonstrations, all achieved on *bare* quantum dots. In the mean time, significant progress has been made by placing the artificial atoms inside optical cavities to modify their electro-magnetic properties, leading to the so-called “cavity

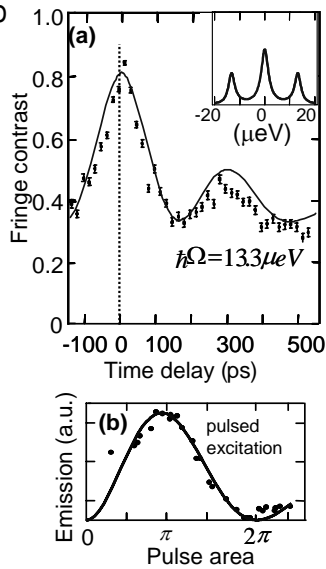


Fig. 1

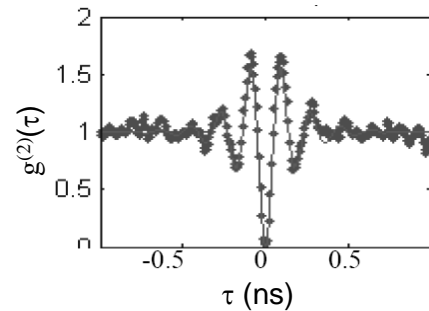


Fig. 2

QED” (cavity quantum electrodynamics) with artificial atoms. Indeed, demonstration of the Purcell effect (weak coupling) as well as vacuum Rabi oscillation (strong-coupling). These cavity-QED experiments, however, demonstrated only “passive” control of quantum state in a sense that the external drive are not used to actively shapes the quantum state. While it is expected that achieving active control of QDs in the cavity will open new doors in solid-state based quantum information sciences, there had not been any clear demonstration to date.

Here we report our progress toward this endeavor. In particular we show the achievement of resonantly controlled light emission of quantum dots in the cavity, including the observation of Mollow triplets in time domain characterized by oscillations in the first order photon-photon correlation function, $g^{(1)}$ [1] (Fig. 1(a)). Moreover, by using pulse laser, we observed nearly ideal fidelity in the Rabi flopping of the excitonic qubits [1] (Fig. 1(b)). Finally, we investigate the quantum statistic of the emitted photons. We show that the second order correlation function, $g^{(2)}$ [1] exhibit strong oscillations

instead of the commonly known anti-bunching dip at $\tau = 0$ (Fig. 2). By using the directly measured T1 and T2 time at low excitation intensity, we found that $g^{(2)}(\tau)$ fits very well with an ideal two-level model with constant values of T1 and T2. We further discuss this behavior in the context of quantum information interface between the localized qubits and the flying photon qubits.

*This work was done in collaboration with A. Muller (UT-Austin), E.B. Flagg (UT-Austin), G. Salamo (U of Arkansas), and D. Deppe (U of Central Florida). The work was supported by the National Science Foundation and W.M. Keck Foundation.

3:45PM IAN057 (Invited)

Self-Assembled Semiconductor Guanosine nanostructures for molecular electronics and photonics

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² Department of Electrical Eng., Virginia Commonwealth University, Richmond, VA, USA

Nanoscale hybrid molecular organic materials based on self-assembled guanosine molecules conjugated to GaN semiconductors has been used to design novel photonic and electronic devices in the ultraviolet wavelength regime. Two specific classes of devices such as photodetectors and photonic crystals will be discussed. The self-assembled guanosine supramolecule shows semiconductor properties and has polarization along its axis due to the dipole moment of guanosine molecules. We experimentally demonstrated the polarization and semiconductor properties of the supramolecule with nanoscale metal-semiconductor-metal structure on passivated Ga-terminated GaN surface. Metal-semiconductor-metal based photodetector was fabricated using ordering of modified guanosine based semiconductor nanowires which exhibit $I-V$ characteristics with high current response and higher rectification ratio compared to Si based hybrid photodetectors. Photocurrent response of a two-terminal device shows the typical characteristics of a semiconductor photodiode with a cutoff wavelength at ~ 325 nm. The *current-voltage* characteristics have been elucidated using the induced polarization properties of self-assembled guanosine semiconductor [1]. The transport properties of the self-assembled guanine molecule depends strongly gap between the nanoelectrodes. The self-ordering of the guanine molecule is observed for gap length < 480 nm.

We also explore the feasibility of designing self-assembled guanosine based photonic crystal conjugated to GaN matrix for UV-Visible photonic crystal waveguides. The low refractive index of the modified guanosine crystals and the high index of the GaN matrix provides the contrast for realizing photonic crystal in the UV region which can be tuned by varying the concentration of the molecular material.

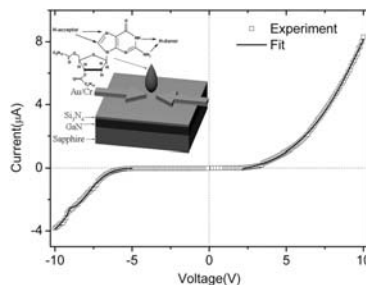


Fig1. Current-voltage characteristics of a two-terminal nanoscale device based on semiconductor deoxyguanosine deposited in between Au electrodes on GaN substrates. Inset is the schematic of UV-visible photodetector based on modified deoxyguanosine on GaN substrates

4:15 PM IAN050 (Invited)

Spin-dependent dynamics in confined geometries

R. Winkler

Department of Physics, Northern Illinois University, DeKalb, IL 60115, USA

Spin-orbit coupling in semiconductor nanostructures gives rise to highly nontrivial dynamics of the charge carriers [1]. On the one hand, it affects the spin dynamics of the electrons, giving rise to phenomena like a spin splitting of the energy levels at zero magnetic field, spin-dependent geometric phases, spin precession, and the electrical generation of spin densities. On the other hand, it also affects the orbital dynamics of the electrons. Resulting phenomena that have attracted recent interest include the electrical generation of spin currents and the spin Hall effect. In recent years, spin-dependent phenomena in nanostructures have received a great deal of attention due to possible applications in the field of quantum information processing.

