

The Hebrew University of Jerusalem
Faculty of Science

The Center for Nanoscience
& Nanotechnology

Activity Report for 2009-10

Plan for 2010-11



The Harvey M. Krueger Family Center
for Nanoscience and Nanotechnology

האוניברסיטה העברית בירושלים
The Hebrew University of Jerusalem





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**The Harvey M. Krueger Family
Center for Nanoscience and Nanotechnology**
at the Faculty of Science

**Activity Report for 2009-10
and plan for 2010-2011**

Submitted as part of the Forum for National R&D Infrastructure (TELEM)
and Israel National Nanotechnology Initiative (INNI) program
of establishing Centers for Nanoscience and Nanotechnology

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Introduction

The TELEM program in nanoscience and nanotechnology at the Hebrew University is entering its fifth year. The goals of this ambitious five-year program include recruitment of new faculty members, upgrading of the central infrastructure and multi-user facilities, and enhancing significantly the scientific and technological activities in nanoscience. With this, we intend to realize the enormous scientific potential already sprouting at the center, leading to additional breakthroughs with hope of reaching technological fruition.

The five year program budget totals 30 Million \$ on a basis of 1/3 funding from TELEM, matched by 1/3 funding from external donations and 1/3 funding from Hebrew University sources. This report summarizes the activities and developments during the fourth year of the TELEM project at the Hebrew University, covering the academic year 2009-10. During this period, the outstanding scientific output intensified. Concerning the chosen focal areas, we have focused further the topics redefining some of them, and assigned scientific leaders for each area. We also note again, as in the last year, increased scientific publications in the directions of the focal areas, which is a direct indication of their relevance. The scientific foundation established in the first four years of the TELEM program is already leading to technological initiatives and applications as can be witnessed from the launch of start-up companies, signing of licensing agreements, and continued surge of new patents and ties with industry.

In terms of infrastructure, the main upgrade was the purchase of a new ultra-high resolution scanning electron microscope that was installed and put into use in record time of a few months. The first cycle of students in the new study program towards M.Sc. degree with specialization in Nanoscience and Nanotechnology completed successfully the first year of studies, and a second group of selected students joined the program in October 2010. The report also includes an outline of the plan for 2010-2011, the fifth year of the program.

Summary of 2009-10 activities

During 2009-2010 we have succeeded to meet the program goals and even exceeded some of the pre-defined milestones in the number of new faculty and students for advanced degrees, and the number of patents.

The recruitment of outstanding new faculty members in nanotechnology continued. Dr. Yossi Paltiel, formerly scientist at Soreq NRC, was nominated as a Senior Lecturer in Engineering-Applied Physics. His research interests focus on hybrid organic inorganic quantum nanodevices. Yossi is an experimentalist and large investments have been applied toward his start-up funds. He managed in a short time to form a very active research group. Dr. Yaakov Nahmias was nominated as a senior lecturer in bio-engineering, and works on the development of high-throughput micro- and nano-fabricated living cell arrays for the study of liver development, regeneration, and metabolism. Dr. Nahmias was awarded recently the prestigious young investigator grant from the European Research Council (ERC). These young researchers join 10 earlier recruits that are already leading active research groups (recruited in the period 2005-2009).

The Hebrew University Center for Nanoscience and Nanotechnology (HUCNN) encompasses today 50 research groups from the diverse disciplines of Chemistry (20), Physics (11), Applied Physics and Engineering (9), Life Sciences, Medicine and Earth Sciences (10).

A second component of last year's activity concerns the continued development of central research infrastructure in nanoscience and nanotechnology, serving as multi-user facilities for the center members and students, for the university researchers and for industry users. The main investment last year was directed towards the purchase of an ultra-high resolution SEM, enabling unique capabilities of imaging organic and biological materials at low irradiation conditions. The UHR-SEM was installed and operated in the Unit for Nanocharacterization (UNC) in the summer of 2010. At the Unit for Nanofabrication (UNF), which includes a set of clean rooms in total area of 300 m², we have purchased new oxidation and doping furnaces. The sputtering system was refurbished and upgraded. A tailor-made work station for wet-etching, including a hood and sophisticated dosimeters, was installed. These installations required further upgrading of the infrastructure of the clean room by installing updated air treatment facilities. A wafer dicing machine and ellipsometer for thin layer characterization was purchased and installed.

With respect to lab infrastructure for the central core facilities of the HUCNN and its units, the university allocated an additional area of 100 m² adjacent to the present location. Planning of the new lab space has been completed and the renovation and adaptation work shall be carried out in the coming months.

The usage of the facilities by the center member, students and other researchers continue to increase. Particular emphasis was set forth on increasing the use by industry: in the UNC 40 companies, in the UNF 12 companies. In particular use by start-up companies, served by the technical support staff and the high level equipment, has been intensified. We also established a new model of open door policy for fab-less start-up companies to use the facilities around the clock at very affordable rates and without bureaucratic constraints.

The scientific achievements of the period of 2009-2010 are noteworthy. Members of The Hebrew University Center for Nanoscience and Nanotechnology (HUCNN) have published in this period 183 papers in leading scientific journals. Important contributions were published in the top scientific journals including Nature Materials, Nature Nanotechnology, Proceedings of the National Academy of Sciences (PNAS), Physical Review Letters, Nano Letters, Journal of the American Chemical Society, Angewandte Chemie International Edition, Applied Physics Letters and more. So far, since January 2007, 740 papers were published. Our research areas may be grouped into the three major directions of the INNI: Nano-Materials, Nano-Electronics and Optics, and Nano-Bio.

Four cross-platform directions have been re-examined and are being redefined following the recommendations of the INAB. We have nominated principle investigators of the center to lead each of the directions as further means of intensifying the activities in the specific directions which are aimed to be followed in the next phase of the INNI program. We already report on significant output in terms of scientific publications in these areas. We also identify already patent applications leading to technological applications:

- A. Solar Energy enabled by Nano-materials & Nanotechnology
- B. Nano Photonics for sensing and communication applications
- C. Nano Medicine for targeted drug delivery
- D. Nano-Biomaterials for industrial and medical applications

An impressive number of students, far exceeding the original target number, are studying for advanced degrees in nanoscience and nanotechnology. Based on 44 personal summaries of the HUCNN members, we have about 32 post-doctoral fellows in the different groups. An impressive number of 173 Ph.D. and 185 M.Sc. students are

presently enlisted in these groups. Three fellowships for excellent graduate students were awarded and four nanoscience prizes. The new M.Sc. program with specialization in Nanoscience and Nanotechnology was successfully launched, with the first group of ten students carrying out the first year studies in the three initial tracks including chemistry, physics, and engineering-applied physics. 10 additional students were selected for the second round starting in October 2010, and we already notice increased interest in the program and improvement in admission standards for the candidates.

Academic activities of the center during the past year included continuation of the highly attended nano-seminar series. 18 lectures by researchers from Israel and abroad were presented. A two-day conference, in which ~180 center members and students participated, was held in Ashkelon, hosting four invited speakers (three from abroad and one from Israel) and 20 talks by faculty and students. Two poster sessions were carried out, exhibiting 64 posters by the students, while the excellent posters were awarded prizes.

On the path to industrial applications we report on a notable number of 75 new patent applications during 2009–2010. Moreover, 24 older patents were granted during this time. Members of the center are participating in four MAGNET programs related to nanotechnology, representing a very significant contribution: The Biomedical Imaging Consortium (two members), the Solar Energy Solutions Consortium (SES, 6 members), the Nanotube Solutions (NES, 4 members), and the newly launched Tera Santa Consortium (2 members). A MAGNETON is also taking place. In addition, the Yissum Baby Seed project has funded several programs involving nanotechnology, in water purification, solar energy harvesting, and nano-bio application, to bring closer their commercial potential. Center members are also cooperating with industry through rendering R&D services, and 19 such cooperation took place last year.

During this period 14 licensing agreements involving patents in nanotechnology were reached, signifying very high potential for commercialization. Qlight Nanotech, a start-up company, continued activities in cooperation with Merck KGaA. Additional companies founded based on nanotechnologies of center members continued their activities.

Meeting the milestones of 2009-10:

Faculty recruitments: two new faculty members were recruited. The original plan included Dr. Yossi Paltiel in applied physics-engineering which was supported by us with 300K USD in setting his labs. During the course of last year, we identified a new recruit in the field of bio-engineering with clear connection to nanotechnology and he also joined the center. Therefore, we are happy to report a total of 12 faculty members recruited since 2005.

Central Equipment acquisitions:

At the UNC: FEI Magellan 400L Ultra-High Resolution Scanning Electron Microscope (UHR-SEM) combined with the Oxford Inca 450 Energy Dispersive Spectrometer. Additional Oxford Inca 450 EDS replaced the old EDAX system on the Sirion HR-SEM. Total cost ~925K USD.

At the UNF: Dicing System (77K USD), furnaces for silicon oxidation/doping/ annealing (300K USD), clean room AC upgrade (125K USD), hood for acids (120K USD), Sputter Coater upgrade (40K USD), basic ellipsometer (40K USD).

Publications: 183 publications in nanoscience and nanotechnology in peer-reviewed journals in 2010 (until October 2010). 740 publications since the program initiation.

Students: 32 postdocs, 173 Ph.D. students, 185 M.Sc. students presently enlisted in member groups. The number of students continues to far exceed the original goals (100 students).

Patents and commercialization: 75 patent applications (26 applications in 2008, 67 in 2009). The numbers greatly exceed those projected for the entire program (50 patents). 24 older patents were granted in the report period. Additionally, 14 license agreements towards commercialization were signed (11 in 2008, 12 in 2009). Start-up companies continued their activities. These indicate progress towards successful commercial implementation.

Implementation of INAB recommendations

INAB assessed that impressive recruitments of young scientists have taken place and requested that future plans for high-level recruitment to be vigorously continued. To this end we recruited Dr. Yossi Paltiel as senior lecturer in Engineering-Applied Physics. In addition, a new faculty member in Biomedical Engineering, Dr. Yaakov Nahamias, joined the center as well. This brought the number of recruits already to 12, which already meets the original program goals.

With regard to the focal areas INAB assessed that clear and appropriate attention was given to these and that they were indeed based on our major research areas, yet may require further focusing. To address this, we have redefined the focal areas establishing a new focal area on nano-biomaterials. In addition, we designated principle investigators to serve as scientific leaders of each of the focal areas. Of note is the scientific and technological outputs already emerging from these focal research directions.

In terms of usage of equipment both by center members and external users, there is an on-going request to increase its use, and also use by industry. Addressing this, we even further increased usage by training a large number of independent users, usually advanced degree students. In addition, we designated a class of 'super-users', over 20 highly experienced users, that are now allowed to work over-night. The competitive pricing scheme also encourages students for independent operation and use in evening hours. Overall, we have witnessed a rise in usage of the major equipments both at the UNC and the UNF. In terms of usage by industry, we encouraged this further by devising an open-door policy for extended independent use even after regular hours of operation. Already, this has attracted several start-up companies to use the facilities for their needs.

In terms of equipment purchases exceeding 0.5M \$, INAB requested to apply principles of reporting. A procedure was suggested by the forum of center heads during the year. We applied this already to the purchase of the new UHR-SEM system, which was supplied in record time and will become fully operable during this coming year.

In terms of industry relations, INAB assessed that progress in our ties with industry continues well and requested further promotion of those. Indeed, aside from the on-going MAGNET programs in Nanotechnology related areas; Nanotube Solutions (NES) with four groups of the center, and the Solar Energy Solutions (SES) MAGNET with six research groups from the center. An additional MAGNET was launched, Terra Santa, focused on fast optical communications, with two member groups participating. One MAGNETON was continued. In addition, the Yissum baby seed program has funded six programs involving Nanotechnology to bring them closer to commercialization. Agreements with industry and licensing agreements intensified as well. With regards to promotion of start-ups, several start-up companies continued their activities.

2009-2010 Activity Report

A. Recruitment of new world class faculty members:

One of the major goals of the program is the recruitment of new faculty in nanoscience. In the academic year of 2009-10 two new faculty members, active in nanoscience, were recruited. The original plan to absorb Dr. Yossi Paltiel was carried out. In addition, Dr. Yaakov Nahmias, who joined the new bio-engineering program, was recruited as a new member in light of the obvious overlap of his activities with nanoscience. Both researchers have set-up labs, recruited new students, were awarded external prestigious grants, and already initiated their ambitious research programs. This brings the number of faculty recruited to the Hebrew University with the program to 12, already meeting our goal in the program of recruiting 12 faculty members in diverse areas of nanoscience.

Dr. Yossi Paltiel

Senior lecturer in Engineering-Applied Physics, previously tenured researcher at the Condensed Matter Department in the Soreq Nuclear Research Center (NRC). Yossi completed Ph.D. in Physics at the Weizmann Institute, and then worked as a physicist at Chiaro. Following this, he joined Soreq NRC as a researcher. While in Soreq, he took a sabbatical at the high tech industry, and served as head of the electrooptics group in Compass Electrooptical Systems. He brings to his position experience in basic and applied research, alongside with hands-on experience in the high tech industry.



Dr. Paltiel's research is focused on inorganic-organic quantum nanostructures integrated into electronic devices. Quantum nano-structures are likely to become primary components of future electronic devices. Practical realization of quantum devices faces a number of challenges. These problems include phase relaxation (decoherence) that erodes operation of a quantum device as well as the problems of control, such as manipulation and measurement of the quantum states in a device. However, the benefits from the successful implementation of these devices can be enormous and have to do with the fact that, in their operation, the quantum devices utilize the fundamental properties of nature that do not have direct analogs in classical physics. His research aims to understand the relations between the environment and the nano system and create a controlled system for room temperature quantum device operation. His studies employ a "nano-toolbox" that includes semiconductor narrow band nanocrystals, metal nano-particles and organic molecules that link the nanocrystals to a substrate. These are coupled to the substrate by organic molecules that will serve as efficient controlled couplers. It is expected that this approach will yield a generic nanoengineering toolbox that will enable using quantum mechanics at room temperature, and will bring about new types of devices such as single photon detectors and emitters, light emitting diodes, IR sensors, solar cells, and photo-electrical devices. In this case, the needed quantum coherent paths are created in the small scale while the measurements of the device are classical; nevertheless they will probe the large scale ensemble of pathways. Farther to the future, this methodology is aimed at producing a generic technology for constructing nano-systems in which many devices are interconnected, operate in unison, and are coupled to their macroscopic environment

without inhibiting their quantum nature, which can supply a realistic technological chassis for quantum computing.

Specific research topics related to Nanoscience and Nanotechnology:

- Fabrication and physical characterization of nano-electronic devices
- Growth of nanodots using molecular beam epitaxy (MBE) towards implementation in detectors, sensors and lasers
- Spin and charge transfer between nanodots and substrates
- Coupling of quantum dots and quantum wells – the coupling between the nanoworld and the bulk. Polymer coupling of Quantum dots
- Hybrid organic inorganic nano devices
- Quantum logic systems coupled to classical devices.