In my talk I will focus, in particular, on the interplay between spin precession and the orbital motion of charge carriers. For spin 1/2 electrons, spin-orbit coupling can be interpreted as an effective magnetic field that results in an oscillatory motion of spin noneigenstates which is the well-known spin precession. Hole systems, on the other hand, are characterized by an effective spin 3/2. In my talk I will show how these hole spins can precess even in the absence of an external or effective magnetic field [2]. In particular, hole spin precession can give rise to an alternating spin polarization.

The orbital dynamics of charge carriers in the presence of spin-orbit coupling is likewise characterized by an oscillatory component. For relativistic electrons the oscillatory motion is known as *Zitterbewegung* [3]. I will show that many remarkable analogies exist between the *Zitterbewegung* of relativistic quantum mechanics and the oscillatory orbital dynamics of electrons and holes in semiconductors [4]. Moreover, the oscillatory orbital motion is closely related to the precession of the spin degree of freedom. In the presence of an electric field that is driving the charge carriers, precessing spins give rise to the formation of spin currents whereas those spins that do not precess give rise to the formation of nonequilibrium spin densities [5].

[1] R. Winkler, *Spin-Orbit Coupling Effects in Two-Dimensional Electron and Hole Systems* (Springer, Berlin, 2003)

[2] D. Culcer, C. Lechner, and R. Winkler, *Phys. Rev. Lett.* **97**, 106601 (2006)

[3] E. Schroedinger, *Sitzungsber. Preuss. Akad. Wiss., Phys. Math. Kl.* **24**, 418 (1930)

[4] R. Winkler, U. Zuelicke, and J. Bolte, *Phys. Rev. B* **75**, 205314 (2007)

[5] D. Culcer and R. Winkler, arXiv:0708.4009, accepted for publication in *Phys. Rev. Lett.*

5:00PM Dinner

Session: Transport in Nanoscale (Villa)

Tuesday Evening, February 5th, 2008

7:00PM IAN039 (Invited)

Electronic Transport in Nanoscale P-donor Devices defined by STM based Hydrogen Resist Lithography on Si

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²Centre for Quantum Computer Technology, School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia

We have previously demonstrated nano-scale device fabrication in silicon through a combination of STM lithography, gaseous precursor dosing, and low-temperature Si growth [1,2]. By patterning a hydrogen resist layer on the Si(100) surface with an STM and dosing with phosphine, planar dopant nanostructures are defined. This technique has the potential to scale down towards single donor devices with atomically precise placement [3,4]. Si encapsulation at low temperatures preserves the dopant pattern and protects the buried device, which is contacted ex-situ with aluminum contacts defined by electron beam lithography. With this approach, nanoelectronic devices such as tunnelling gaps, nanowires, dots and arrays have been demonstrated [5-7].

In my talk, I will present a completely UHV based approach to in-plane gated donor devices using multi-terminal structures. Such an approach has the advantage that all conducting regions are defined during the lithographic process in-situ and surfaces which come into contact with air are kept far from the active electronic device region. We show that this leads to highly stable and tunable devices minimizing the influence of charge traps typically found in oxides or at interfaces to metallic gate electrodes.

In a first step we investigate the dependence of non-linear transport through tunnel gaps on gap size in an effort to minimize effects of barrier deformation due to large biases [Fig. 1a)]. In a second generation device [Fig.1b)] with optimised gap geometries we demonstrate a fully tunable quantum dot showing Coulomb Blockade oscillations that can be adjusted over many periods with the three in-plane gate electrodes [Fig.1c)]. Ultimately, such an in-plane gate approach will be limited by the smallest conducting wires that can be fabricated with our technique and we find that down to lithographic widths of 2.5 nm, donor wires are conducting with resistances down to 13 k Ω .

These devices are prototypes for a new generation of donor based nanostructures with a wealth of functionality that can be implemented simply by "drawing" with an STM tip, a technique which has the ability to produce devices approaching the single donor limit.

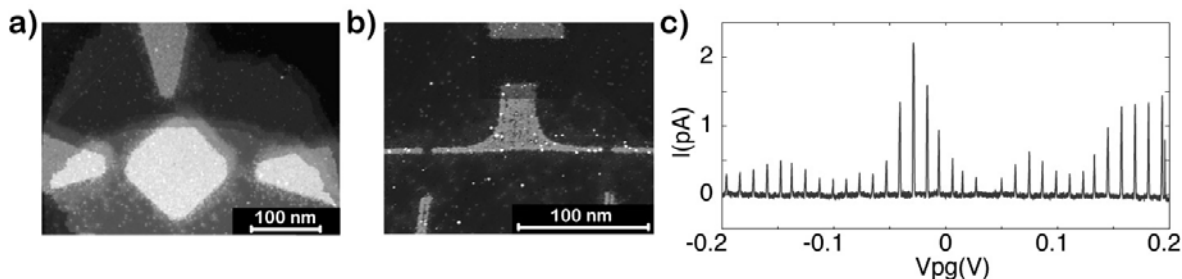


Fig1. Three of the investigated structures. a) Three terminal dot structure for investigation of the tunnel gaps b) optimised five terminal quantum dot structure exhibiting tunable CB-oscillations c) as a function of the voltage applied to the top plunger gate.

- [1] F. Rueß et al., Nano Letters 4, 1969 (2004).
- [2] M.Y. Simmons et al., Mol. Sim. 31, 505 (2005).
- [3] J.R. Tucker and T.-C. Shen, Solid State Electron. 42, 1061 (1998).
- [4] S.R. Schofield et al., Phys. Rev. Lett. 91, 136104 (2003).
- [5] F.J. Rueß et al., Nanotechnology 18, 044023 (2007).
- [6] F.J. Rueß et al., Small 3, 563 (2007).
- [7] W. Pok et al., IEEE Trans. Nanotechn. 6, 213 (2007).