Selected publications

1. **Y. Paltiel et. al.** *Dyanmic instabilities and memory effects in vortex matter* Nature **403**, 398-401 (2000).
2. **Y. Paltiel**, N. Snapi, A Zussman and G. Jung, *Non-Gaussian dark current noise in p-type quantum-well IR photodetectors*, Applied Physics Letters **87**, 231103 (2005).
3. S. Shusterman, A. Raizman, A. Sher, **Y. Paltiel**, A. Schwarzman, E. Lepkifker and Y. Rosenwaks, *Nanoscale Mapping of Strain and Composition in Quantum Dots Using Kelvin Probe Force Microscopy*, Nano Lett. **7**, 2089-2093 (2007).
4. D. P. Kumah, S. Shusterman, **Y. Paltiel**, Y. Yacoby, R. Clark, *Atomic-scale mapping of quantum dots formed by droplet epitaxy*, Nature Nanotechnology **4** 835 (2009).
5. S. Shusterman, A. Raizman, A. Sher, **Y. Paltiel*** A. Schwarzman, O. Azriel, A. Boag, Y. Rosenwaks* and **P. L. Galindo**, *Two Dimensional Imaging of Strain and Composition Induced Confinement Potential in III-V Quantum Dots*, Europhys Letters **88** 66003 (2009).
6. S. Shusterman, A Reizmann, and **Y. Paltiel**, *Narrow Gap Droplets Heteroepitaxial Narrow Gap Droplets Heteroepitaxial Nanodots Growth Mode*, Infrared Physics and technology **52**, 229-234 (2009).
7. **Y. Paltiel**, G. Jung, T. Aqua, D. Mocatta, U. Banin, and R. Naaman, *Collective Effects in Charge Transfer within a Hybrid Organic-Inorganic System*, Physical Review Letters **104**, 016804 (2010).

Dr. Yaakov Nahmias

Senior lecturer in Engineering – Life Sciences (joint appointment). Formerly postdoc in The University of Minnesota and Harvard Medical School, Dr. Yaakov Nahmias joined the Hebrew University faculty last year (Summer 2009). He has formed a new research team and is already engaged in various research projects. His research is focused on the development of high-throughput microfabricated living cell arrays for the study of liver development, regeneration, and metabolism. The interest is on Metabolic Programming:



understanding how liver cells process information and make metabolic decisions. Their goal is to control patient's metabolism using this approach, aiming to develop the next generation of drugs for the treatment of metabolic diseases such as diabetes, obesity, and atherosclerosis.

Specific research topics related to Nanoscience and Nanotechnology:

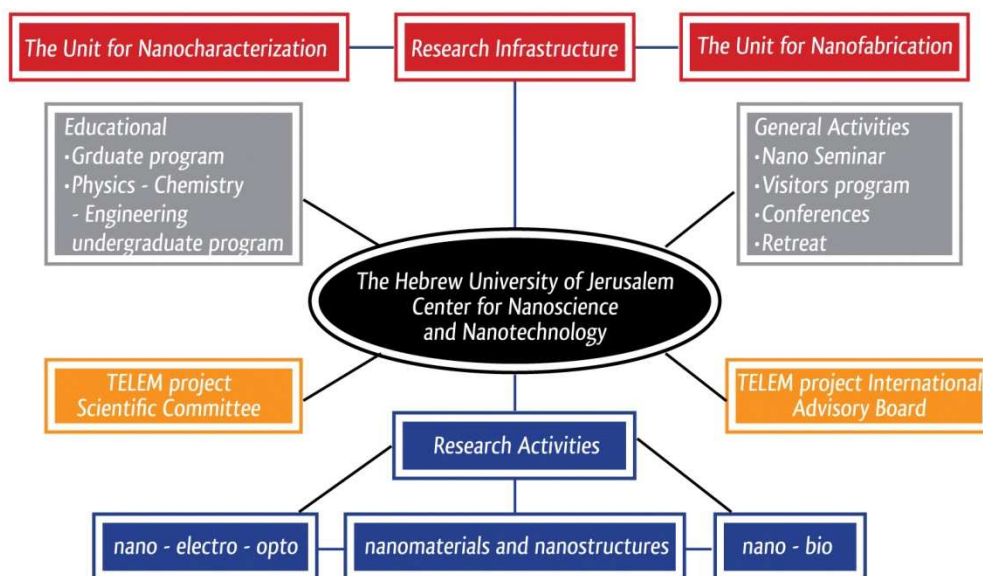
- **Transcriptional Activity Array:** exploring the dynamic activity of a network of transcription factors in living cells
- **Virus-Host Interactions in Cell Micropatterns:** explore the role of cell-cell contact in mediation of HCV infection
- **Human-on-a-Chip:** Fabrication of tissue engineered structures on micro- and nano-fluidic devices to mimic cross organ interactions of human metabolism

Selected publications:

1. S. Kidambi, R. Yarmush, E. Novik, P.B. Chao, M.L. Yarmush, **Y. Nahmias**, *Oxygen-mediated enhancement of metabolism, functional polarization, gene expression, and drug clearance in co-cultures of primary hepatocytes*, Proc Natl Acad Sci USA 106(37):15714-9 (2009)
2. J. Wagoner, A. Negash, O.J. Kane, L.E. Martinez, **Y. Nahmias**, N. Bourne, D.M. Owen, J. Grove, C. Brimacombe, J.A. McKeating, E. Pécheur, T.N. Graf, N.H. Oberlies, V. Lohmann, F. Cao, J.E. Tavis, and S.J. Polyak *Multiple Effects of Silymarin on the Hepatitis C Virus Lifecycle*. Hepatology accepted
3. B. Uygun, A. Soto-Gutierrez, H. Yagi, M.L. Izamis, C. Shulman, J. Milwid, **Y. Nahmias**, A. Tilles, F. Berthiaume, M. Hertl, M.L. Yarmush, K. Uygun. *Organ Engineering: Decellularized Liver Matrix and the Generation of a Transplantable Recellularized Graft*, Nature Medicine accepted
4. **Y. Nahmias**, J. Goldwasser, M. Casali, D. van Poll, T. Wakita, R. T. Chung, M. L. Yarmush, *ApoB dependent HCV Secretion is Inhibited by the Grapefruit Flavonoid Naringenin*, Hepatology 47(5):1437-45 (2008)
5. O. Benny, O. Fainaru, A. Adini, F. Cassiola, L. Bazinet, I. Adini, E. Pravda, **Y. Nahmias**, S. Koirala, G. Corfas, R. J. D'Amato, J. Folkman, *An orally delivered small-molecule formulation with antiangiogenic and anticancer activity*, Nature Biotechnology. 26(7):799-807 (2008)
6. **Y. Nahmias**, D. J. Odde, *Micropatterning of living cells by laser-guided direct writing: application to fabrication of hepatic-endothelial sinusoid-like structures*, Nature Protocols, 1(5):2288-2296(2006)

B. Research Map: Nanoscience and Nanotechnology (NN)

Scheme 1 below presents the structure of the center and its focus on three main topical research areas: **Nano-Materials**, **Nano-Bio** and **Nano-Electronics and Optics**. These were defined by the INNI as national priority research areas. We detail below main projects and research themes under these three research areas also listing the main researchers involved in each direction.



Scheme 1: Structure of the Hebrew University Center for Nanoscience and Nanotechnology and main research directions

(i) Nanomaterials:

- Development of novel semiconductor, metallic and magnetic nanocrystals and nanowires (Banin, Yerushalmi, Magdassi, Asscher, Felner, Davidov, Paltiel)
- Integration of novel nanocrystals, biomolecules, and nerve cells with electrode structures (Porath, Yitzchaik, Sa'ar, Shappir, Spira, Lewis, Banin, Millo, Balberg, Willner).
- Development, positioning and assembly of nanomaterials with nanometer precision in parallel manner (Shenhar, Willner, Mandler, Banin, Porath, Yitzchaik).
- Sol-Gel based functional nanomaterials (Avnir, Lev, Magdassi, Reisfeld, Abu-Reziq, Garti)
- Nanostructures for solar energy harnessing (Asscher, Banin, Sa'ar, Balberg, Millo, Yitzchaik, Mandler, Reisfeld, Yerushalmi)
- Electronic and Optoelectronic devices with organic/inorganic composites including solar cells, transistors, memory elements and light emission elements (Sa'ar, Yitzchaik, Porath, Asscher, Millo, Banin, Paltiel, Reisfeld, Rapaport, Shappir, Levy, Willner)
- Nanoscale superconductors, magnets and quantum coherent effects (Katz, Ovadyahu, Millo, Felner, Paltiel)
- Nanosystems for environmental schemes (Mandler, Belkin, Shoseyov)

- Nanocrystalline semiconductors, porous silicon and composite materials (Sa'ar, Millo, Balberg, Asscher)
- Nanosystems and nanoparticles in catalysis and photocatalysis (Abu-Reziq, Asscher, Banin, Yerushalmi, Sasson)
- Polymer and block-copolymer nanotechnology (Shenhar, G. Marom, Banin, Cohen)
- Nanomaterials for catalysis and photocatalysis (Blum, Asscher, Abu-Reziq, Sasson, Avnir, Banin, Lev)

(ii) Nanoelectronics, Nanooptics, Nanophotonics:

- Single nanocrystal electronic and optical devices such as light emission, charge sensing transistors, charge-based memory devices (Porath, Rapaport, Agranat, Paltiel, Yerushalmi, Shenhar, Banin, Millo, Schiller)
- Qubits based on superconductor systems (Katz)
- Quantum optics (Eisenberg)
- Photonic crystals and nanophotonic devices (Levy, Sa'ar, Agranat, Davidov, D. Marom, Rapaport, Paltiel)
- Methods of patterning surfaces for nanoelectronic applications (Shenhar, Mandler, Yerushalmi, Lewis, Porath, Shoseyov)
- Semiconductor quantum structures for detectors, light emitting devices and lasers (Rappaport, Sa'ar, Shappir, Paltiel, D. Marom, Levy, Banin)
- Developing new concepts for nanolithography (Asscher, Willner, Shenhar, Lewis, Porath).
- Single molecule based electronic devices (Baer, Porath)
- Nano-plasmonics concepts and devices (Levy, Rapaport, Paltiel, Sa'ar, Lewis, Banin)
- Dielectric properties of nanomaterials (Feldman, Agranat)

(iii) Nano-bio:

- Biosensors based on various nanosystems and nanoparticles (Willner, Belkin, Rubinsky, Nahmias, Vaknin, Yitzchaik, Agranat, Mandler, Domb, Banin)
- Novel drug-delivery schemes (Benita, Golomb, Berenholz, Domb, Avnir, Magdassi, Rubinski).
- Sensors for water quality and other environmental aspects (Belkin, Mandler, Willner)
- Studies and regulation at the single cell level (Balaban, Nahmias)
- Bio-molecular nanostructures, microtubules (Raviv, Shoseyov, Reches)
- Integration of Neurons onto electronic and optoelectronic devices (Spira, Yitzchaik, Sa'ar, Shappir).
- Tissue and bone engineering based on nano-scaffolds (Gazit, Rubinsky, Shoseyov, Nahmias)

C. Scientific output – publications

We report on significant scientific contributions. Full details are provided in the personal summaries of 44 center members included in the second part of the report, while a selected list of major publications in high impact journals show-casing our achievements are concentrated below.

Overall we counted **183 publications in 2010** (until October, not yet for the full year). **Since 1.1.2007, 740 papers were published in peer-reviewed journals**, an impressive scientific output. The list includes publications in top journals including Nature Materials, Nature Nanotechnology, Nature Photonics, Nature Methods, Nature Chemistry, Nature Medicine, Proceedings of the National Academy of Science (PNAS), Physical Review Letters, Nano Letters, Journal of the American Chemical Society, Angewandte Chemie International Edition, Advanced Materials, Accounts of Chemical Research, the Journal of Physical Chemistry, Langmuir, Chem. Comm., Physical Review B, Applied Physics Letters, Small, Nanotechnology, Optics Letters, Optics Express and more.

List of selected publications

1. "Hybrid nanoscale inorganic cages", Janet E. Macdonald, Inna Popov, Uri Banin, *Nature Materials*, Vol. **9** Issue:10, 810-815 (2010).
2. "Atomic-scale mapping of quantum dots formed by droplet epitaxy", D. P. Kumah, S. Shusterman, Y. Paltiel, Y. Yacoby, R. Clark, *Nature Nanotechnology* **4** 835 (2009).
3. "Logic implementations using a single nanoparticle–protein hybrid", Izhar Medalsy, Arnon Heyman, Michael Klein, Oded Shoseyov, F. Remacle, R.D. Levine and Danny Porath, *Nature Nanotechnology* (Article) **5**, 451 (2010).
4. "A DNA sequence scanned", Danny Porath, *Nature Nanotechnology* **4**, 476 (2009).
5. "Universal DNA Computing Circuits Using Libraries of DNAzyme Subunits", J. Elbaz, O. Lioubashevski, F. Wang, F. Remacle, R.D. Levine and I. Willner, *Nature Nanotechnology*, **5**, 417-422 (2010).
6. "Biocatalytic Cascades are Activated on Topologically Programmed DNA Scaffolds", O.I. Wilner, Y. Weizmann, R. Gill, O. Lioubashevski, R. Freeman and I. Willner, *Nature Nanotechnology*, **4**, 249-254 (2009).
7. "Scale-free optics and diffractionless waves in nano-disordered ferroelectrics", E. Del Re, E. Spinozzi, A. J. Agranat, and C. Conti, *Nature Photonics*, Accepted for publication (2010).
8. "Automated imaging using ScanLag reveals previously undetectable growth phenotypes", Levin-Reisman, I., Gefen, O. Fridman, O., Ronin, I., Shwa, D., Seftel, H., and Balaban, N. Q., (2010) *Nature Methods* epub Aug. 1
9. "In-cell recordings by extracellular microelectrodes", Aviad Hai, Joseph Shappir, and Micha E. Spira (2010). *Nature Methods*. **7**(3):200-2
10. "Organ Engineering: Decellularized Liver Matrix and the Generation of a Transplantable Recellularized Graft", B. Uygun, A. Soto-Gutierrez, H. Yagi, M.L. Izamis, C. Shulman, J. Milwid, Y. Nahmias, A. Tilles, F. Berthiaume, M. Hertl, M.L. Yarmush, K. Uygun., *Nature Medicine* (accepted)
11. "Chiral Imprinting of Palladium with Cinchona Alkaloids", L. Duran Pachon, I. Yosef, T. Markus, R. Naaman, D. Avnir and G. Rothenberg, *Nature-Chemistry*, **1**, 160 - 164 (2009). Highlighted in: * H. Birch, *Chemistry World*, April 19, 2009, * *Chem. & Eng. News*, May 4th, 2009, p. 10, * *Science Daily*, April 24, 2009, **AlphaGalileo*,

April 22nd, 2009, * *Science Centric*, April 22, 2009, * *PhysOrg*, April 23rd, 2009, * *Nanotechnology*, April 22, 2009, * *AZoM-Materials*, April 23, 2009, * and additional highlights

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Fig. 1: Cover page of article on conductive transparent inkjet printed metallic ring arrays, published in ACS Nano, 2009

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D. Educational programs and academic activities

New cross-disciplinary M.Sc. program with specialization in nanotechnology

Last year the new cross-disciplinary M.Sc. program in Nanoscience and Nanotechnology was launched in three initial tracks leading to a M.Sc. degree. Ten students were selected based on high grade requirement in the B.Sc. studies, followed by an interview by the study committee. They completed successfully their first year of studies in the following tracks:

- Specialization in Nanoscience and Nanotechnology in Chemistry – three students
- Specialization in Nanoscience and Nanotechnology in Physics – four students
- Specialization in Nanoscience and Nanotechnology in Engineering-Applied Physics - three students

The program requires students to take 35 credit points in courses (more than regular M.Sc. program which is 30 points), and in the first year they indeed focus on these studies. Two joint and compulsory courses in nanoscience were given, including the course “Physical Chemistry of Nano Materials” and a course in Material Characterization. Of note is a new course on nano-fabrication that includes practical lab sessions carried out at the Unit for Nanofabrication. Aside from these courses, the students attended a set of compulsory courses at their respective core disciplines (Chemistry, Physics or Engineering-Applied Physics). Wide selection of courses in nanoscience is offered in the different disciplines and these are open for all the students of the program.