7:30PM IAN035 (Invited)

Coherent Transport in Few Electron Triple Quantum Dot Circuits

Andy Sachrajda

Institute for Microstructural Sciences, National Research Council of Canada, Ottawa, Ontario, Canada K1K 0H7

An account will be given of coherent electron transport measurements in triple quantum dot circuits. The ring arrangement of quantum dots is defined electrostatically from a 2DEG. The stability diagram of the system is mapped out revealing a series of phenomena absent in single and double quantum dot arrangements. These include quadruple points, quantum cellular automata effects and type two triple points at which QCA effects and three resonant configurations coexist. We are able to set up strategically important configurations and study coherent magneto-transport with these settings. In addition to the expected Aharonov-Bohm effect higher frequency coherent components are also found to be present. These will be discussed and compared to existing theoretical ideas.

8:00PM IAN031 (Invited)

Tunable Coulomb Blockade in Nanostructured Graphene

C. Stampfer*, F. Molitor, J. Güttinger, D. Graf, T. Ihn and K. Ensslin,

Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland

We report Coulomb blockade and Coulomb diamond measurements on an etched, tunable single-layer graphene single-electron transistor (SET) [1]. The device shown in Figs. 1(a) and 1(c) consists of a graphene island connected via two narrow graphene constrictions with a width of approx. 50nm to a source and a drain contact. The device is fully tunable by three lateral graphene side gates, two barrier gates SG1,2, and the plunger gate PG. The functionality of lateral graphene gates has been also investigated in a different device, namely a side gated graphene Hallbar [2]. There an average penetration depth of the side gate created field of approx. 90 nm is shown. On the nanostructured SET Coulomb blockade resonances are observed and from Coulomb diamond measurements (see, e.g., Fig. 1(d)) a charging energy of 3.5 meV is extracted. For increasing temperatures we detect an intricate interplay between the temperature dependence of the nanostructured graphene barriers and that of the Coulomb blockade resonances.

- [1] C. Stampfer, J. Güttinger, F. Molitor, D. Graf, T. Ihn, and K. Ensslin, „Tunable Coulomb blockade in nanostructured graphene”, submitted, arXiv:0709.3799, (2007)
- [2] F. Molitor, J. Güttinger, C. Stampfer, D. Graf, T. Ihn, and K. Ensslin, “Local gating of a graphene Hall bar by graphene side gates”, submitted, arXiv:0709.2970v1, (2007)

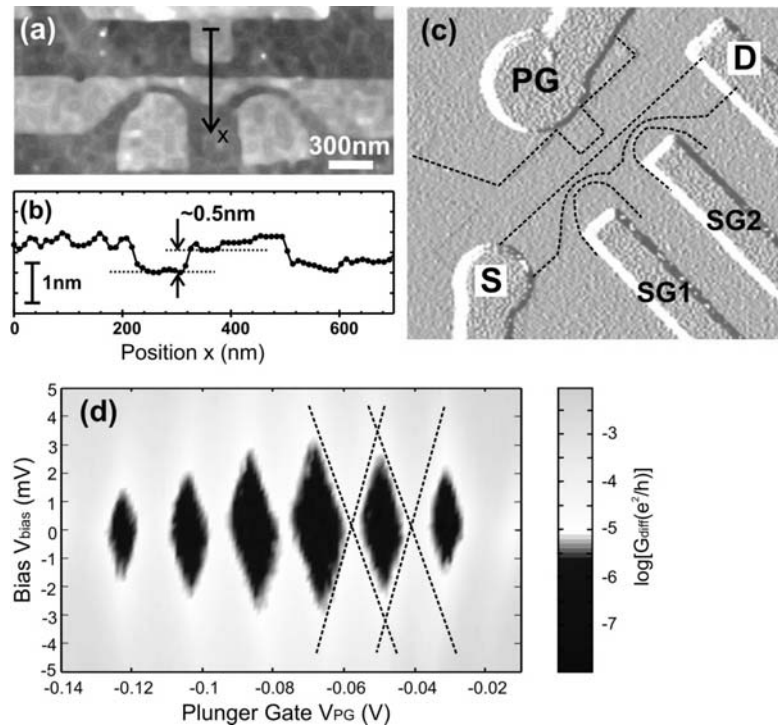


Fig1. Nanostructured graphene quantum dot device. (a) Scanning force microscope (SFM) image of the investigated graphene device after etching and (c) after contacting the graphene structure. The minimum feature size is approx. 50 nm. The dashed lines indicate the outline of the graphene areas. (b) SFM cross-section along a path x [marked in (a)] averaged over ~ 40 nm perpendicular to the path proving the selective etch process. (d) Coulomb blockade diamonds in the differential conductance G_{diff} , represented in a logarithmic gray scale plot (dark regions represent low conductance). Images are taken from Ref. [1].

8:30PM Break

8:45PM IAN013 (Invited)

Transport in quantum dots with time- and spatial resolution

Thomas Ihn, Simon Gustavsson, Thomas Müller, Arnd Gildemeister

Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland

Quantum dots have in the past been intensely studied by electronic transport experiments. Such experiments have shown unprecedented potential to control individual electrons on the level of the charge and the spin degrees of freedom. Recently, two experimental trends have enabled us to look at quantum dot transport from new perspectives. On the one hand, scanning probe techniques applied at dilution refrigerator temperatures offer the opportunity to study quantum dots with spatial resolution. On the other hand, measurements with a charge detector close to quantum dots and double quantum dots have been extended to bandwidths large enough to study hopping of individual electrons in real time. In this talk our recent experiments on both aspects will be briefly reviewed and future perspectives will be discussed.

We have recently demonstrated the realization of a scanning force microscope operating at temperatures around 100 mK in a dilution refrigerator [1]. The microscope has been successfully used for the investigation of quantum dot structures defined laterally on Ga[Al]As two-dimensional electron gases by using the so-called room temperature AFM-lithography technique.

At low temperatures, the scanning gate technique which has been applied by several groups worldwide has been investigated in detail by using quantum dot systems for a study of the tip-induced potential [2] and a method for optimizing this potential in situ has been demonstrated [3]. It has been shown that this technique, applied to a quantum dot with an adjacent quantum point contact charge detector gives novel insights complementary to those from pure transport studies [4]. However, the Holy Grail of finding ways to imaging and controlling individual quantum states on length scales below 100 nm remains to be discovered.

In complementary experiments tunneling of individual electrons in quantum dots has been detected in real time as the random telegraphic switching signal in a nearby quantum point contact detector [5]. The method has allowed us to study shot noise in tiny sub femtoampere quantum dot currents [5–7], to detect the self-interference of single electrons in a double-dot interferometer device, and to detect single photons using photon-assisted tunneling [8]. It turns out that the charge detection technique gives access to very accurate values of system parameters inaccessible in conventional transport experiments, such as tunneling rates for electrons from the dot into source and drain, or the coupling strength between the dots of a double dot system. We will finally discuss prospects and benefits of combining the spatial resolution of the scanning probe techniques and the time resolution of the charge detection technique in a new generation of experiments.

[1] A.E. Gildemeister, T. Ihn, C. Barengo, P. Studerus, K. Ensslin, *Rev. Sci. Instrum.* **78**, 013704 (2007).

[2] A. Gildemeister, T. Ihn, M. Sigrist, K. Ensslin, *Phys. Rev. B* **75**, 195338 (2007).

[3] A. Gildemeister, T. Ihn, M. Sigrist, K. Ensslin, *Appl. Phys. Lett.* **90**, 213113 (2007).

[4] A. Gildemeister, T. Ihn, R. Schleser, K. Ensslin, D.C. Driscoll, A.C. Gossard, *J. Appl. Phys.* **102**, 083703 (2007).

[5] S. Gustavsson, R. Leturcq, B. Simovic, R. Schleser, T. Ihn, P. Studerus, K. Ensslin, D.C. Driscoll, A.C. Gossard, *Phys. Rev. Lett.* **96**, 076605 (2006).

[6] S. Gustavsson, R. Leturcq, B. Simovic, R. Schleser, P. Studerus, T. Ihn, K. Ensslin, D.C. Driscoll, A.C. Gossard, *Phys. Rev. B* **74**, 195305 (2006).

[7] S. Gustavsson, R. Leturcq, T. Ihn, K. Ensslin, M. Reinwald, W. Wegscheider, *Phys. Rev. B* **75**, 075314 (2007).

[8] S. Gustavsson, M. Studer, R. Leturcq, T. Ihn, K. Ensslin, D. C. Driscoll, A. C. Gossard, arXiv:0705.3166

9:15PM IAN011 (Invited)

Electronic Interaction in Coupled Quantum Systems

D. Schröder, V. Khrapay, J.P. Kotthaus, S.Ludwig

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Solid state based quantum dots (QD) are heavily discussed for applications as qubits, but also provide a beautiful playground for basic research on artificial molecules. First, concepts needed to understand transport and charge spectroscopy measurements on coupled QDs will be developed. Then experimental results on a few electron triple QD [1], a double QD quantum ratchet [2] and interaction mechanisms involved are discussed.

Our few electron serial triple QD is electrostatically defined in a standard GaAs/AlGaAs heterostructure containing a two-dimensional electron system. Ground state stability diagrams detected with a single quantum point contact (QPC) demonstrate complete control of the triple QDs charge configuration in the few electron regime. We discuss the complex interplay between charge states of the three coupled QDs near points of high degeneracy. In this regime we observe electron transport through the three QDs reflecting quantum cellular automata physics.

The second part of the talk will be devoted to the interaction of a strongly driven QPC with another unbiased QPC or a double QD. These experiments can be seen in the context of back-action of a charge detector (the QPC) onto a qubit (the double QD). Using the strongly driven QPC as non-equilibrium energy source we realize a double QD quantum ratchet. A second experiment involving two QPCs [3] illuminates the possible role of electron-phonon interaction in such devices.

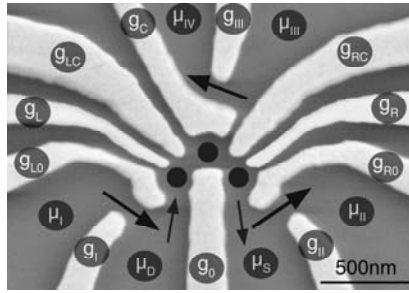


Fig1. Scanning electron micrograph of the wafer surface containing metal gates used to laterally define a serial few electron triple QD (red circles) and three QPCs (blue arrows).

1. D. Schröer et al., Phys. Rev. B 76, 075306 (2007).
2. V. Krapay et al., Phys. Rev. Lett. 97, 176803 (2006).
3. V. Krapay et al., Phys. Rev. Lett. 99, 96803 (2007).

9:45 PM IAN054 (Invited)

Surface-acoustic-wave dynamic quantum dots

M. Kataoka, M. R. Astley, R. J. Schneble, A. L. Thorn, C. H. W. Barnes, C. J. B. Ford, D. Anderson, G. A. C. Jones, I. Farrer, D. A. Ritchie, and M. Pepper

Cavendish Laboratory, J J Thomson Avenue, Cambridge CB3 0HE, United Kingdom

Surface-acoustic-wave (SAW) single-electron transport [1] offers a unique system of dynamic quantum dots in a semiconductor material. Piezoelectric potential modulation travelling with SAW in a GaAs/AlGaAs heterostructure can be used to pump electrons one by one through a depleted one-dimensional channel. If the channel is long enough, a series of dynamic quantum dots can form, each trapping only one electron. I will discuss our recent experiments on SAW dynamic quantum dots, including our observation of electron tunnelling from dynamic quantum dots [2], non-invasive detection of dynamic quantum dot charge [3], and an electron transfer between a gate-defined static quantum dot and a dynamic quantum dot [4].