The program is led by Prof. Uriel Levy (Engineering-Applied Physics) serving as its chair, and is run by a committee with representatives of each discipline in addition: Prof. Shlomo Magdassi (Chemistry), and Prof. Ronen Rappaport (Physics). Each of the members also serves as an advisor for the students in his core discipline.

The students in the program receive a fellowship funded by the generous donation of Ruthellen and the late Monte Toole, in memory of the late Monte Toole. Ruthellen Toole visited the nanocenter in November 2009 and met in person with students of the new program.

M.Sc. program in Chemistry of Materials and Nanotechnology

In chemistry, the studies program in the direction of "Chemistry of Materials and Nanotechnology" continued to address the high interest of students in a more specialized and less selective program, beyond the specific new program described above. Last year six students graduated with M.Sc. degree in this program. The total number of students in this track was 49.

Academic activities

1. Students, fellowships and awards

In terms of students performing research in nanoscience and nanotechnology, member groups had overall 32 postdoctoral fellows in 2010 (21 in 2008, 27 in 2009), 173 Ph.D. students (124 Ph.D. students in 2008, 159 in 2009), and 185 M.Sc. students (135 M.Sc. students in 2008, 169 in 2009). This represents an outstanding group of skilled scientists and engineers in nanoscience as targeted by the program, surpassing by far our original plans.

The center continued its support for three excellent graduate students with a fellowship graciously donated by the CAMBR foundation for the 4th year. The students and their research topics were:

Michael Riskin (Chemistry) – "Developing Methods for the Optically Controlled Deposition of Magnetic Nano-Structures on Surfaces"

Daniel Zucker (Medicine) - "Improving Cancer Therapy by Combination of Drugs delivered via Nanoscale Liposomes Formulations Based on Nanotechnology Principles"

Asaf Salant (Chemistry) – "Quantum Particle Sensitized Solar Cells"

Given the success of the first phase of the CAMBR fellowships program, the donor, Mr. Allen Skolnick, has kindly agreed to continue to a second phase with an additional four fellows for the next four years, and these were indeed chosen already by the center prize committee, and will receive support starting October 2010.

The nanocenter **Award for Excellent Ph.D. Students** was also awarded in the prize ceremony held at the end of the 2010 Annual Conference (see photographs below). The prizes were supported by the generous donation of Mr. Kenneth L. Stein and the Goldie Anna Charitable Trust. The following students were given the prize for their work:

Eyal Yoskovitz (Chemistry) from the group of Prof. U. Banin on "Nanoscale Near-Field Imaging of Excitons in Single Heterostructured Nanorods"

Izhar Medalsy (Chemistry) "SP1 Protein-Nanoparticle Hybrids as Building Blocks for Nanoelectronic Applications"

Sivan Pearl (Physics) "Single-Cell Study of Mammalian Cell-Cycle Variability"

Aviad Hai (Life Sciences and Applied Physics), "In-cell recordings by Extracellular Microelectrodes"

2. Seminars and conferences:

The nano-seminar series continued. This bi-weekly gathering, organized by Prof. Danny Porath of the Center, continued to showcase top speakers from the field of nanoscience and nanotechnology from Israel and abroad. The attendance by faculty and students of the different disciplines is high and the speakers are requested to provide a broad background suitable for the interdisciplinary nature of the audience. In the past year, the speaker list and titles included:

Title	Name	Affiliation	Date
Constructive Lithography Goes from Serial to Parallel: Contact Electrochemical Pattern Generation and Transfer	Prof. Jacob Sagiv	Dept. of Materials and Interfaces, Weizmann Institute	25.10.09
The Bio-Electronic Synapse – Fusing Electronics with Molecular Biology	Prof. Uri Sivan	Dept. of Physics, Technion	08.11.09
The Noise of Nano Coupling	Dr. Yossi Paltiel	Dept. of Applied Physics, HUJI	22.11.09
Magneto lithography- A new method for fast and efficient high resolution chemical patterning on non-flat surfaces	Prof. Ron Naaman	Chemical Physics, Weizmann Institute	06.12.09
Unified approach to: electron affinity, transfer, transport, blockade and ionization	Prof. Roi Baer	Institute of Chemistry, HUJI	20.12.09
Colloidal Semiconductor Nanocrystal Qdots	Prof. Louis Brus	Columbia University, NY, USA	28.12.09
Thermoelectricity at the nano scale	Dr. Yonathan Dubi	Los Alamos National Lab, USA	03.01.10
Electron Transport Through Single-Molecule Junctions	Dr. Oren Tal	Chemical Physics, Weizmann Institute	17.01.10
Semiconductor Nanocrystals as Building Blocks for Hybrid Functional Structures	Prof. Andrey Rogach	City University of Hong Kong	10.02.10
Synthesis and assembly of shape and composition-controlled colloidal nanocrystals	Prof. Liberato Manna	Istituto Italiano di Tecnologia, Genova, Italy	18.02.10
Current-Driven Molecular Machines	Prof. Tamar Seidman	Northwestern University, USA	7.03.10
Stacking and Registry Effects in Layered Materials: The Case of Hexagonal Boron Nitride	Dr. Oded Hod	School of Chemistry, Tel Aviv University	11.04.10
Nanophotonics as a platform for focusing, confinement and modulation of light	Dr. Uriel Levy	Dept. of Applied Physics, HUJI	25.04.10
Nanomaterials: From Synthesis to Applications	Prof. Fernando Patolsky	School of Chemistry, Tel Aviv University	09.05.10
Active Plasmonic Devices Employing Extreme Light Concentration	Prof. Mark L. Brongersma	Stanford University, USA	11.05.10
Holographic Optical Tweezers: Reaching into the Microscopic World	Dr. Yael Roichman	School of Chemistry, Tel Aviv University	16.05.10
Nanoscale Imaging of Excitons in Single Semiconductor Nanocrystals	Eyal Yoskovitz	Institute of Chemistry, HUJI	30.05.10
Atom-Mediated Photon-Photon Interactions by Cavity QED with Chip-Based Micro-Resonators	Prof. Barak Dayan	Chemical Physics Weizmann Institute	13.06.10
Self-Assembled Soft Materials and the In- Situ Synthesis of Nanoparticles	Prof. George John	Dept. of Chemistry, The City College of New York, U.S.A	17.06.10

On 21-22 June 2010 the Center held its annual conference in a format of a two day workshop in Ashkelon. The organizing committee of the conference included Prof. Uriel Levy, Prof. Ronen Rapport and Dr. Roy Shenhar along with Prof. Banin and two Ph.D. students – Ronit Freeman (Chemistry), and Yoni Shalibo (Physics). Enrollment and participation were impressive with attendance of 178 center faculty members, students and scientific staff. The program, attached below, included three key-note speakers from abroad: Prof. Axel Muller from University of Bayreuth, Germany; Prof. Irving Herman, from Columbia University, USA and Prof. Chia-Seng Chang from the Academia Sinica, Taiwan, as well as one keynote talk by Prof. Arie Zaban from Bar Ilan University. It featured also 20 speakers from the faculty and students of the HUCNN. Two extensive poster sessions were held, where 64 posters were shown. In the closing session a ceremony was held where the Nano-Prize for excellent students was awarded, see photographs below:



Poster session 2010



Annual Conference audience 2010



Izhar Medalsy receives the HUCNN prize



Kathy Margulis receives the poster prize

2010

**The Harvey M. Krueger Family
Center for Nanoscience and Nanotechnology**

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Ronit Freeman, Yoni Shalibo

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 האוניברסיטה העברית בירושלים
The Hebrew University of Jerusalem

In the same session, five awards to the best posters were also distributed as listed below:

Sahar Melamed from the group of Prof. S. Belkin on "Nanoliter Immobilization and Long Term Preservation of Whole-Cell Microbial Reporters".