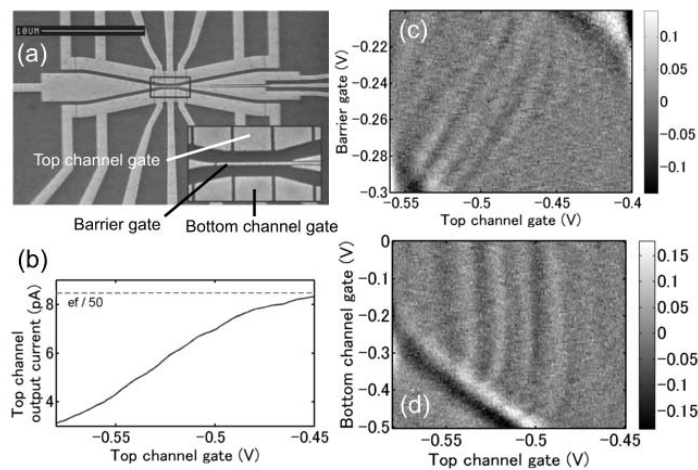


Fig1. Tunnelling experiments on surface-acoustic-wave dynamic quantum dots.

1. J. M. Shilton *et al.*, *J. Phys.: Condens. Matter* **8**, L531 (1996).
2. M. R. Astley *et al.*, *Phys. Rev. Lett.* **99**, 156802 (2007).
3. M. R. Astley *et al.* (to be published).
4. M. Kataoka *et al.*, *Phys. Rev. Lett.* **98**, 046801 (2007).

Session: Virtual VC-IAN Session Two

Wednesday Morning, February 7th, 2008

8:00AM IAN001V (Invited), (2PM, Spain)

Nanotube ElectroMechanics

Adrian Bachtold

CIN2 and CNM Barcelona, Campus UAB, E-08193 Bellaterra. Spain

Carbon nanotubes are often recognized as the ultimate material for high-frequency mechanical resonators. For instance, nanotube resonator devices hold promise for ultralow mass detection or quantum electromechanical experiments. However, the detection of the mechanical vibrations remains very challenging. In this talk, I will present a novel detection method of nanotube vibrations, which is based on atomic force microscopy [1]. This method enables the detection of the resonances up to 3.1 GHz with subnanometer resolution in vibration amplitude. Importantly, it allows the imaging of the mode-shape for the first eigenmodes.

I will also report on a new artificial nanofabricated motor in which one short nanotube moves relative to another coaxial nanotube. This motion is shown to consist of translation and/or rotation, depending on the atomic interaction between the nanotubes. The motion is actuated by imposing a thermal gradient along the device, allowing for sub-nanometer displacements. This is, to our knowledge, the first experimental demonstration of displacive actuation at the nanoscale by means of a thermal gradient.

The collaborators are D. Garcia-Sanchez, A. Barreiro, A. San Paulo, M.J. Esplandiu, R. Rurali, E.R. Hernández, J. Moser, B. Lassagne, F. Perez-Murano, L. Forró, and A. Aguasca.



D. Garcia-Sanchez, A. San Paulo, M. J. Esplandiu, F. Perez-Murano, L. Forro, A. Aguasca, and A. Bachtold, *Phys. Rev. Lett.* **99**, 085501 (2007).

8:30AM IAN021V (2:30PM, Italy)

Multi-electron dynamics in coupled quantum dots: the role of interdot Coulomb interaction

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¹ INFN-CNR S3 National Research Center, Via Campi 213/A, 41100 Modena, Italy

² Dipartimento di Fisica, Università di Modena e Reggio Emilia, Modena³ Institut für Physik, Karl-Franzens-Universität Graz, Universitätsplatz 5, 8010 Graz, Austria

Semiconductor coupled quantum dots (CQDs) have been proposed for many novel nanoelectronic devices, including solid-state quantum logic gates. The ability to control coherent charge oscillations between the coupled dots is essential for the development of these devices. While this has motivated a large number of theoretical studies on the *single-particle* dynamics in CQDs, the state-of-the-art experiments deal with *multi-particle* charge oscillations [1,2]. The behavior of these oscillations is determined by the competition between the two interaction mechanisms coupling the quantum dots, namely inter-dot tunneling and Coulomb correlation. As a result, one would expect involved inter-dot oscillation patterns[3,4]. Surprisingly, this is not what one observes in the experiments [1,2], where multi-electron charge oscillations display a simple sinusoidal time-dependence, very much as in the single-electron limit. This is in spite of the fact that the CQDs were in the strong Coulomb correlation regime.

To gain understanding of the actual role played by Coulomb interaction, in this work we investigate theoretically the time evolution of correlated few-electron states oscillating in a CQD device. Our model consists of two tunnel-coupled vertical dots (see figure). The electron states are computed with a Full Configuration Interaction approach starting from the 3D single-particle states ensuing from an effective mass description of the device. The time evolution is calculated within the Pauli master equation formalism, including electron-electron interaction *exactly*, as well as first-order coupling of the carriers with the acoustic phonons.[5]

In a typical simulated experiment, we initialize the system applying a strong bias, which leads to the charge density partially or totally localized in one of the dots. Next we remove the bias and observe the multi-electron state oscillate coherently between the two dots. We find that the oscillatory behavior is profoundly affected by the number of carriers (see figure) and the strength of the inter-dot Coulomb interaction. While the latter induces multi-frequency oscillation patterns, in the limit of strong correlation a single-frequency behavior is retrieved, which may explain the experimental results of Refs. [1,2]. We also show how to tailor the few-particle oscillation pattern by engineering the CQD confining potential or by using external magnetic fields. Finally, we show that our findings are robust upon inclusion of the interaction with the environmental phonon bath.[6]

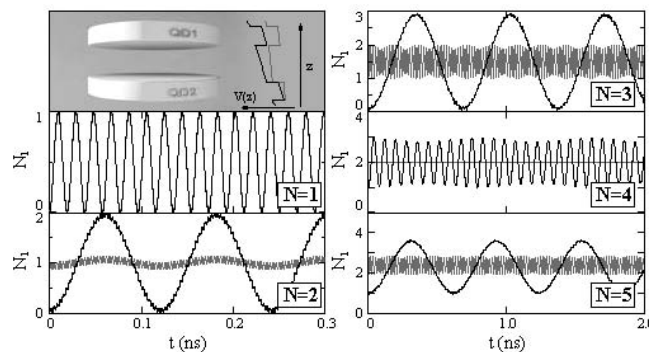


Fig1. Schematic of the CQD system under study, and charge oscillations as a function of time, for different number of electrons in the CQDs. The electric bias $V(z)$ that initializes the system, is removed at time $t=0$.

1. T. Hayashi, et al. *Phys. Rev. Lett.* **91**J. Gorman, et al. *Phys. Rev. Lett.* **95**Z.Y. Zhang, and S.J. Xiong, *Phys. Rev. E* **57**, 3668 (1998).
2. P. Zhang, and X.G. Zhao, *Phys. Lett. A* **271**J. I. Climente, et al. *Phys. Rev. B* **74**A. Bertoni et al. *Phys. Rev. B* (at press). Arxiv:0710.5617.

8:45AM IAN022V (4:45PM, Russia)

Nanodesign and Spatial Non-Smooth Transformations

R. R. Bashirov

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Topologically, the most of nanoscale quantum objects synthesized recently, fall into three large classes of X-, T-, and L- shaped quantum wells and superlattices made up of them [1,2]. Being fabricated by means of different techniques, objects within each class inherit some common features conditioned by their topology. The problem of producing an object with desirable properties is a great challenge for band structure engineering. In this work we propose the method for analytical treatment of carrier spectrum problem for such objects. Our approach is based on non-smooth transformations, first applied for mechanical systems under pulsed excitations [3]. The consideration is based on the piecewise functions:

$$e(x_i) = \begin{cases} 1, & \text{if } 2n < x_i \leq 2n + 1 \\ -1, & \text{if } 2n - 1 < x_i \leq 2n \end{cases} \quad (n = \dots - 1, 0, 1, \dots) \quad (1)$$

The class of 2D potentials for single particle Schrödinger equation investigated here can be represented as:

$$V(x, y) = V_0 + V_1 \cdot e_1 + V_2 \cdot e_2 + V_3 \cdot e_3, \quad (2)$$

where V_i are constants and $e_1=e(x)$, $e_2=e(y)$, $e_3= e_1 \cdot e_2$. Cyclic algebra for e_i products takes place due to obvious attribute $e_i^2=1$, thus $e_1= e_3 \cdot e_2$ and $e_2= e_3 \cdot e_1$. Then a wave function adopts the same structure: $\psi(x, y) = \varphi_0 + \varphi_1 \cdot e_1 + \varphi_2 \cdot e_2 + \varphi_3 \cdot e_3$, and Schrödinger equation can be represented as a matrix one of 4x4 dimension. The corresponding matrix potential now does not depend on spatial variables x and y . It has been shown that Schrödinger equation with potential (2) has analytical solutions. These solutions appear to be interesting themselves, giving, for instance, eigen-values and eigen-functions for two crossing quantum wires or three-terminal nanotube for combinations of e_s , for instance. Another pattern is a quantum well grown on the cleaved edge of a superlattice, had been investigated numerically [4]. Besides, partial analytical solutions may serve for calibration of numerical algorithm, when common those are not approachable. We believe that method can essentially speed up computing work for quantum engineering of specific nanoscale objects.

1Madhud Menon, Antonis N. Andriotis, and Deepak Srivastava, *Phys. Rev. Lett.* **91**, 145501 (2003).

1. L. Pfeiffer, K.W. West, H.L. Stormer, J.P. Eisenstein, K.W. Baldwin, D. Gershoni and J. Spector, *Appl. Phys. Lett.* **56**, 1697 (1990)
2. V.N. Philipchuk, *Jornal of Sound and Vibration* **249** (2), 399 (2002).
3. Z. S. Gribnikov, R. R. Bashirov, H. Eisele, V. V. Mitin, and G. I. Haddad. *J. Appl. Phys.* **93**, 330 (2003).
4. L. Wei and Y.-N. Wang, *Phys. Rev. B* **75** 193407 (2007).

9:30AM Transportation to Sea World

Session: Nanocrystal (Villa)

Wednesday Evening, February 6th, 2008

7:30PM IAN019 (Invited)

Multiexciton Multiplication in Semiconductor Nanocrystals through Energy Transfer

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Photophysical processes in colloidal semiconductor nanocrystals (NCs) have been intensely studied for more than ten years. A variety of novel phenomena have been discovered in these systems that result either from the high surface to volume ratio or from the spatial confinement of charge carriers. Over the past few years, such studies have begun to focus on processes that involve multiple, coupled NCs. These processes include charge transfer, spin transfer, and energy (exciton) transfer (ET). Recent work in our laboratory has shown that ET may offer a way to increase optical gain and to reduce pumping power required to reach the gain threshold in NC-based lasers. In order to understand how ET can enhance optical gain in NC-based lasers, it is important to realize that the achievement of optical gain in these systems requires the formation of significant populations of biexcitons or multiexcitons in the NC ensemble. Since multiexcitons are required for lasing, a high excitation density is needed to achieve optical gain. Furthermore, multiexcitons can decay into single excitons rapidly via the Auger process, so that even when a population inversion is created, it is generally short-lived. Consequently, it has previously been necessary to pump NCs with high-power, amplified, femtosecond lasers in order to observe lasing.