Nir Waiskopf from the group of Prof. U. Banin on "Labeling the Cholinesterase Enzymes using Fluorescence Nanoparticles for in Vitro and in Vivo Biological Imaging".

Eyal Cohen from the group of Dr. Y. Paltiel on "Coherent Bragg Rod Analysis Study of Semiconductor Epitaxial Quantum Dots".

Kathy Margulis-Goshen from the group of Prof. S. Magdassi on "Formation of organic nanoparticles from microemulsions".

Alexander Freiman from the group of Prof. U. Levy on "Optofluidic evanescent dye laser".

NANO CENTER Annual Conference 2010		Dan Gardens, Ashkelon, June 21-22, 2010	
Monday June 21, 2010		Tuesday June 22, 2010	
9:50-10:10	Opening: Uri Banin Head of the Center Greetings: Isaiah T. Arkin Chairman, Authority for R&D	Nano for Energy Chairperson: Micha Asscher	
Opening Session	Chairperson: Danny Porath	9:00-9:45	Arie Zaban Dept. of Chemistry, Bar Ilan University Built-in Quantum Dot Antennas in Dye-Sensitized Solar Cells
10:10-11:00	Axel Müller University of Bayreuth, Germany Self-Organized Nanostructures from New Block Terpolymers	9:45-10:00	Janet E. Macdonald Chemistry Hybrid Nano-Inorganic Cages
11:00-11:30	Daniel Mandler Chemistry Coating of Biomedical Implants by Electrochemical Methods	10:00-10:30	Amir Sa'ar Physics Porous Silicon Nanostructures: from Science to Applications
11:30-12:00	Simon Benita Pharmacology, Medicine The Potential Switch from Intravenous to Oral Docetaxel Therapy by Stealth Nanocapsules	10:30-10:45	Gil Tokor Chemistry Dramatically Enhanced Photo-induced Processes Within Porous Silicon
12:00-13:30	Lunch	10:45-11:15	Coffee Break + Key return
Self Assembly	Chairperson: Shlomo Yitzchaik	Nano Bio Chairperson: Yechezkel Barenholz	
13:30-14:00	Roy Shenhar Chemistry Nanoparticle Assembly into Branched Structures via Dynamic Patterning	11:15-11:45	Yaakov Nahmias Applied Physics Development of a High-Throughput Transcriptional Activity Array
14:00-14:15	Carsten Teller Chemistry Supramolecular Nucleic Acid Structures for the Control of Biocatalytic Transformations	11:45-12:00	Shaul Lapidot Agriculture Bioinspired Nanocomposites of Resilin and Cellulose Whiskers
14:15-14:30	Michael Grouchko Chemistry Self Sintering of Metallic Nanoparticles at Room Temperature	12:00-12:15	Abba Prieu Biochemistry, Medicine Nanodiamond-based Diagnostic Kits for Ultrasonic Immunoassay
14:30-15:00	Irving Herman Columbia University, USA Investigating Nanomaterials Composed of Nanocomponents: Ordered Arrays of Nanoparticles and Nanoparticle-Carbon Nanotube Hybrids	12:15-12:45	Uri Raviv Chemistry Ions at Dipolar and Charged Interfaces
15:00-15:30	Coffee Break	12:45-14:00	Lunch
Nano Physics	Chairperson: Uriel Levy	14:00-15:15	Poster Session 2
15:30-16:00	Ronen Rapaport Physics and Applied Physics Dipolar Exciton Fluids: Study and Manipulation of Interacting Two-Dimensional Bosons "in a Chip"	15:15-15:30	Coffee Break
16:00-16:15	Yoni Shalibo Physics Probing and Manipulating Individual Defects within a Josephson Tunnel Junction	Nanocenter Awards Chairperson: Uri Banin	
16:15-16:30	Har'el Ilan Applied Physics Formation of Conductive Layers in Potassium Lithium Tantalate Niobate Substrate by Implantation of High Energy Protons	15:30-16:20	Chia-Seng (Jason) Chang Academia Sinica, Taiwan In Situ Studies on Dynamic Properties of Carbon Nanotubes with Metal Clusters
16:30-17:00	David Avnir Chemistry Chiral Nanoporosity	16:20-16:35	Eyal Yoskovitz Chemistry Nanoscale Near-Field Imaging of Excitons in Single Heterostructured Nanorods
17:00-19:00	At leisure	16:35-16:50	Izhar Medalsy Chemistry SP1 Protein-Nanoparticle Hybrids as Building Blocks for Nanoelectronic Applications
19:00-20:30	Gala Dinner	16:50-17:05	Sivan Pearl Physics Single-Cell Study of Mammalian Cell-Cycle Variability
20:30-22:30	Poster Session 1	17:05-17:20	Aviad Hai Life Sciences and Applied Physics In-cell Recordings by Extracellular Microelectrodes
		17:20-17:50	Poster winners prize distribution + farewell and conclusion
		18:00	Bus Departure

All the academic activities of the Nano Center, including the Excellent Ph.D. Students Awards, annual conference, seminars and lectures were supported by the generous donation of Mr. Kenneth L. Stein and the Goldie-Anna Charitable Trust.

E. Basic Equipment

1. Acquisition of equipment for the Nano Center:

The development of central research infrastructure in nanoscience and nanotechnology, to serve as multi-user facilities for the center members and students, for the university researchers and for industry users, has continued. The facilities are organized in two units:

- The Unit for Nano-characterization (UNC), opened in 2002
- The Unit for Nanofabrication (UNF), opened in 2007.

This year we have upgraded the equipment and the research facilities in both units of the Nano Center. A major research tool that has been purchased and already been installed in the UNC is the **FEI Magellan 400L Ultra-High Resolution Scanning Electron Microscope (UHR-SEM)** combined with the **Oxford Inca 450 Energy Dispersive Spectrometer** (with 20 mm² Si detector, LN free). This system provides a major upgrade to the imaging and analytical capabilities of the UNC, particularly in terms of highly improved resolution at SE (secondary electrons) and BSE (backscattered electrons) modes, and also provides new modes of operation: STEM, low-voltage ($\geq 50V$) imaging, integrated CryoCleaner and PlasmaCleaner, etc). We expect the Magellan system to be another workhorse of the UNC, to be used by many students and researchers for their research needs. In addition, we expect the system to reduce the heavy load on the HR-SEM (the Sirion system) thus shortening the wait time and increasing the availability of these tools. An **additional Oxford Inca 450 EDS** replaced the old EDAX system on the Sirion HR-SEM.

This year we continued to equip the UNF with basic equipment required to address emerging needs of researchers and young PIs recruited under the present program. Many of those young PIs and their students are frequent users of UNF. Major equipment, that has already been purchased and is expected to be installed these days, is a system of atmospheric pressure, high-temperature **furnaces** for oxidation (dry and wet), diffusion and annealing processes. The system will complement the existing thin-film etching and deposition facilities of the UNF (such as RIE, PECVD, evaporator and the E-beam lithography system) to provide a complete line of fabrication tools to create modern electronic, photonic and mechanical devices, from diodes and transistors to optical waveguides, MEMS membranes etc. Few additional tools that have been installed in UNF this year are **wafer dicing** machine, a new **chemical hood for acids**, **vacuum oven** and **ellipsometer**. In addition we have upgraded the **sputtering system** and installed it in the clean room.