We have recently demonstrated that biexcitons and/or higher multiexcitons can be generated via ET even under low-to-moderate excitation density. For example, if two different types of NCs with different exciton energies are mixed such that the NCs are in close proximity to one another, then those NCs with higher exciton energies will act as exciton (energy) donors, and those with lower exciton energies will behave as exciton (energy) acceptors. Since incident light is collected by all the NCs and the energy is then funneled to the acceptors, the donors effectively serve as light-harvesting antennae.

Time-resolved PL measurements on electrostatically-assembled CdTe NC clusters in solution show greatly enhanced biexciton production when compared with separated NCs. The excitation threshold for biexciton production is significantly reduced in these coupled NC systems, and the relative biexciton population is increased for all power levels. This enhanced biexciton production is a step forward for reduction of the gain threshold in NC-based lasers. A further advantage of these systems is that the optical energy delivered to the system is initially stored as single excitons, which are relatively long-lived (~20 ns lifetime). These single excitons are funneled to the acceptor NCs on a nanosecond time scale, so the duration of gain enhancement may last much longer than the intrinsic biexciton lifetime. Prolonging the gain in this way has an additional advantage in that it takes time for stimulated emission to build up even after optical gain is developed. Results from experiments will be presented and compared with those from detailed numerical simulations. Taken together, our results indicate that improvements in laser output for certain optimized systems may be increased by two orders of magnitude or more by using this strategy.

8:00PM IAN025 (Invited)

Carrier Multiplication and Interfacial Charge and Energy Transfer Involving Colloidal Semiconductor Nanocrystal Quantum Dots (NQDs)

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We have demonstrated in several materials that absorption of a single photon by a nanocrystal quantum dot can produce two or more excitons with up to 100% efficiency, whereas this process is very inefficient in bulk materials. This effect (referred to as carrier multiplication (CM) or multiexciton generation (MEG)), which has been confirmed by several other research groups since our initial demonstration in 2004, can potentially enhance the power conversion efficiency of solar cells via enhancement of current in low-cost device architectures. We observe that generation of multiexcitons occurs on extremely short, sub-picosecond time scales, and appears to be an instantaneous event with our experimental resolution, which provides some insight regarding the mechanism of the process. Leveraging the CM effect in practical applications will require extraction of carriers on time scales less than few hundreds of ps. To better understand conditions where that may be achievable we have investigated interfacial energy and charge transfer processes in assemblies consisting of CdSe NQDs and Ru-polypyridine complexes. We found that the mechanism of quenching is either energy transfer (ET) or charge transfer (CT), depending on NC size. In the case of small NCs, the dominant interaction mechanism is dipole-dipole type ET due to the large overlap of the NC PL and the absorption spectrum of the complex. For large NCs, the overlap of the NC PL and the absorption spectrum of the complex is small and the dominant interaction mechanism is rapid CT. We show that the CT can occur on time scales that are competitive with Auger recombination times, which creates an opportunity for exploitation of CM effect. Demonstrated sensitization of complexes with NQDs opens interesting opportunities for designing new types of photocatalytic materials for solar energy conversion applications.

8:30PM IAN029 (Invited)

Characterization of heat generation from single gold nanoparticle complexes

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Metal nanoparticles efficiently generate heat in the presence of electromagnetic radiation. This process becomes strongly enhanced under plasmon resonance and also depends on the shape and organization of the nanoparticles. In particular, the amount of heat generated and temperature increase depends on the number of nanoparticles in a complex. Metal nanoparticles can be used to induce a phase transformations when they are in thermal contact with a solid matrix, such as ice, and are optically driven. This effect can be used to quantitatively determine the amount of heat generated from colloidal suspensions of metal nanoparticles that are optically excited near the plasmon resonance of the metal NPs. The heat generation from single and small agglomerates of gold NPs is studied with confocal Raman and photoluminescence microscopy. Along with the more traditional spectroscopic methods, we introduce thermo-optical spectroscopy. This method uses the phase transformation of ice to determine the temperature increase around a gold NP complex. With this,

we can measure, not only the optical response of the NPs, but also thermal response. Because the heat generation is dependent upon the mesoscopic character of different clusters of NPs, the gold NPs are first immobilized on a glass substrate and characterized with single particle spectroscopy. After characterization, the temperature profile around the NP complex during optical excitation is determined by measuring the relative amount of water and ice within the excitation volume. The thermal properties of the optically-excited gold clusters are then established by combining theoretical calculations with experimental results. This approach yields a quantitative measure of the amount of heat generated when single or small clusters of gold NPs in water and/or ice are optically driven.

9:00PM Break

9:15PM IAN016 (Invited)

Multi-functionality of bio-derived nanomaterials

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Biology provides a great resource to nanotechnology and insight to many problems by offering exceptional control, chemical specificity, and a large diversity of biomolecular motifs/templates. Therefore, to date, there has been much effort aimed at mimicking these biological processes *in vitro* for synthesis, sensing, and electronics. For example, the biomineralization of gold nanoparticles by bacteria and the controlled biosynthesis of silica by the marine diatom have resulted in new routes to the synthesis and design of materials; while, the excellent sensing capability of biological systems have spurred a multitude of nanoparticle sensors. Herein, through the use of engineered biomolecules, we present the synthesis of mono and bimetallic hybrid nanoparticles; and their uses as sensors, lubricants, and catalysts by exploiting the biomolecule interface.