2. Extent of use of equipment (by institute members and others)

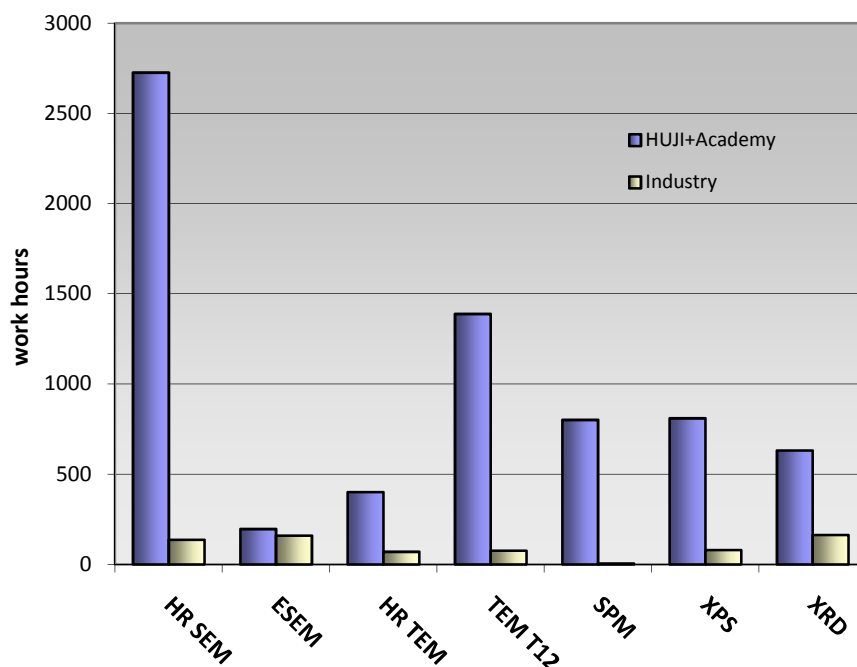
We continued the focus on increasing use of the central equipment. We emphasize training of a large number of independent users, especially in the instruments where this is required and feasible. Notably this includes the SEMs, TEM, AFM, and most of the UNF equipment. This also serves an important educational purpose of the program. Next, we have opened more and more facilities for use over extended hours in the evenings. An additional category of over 20 "super-users" was defined and allowed to work in the center overnight. Finally, we have continued the aggressive pricing scheme to encourage after-hour use by students, offering substantial discounts for evening operation.

At the beginning of 2009, when the wave of the global financial crisis arrived Israel, we decided to cut significantly service tariffs for industry. Our aim was to help industry users, and especially start-up companies, to tide over the financial difficulties and be able to benefit from fruits of the TELEM project. We established very convenient and simple formal agreements, solving the NDA, IP and insurance issues. This provides industry users with easy access to the Nano Center infrastructure (fast-track training, overnight hours, etc.) and the Givat Ram Campus amenities (e.g. lodging in the Faculty Club).

Below we include the summary of usage hours in the UNC and UNF.

The Unit for Nanocharacterization (UNC) activity data presented below covers a 12 months period of November 2009 – October 2010:

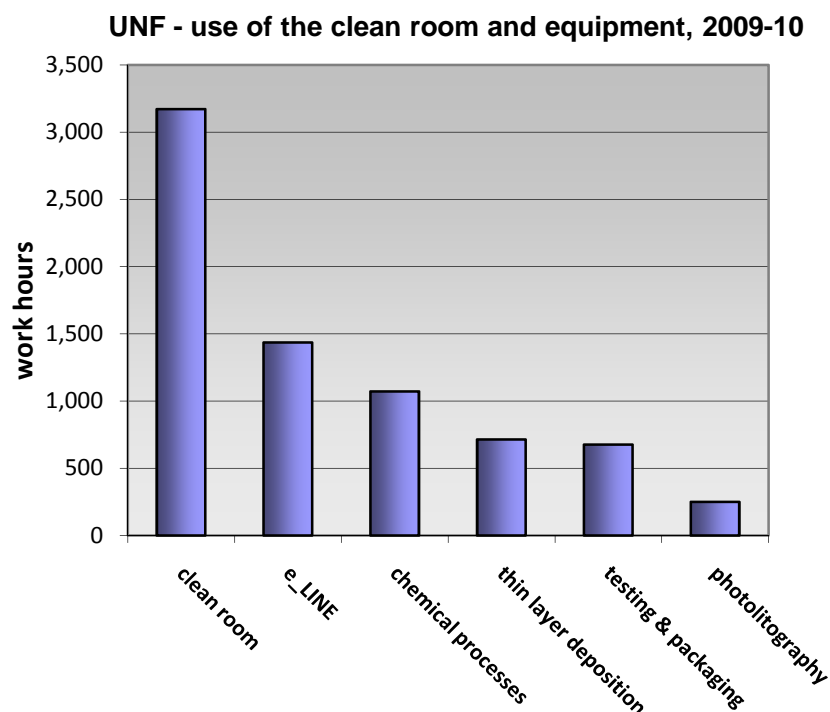
UNC - use of equipment, 2009-10



Remarkably, we have witnessed a continued increase in the use of most instruments, thanks to efforts of the UNC staff, headed by Dr. Inna Popov. For example, the use of the HR-SEM has increased from about ~ 2,300 hours in 2009 to more than 2800 hours in 2010 (a growth of about 20%). This substantial rise in use of the microscope (which reflects the increasing number of young faculties and their students, who work in the field of nanoscience and nanotechnology and use these facilities) has led to substantial longer wait time for the HR-SEM. We expect to a significant improvement after the completion of the installation and training period of the new UHR-SEM (Magellan).

Concerning industrial users, in 2009-10 **forty** companies from all over Israel have used the services of the UNC. Among these are well established companies such as TEVA, Freescale Semiconductor, Siemens Solar Systems, Ahava, AVX, Ophir Optronics, Tempo Ceramics and many start-up companies such as Piercell, Acktar, Atlantium, Cima Nano Tech, Xjet Solar, QLight Nanotech.

The Unit for Nanofabrication (UNF), which is continuously developed and equipped with new capabilities, is extensively used by tens of students and researchers. Figures of usage for UNF include total charged hours of the clean room and grouped facilities of the unit; see chart figure below:



An impressive figure of almost 3200 hours total use (as compared to 2700 hours in 2009) reflects a 20% increase in overall use of the UNF facilities. The most popular facility is still the e-beam lithography system, but we begin to see extensive use of the other facilities of the unit. The UNF staff headed by Dr. Eliav excels in fast absorption of new equipment and methods, and in rapid training of independent users.

We can note with a great satisfaction that during 2009-10, 12 companies used services of the UNF, among them: Numonix, LG, SCD, Acktar, NMB Medical, Oree, Qlight Nanotec, Piercell, and just recently VisIC. The last three are start-up companies, developing their innovative technology using the UNF infrastructure and the UNC capabilities.

Researchers from other universities (TAU, BIU, BGU, Technion), colleges (HIT, JCT) and research institutions (Kamag, Mamag, Haddasa Hospital) are frequent visitors and users of the UNC and UNF.

The detailed list of the scientific and technical staff of the UNC and UNF is presented in Appendix C.

3. Equipment maintenance

All the equipment in the UNC (aside of the SPM and XRD) is covered by annual service agreements: all electron microscopes with the Israeli FEI agent, and the Kratos XPS system directly with the U.K. manufacturer. At the UNF the e-Line is covered by a service agreement. Other major instruments are still under warranty.