9:45PM IAN047 (Invited)

Controlled Synthesis and Upconverted Avalanche Luminescence of Lanthanide Compound Nanocrystals with High Uniformity of Size and Shape

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Promising applications of uniform semiconductor nanocrystals in optoelectronics, catalysis, and biomedicine have driven the development of a wide variety of strategies for their synthesis, including sol-gel techniques, co-precipitation, microemulsion, hydrothermal methods, and thermal decomposition of organometallic compounds. However, major challenges remain for the preparation of ideal nanocrystals, particularly rare-earth compound nanocrystals, with well-tailored, uniform dimensionality, size and shape, high crystallinity, high dispersibility, and desired properties.

The search for new, promising two-photon fluorescence nanomaterials carries on and has become ever more urgent. Nanoscale lanthanide compounds appear to be an ideal candidate for efficient two-photon fluorescence as their bulk form is already a traditional phosphor widely used in flat-panel display, electroluminescent and up-conversion materials. For example, lanthanide compounds have been widely used in catalysts, polarizers, laser host and phosphor materials. More generally, lanthanide compound nanocrystals are currently under vigorous investigation as next generation of catalysts, solar cells, magnetic and optoelectronic nanodevices, and biochemical labels. Although impressive progress has been made in the research on lanthanide compound nanocrystals, it is still challenging to synthesize these nanocrystals with controllable size and shape and new properties of the nanocrystals, both intrinsic and collective, are yet to be discovered.

In the work reported here, we demonstrate our successful synthesis of uniform lanthanide compound nanocrystals with tunable shapes from square-plate to H-like via a simple and facile hydrothermal treatment strategy in a controlled fashion. The nanocrystal materials were thoroughly characterized by X-ray diffraction, transmission electron microscopy, fast Fourier transform (FFT), energy-dispersive X-ray spectroscopy (EDS), infrared absorption spectra, and photoluminescence spectra. Possible mechanisms of the lanthanide compound nanocrystal growth and size and shape evolution are proposed. We have uncovered and studied an unusual two-photon-excited avalanche photoluminescence property of the lanthanide compound nanocrystals. In fact, this, to the best of our knowledge, represents the first systematic studies of two-photon-excited avalanche photoluminescence of any rare earth compound nanocrystals. Mechanistic aspects of the two-photon-excited avalanche photoluminescence will also be discussed. Our work combines synthetic and optical studies of the rare-earth compound nanocrystals and lays a foundation for reinventing their applications in optoelectronics among others, such as optical display, ceramic lasers, and biosensors.

10:15PM IAN004

Efficiently Green Luminescent CdSe/ZnS Nanocrystals Synthesized via Microreaction

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Quantum dots (QDs) with emission in the spectral region from 525-535 nm is of special interest for the preparation of green LEDs and white-light generators^[1]. CdSe/ZnS core-shell structured NCs are among promising candidates^[2]. In this study, triple ligand system (Trioctylphosphine oxide-Oleic acid-Oleylamine) was designed to synthesize small sized CdSe NCs. With the precisely controlled reaction temperature (285°C) and residence time (10s) by the recently introduced microreaction technology, green luminescent CdSe NCs ($\lambda = 522$ nm) with narrow FWHM of PL (30nm) was reproducibly obtained, and $[(C_2H_5)_2NCSS]_2Zn$ was utilized as an environmental-benign ZnS source to synthesize CdSe/ZnS core-shell structures based on the same microreaction system for CdSe NCs. Reaction temperature and residence time was systematically investigated to optimize the coating process. The strengthened mass and heat

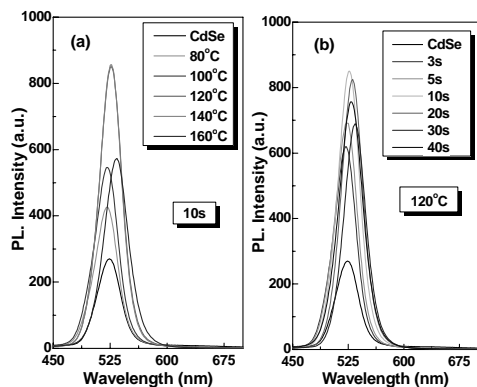


Fig.1. PL spectra for CdSe/ZnS NCs prepared under various coating temperature(a) and residence time(b).

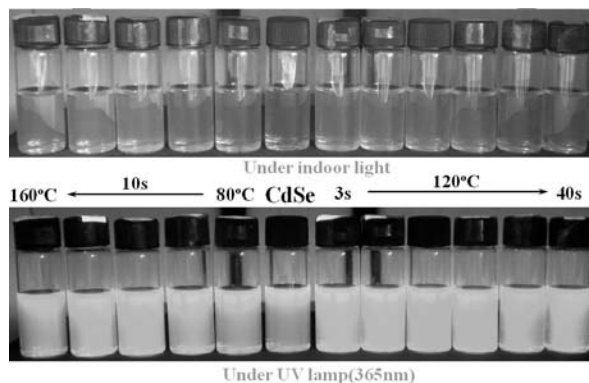


Fig.2. Color photograph demonstrating of the bright fluorescence of CdSe/ZnS NCs with different reaction temperature and residence time

transfer in the microchannel resulted in the encouraged decomposition of $[(C_2H_5)_2NCSS]_2Zn$, which allowed the formation of highly luminescent CdSe/ZnS NCs under short residence time and low reaction temperature ($T=120^\circ C$, $t=10s$), as shown in Fig.1 and Fig.2. The successful formation of ZnS layer was evidence convinced by the substantial improvement of PL intensity, being further confirmed by HRTEM and EDS. The resulted optimized CdSe/ZnS NCs showed efficient luminescence in the pure green range (with PL peak of 526 nm, PL QY $\sim 70\%$), and the narrow FWHM of PL (30nm) was maintained during the capping process.

[1] J. S. Steckel, P. Snee, M. G. Bawendi, et.al., *Angew. Chem. Int. Ed.* 45, 5796(2006)

[2] M. Protire & P. Reiss, *Small* 3, 399(2007)