While the service agreements are designed for major faults we secure immediate response by a UNC technician. In the UNF, there is a technical employee supporting the Clean Room supplies (DI water, gases, etc.).

We expect growth in expenses for maintenance, as the equipment is extensively used by students and wears-out. To this end, we will establish a maintenance fund (see plan for 2010-11).

F. Cooperation in research with other universities

1. Research Cooperations in Israel:

Cooperative research of members of the HUCNN with other universities in Israel is abundant. These are described in the member's reports attached in appendix D. Overall, 95 cooperation of the HUCNN researchers with researchers from other Israeli universities were identified. This represents a significant increase from last year, where 73 cooperations were reported. This reflects formation of extensive research networks. A particular area of note where the cooperation has intensified is in solar energy research, starting from the Solar Energy Solutions (SES) MAGNET.

2. International Research Cooperation and Ties:

A research cooperation was established with Academia Sinica in Taipei, the leading research institute in Taiwan. This unique program, led by Prof. Danny Porath of the HUCNN, was formulated following extensive discussions and mutual visits which took place the year before. Under this program, three projects were approved, involving Israeli teams from the center and teams from Academia Sinica:

PIs	Partner	Title
Oded Millo Uri Banin	Jau Tang Research Center for Applied Science	Telegraphic Noise in Nanorods Photocurrent
Roie Yerushalmi	Jason Chang Institute of Physics	Synthesis of Well-Controlled Doped Nanowires
Danny Porath Oded Shoseyov Yossi Paltiel Mukhles Sowwan	Yu-Tai Tao Institute of Chemistry	Bio-Inspired Organic/Inorganic Hybrid Nano-Electronic Devices

An additional cooperative research programs is supported by the center:

NanoSci ERANET with European partners (3-5 research groups from at least three different countries in each project): HUCNN researchers performed extremely well in this highly competitive research framework, which was peer-reviewed at the highest standards. The center directly supports matching funds necessary for participation of the members. Under the first call that ended in October 2010, two groups of the center won this grant:

I. Willner – "nanoLIGHT" project
U. Banin – "Single NanoHybrid" project

In the second round, research under which has begun a year and a half ago, two additional groups won awards:

R. Shenhar – coordinator of the "Memory" project
A. Lewis – "NANOSPEC" project

G. New patents and patents utilization

Proliferation in patent activity in areas of nanoscience and nanotechnology is observed and is actually impressive. The number of **patent applications** by the center member groups was **46 in 2007-8**, significantly increased to **67 in 2008-9**, and increased even further to **75 in 2009-10**. This is indeed an extraordinary output, surpassing the program goals. Moreover, in 2008, 23 patents were granted, in 2009 19 and so far in 2010, 24 patents were granted.

H. Cooperation with industry, establishment of new start-ups

A framework of significant cooperation with industry is carried out under MAGNET programs. First, the Medical Imaging Consortium (BMP) continued with Prof. S. Magdassi and Prof. A. Rubinstein as members. Second the Nanotube Solutions (NES) MAGNET program entered its second year with four members of the center as partners (Profs. Magdassi, Mandler, Lev and G. Marom). Cooperations with Oran Safety Glass of Kibutz Tzuba, with RAFAEL and with Israel Aircraft Industry (IAI) have continued. The Solar Energy Solutions (SES) MAGNET ran for its first year with a major participation of our researchers with six members from HUCNN including Prof. M. Asscher who is among the scientific coordinators of the program, A. Sa'ar, S. Yitzchaik, D. Mandler, S. Magdassi and U. Banin, and was continued to a second year. Cooperations with 3G Solar, with Tower Semiconductors and with other companies are taking place within the SES program, and some changes took place in the second year. A new MAGNET, Tera Santa, focused on ultrafast TB/sec communication systems, was recently launched with the participation of Prof. Uriel Levy and Dr. Dan Marom. Companies involved in this consortium are ECI Telecom, Finisar, FDON and others. In the frame of MAGNETON, Prof. Mandler continued his cooperation with Afikim.

The applied research fund funded and administered by Yissum (Technology Transfer Company of the HUU) under the frame of their 'Baby Seed' program, also supported several projects in nanotechnology. Six projects led by center members were funded and advanced in this frame. Two projects were directed towards innovative water purification approaches (Prof. Avnir, Prof. Y. Sasson). One project in solar energy conversion (Shappir). Two projects in nanophotonics (Prof. Agranat, Prof. U. Levy). One project in the nano-bio field (Prof. D. Cohn).

Additional ties with industry involve R&D services rendered by center groups to different companies. Impressively, 19 service agreements are taking place, with industries including well established companies (Rafael, Bright Source) and several start-ups (eg. Cima Nanotech. Xtellus, Powermat and more).

I. Success Stories – a short description

In terms of success stories, licensing of various patents took place. Number of license agreements in 2010 was 14. These agreements reflect high potential for the commercialization of technology developed by the center members, and are added to the large numbers of prior licenses from recent years.

Start up companies based on nanotechnology related innovations have also seen continued developments last year. Collplant, based on the technology developed by Prof. Shoseyov, raised 15 M \$ and continued its activities. Qlight Nanotech, developing nanocrystals for display and lighting applications based on technology developed by Prof. Banin, furthered its activities and expanded its R&D program with Merck KGaA and with OCS participation. Overall, there is an impressive number of 12 companies that have been founded from nanotechnologies developed by center members (here we also include start-ups founded before the INNI program started). The list of companies is: Qlight Nanotech, Solgel Technologies Ltd., Nutralease Ltd., Steam Coffee, Nanoptics, I.D.D, Mobious, Nasvax Ltd., Macrobea, Novagali Pharma, and Collplant Ltd.

J. Research grants in nanoscience obtained by the nancenter members and affiliates:

In the following table we summarize the income from research grants of the HUCNN members from the major budgeting sources in 2008-9 and 2009-10 (in millions of NIS):

HU CNN members research grants income		
(in M NIS)		
Funding source	2008-9 44 faculty	2009-10 48 faculty
European Union (FP7 + ERC)	6.4	15.7
Industry R&D, via YISSUM	8.3	6.8
Government + MAGNET	7.2	7.6
ISF + PBC competitive grants	6.8	6.0
Binational funding agencies (BSF, GIF)	1.7	2.1
International competitive grants	1.9	2.8
Donations & Endowments	4.6	6.8
Other/HUJ internal sources	4.7	3.8
Total	41.6	51.6

There is a notable achievement of members of the Nano Center in raising significant research funds from competitive sources. In addition, there is 25% increase in the total income in 2009-10 as compared to the previous year. All this reflects the extensive growing research activity in nanotechnology. We note the significant funding from industry for R&D and from the Office of the Chief Scientist (MAGNET programs). It is a clear indication of strong ties with industry, which clearly recognizes the benefits of the expertise and infrastructure of the HUCNN researchers.

There is remarkable success of the Hebrew University center members in winning the prestigious ERC program grants (administered by the European Research Council). In the category of young investigators, so far, four researchers from the center won these highly competitive grants. Remarkably, two of the recipients are very recent recruits, who joined under the present INNI program. Three members received grants in the category of the Advanced Investigator Grant.

Remarkably, the total funding awarded from all these ERC grants will sum up to 11 Million Euro, over the next few years. This appears as a game changer in research funding for Hebrew University researchers in nanotechnology.

PI	Title	ERC Round	Starting Date
Assaf Friedler	Shifting the oligomerization equilibrium of proteins: a novel therapeutic strategy	ERC StG ¹ – 1 st round	1.07.2008
Yaakov Nahmias	Microfabrication-Based <i>Rational</i> Design of Transcriptional-Metabolic Intervention for the Treatment of Hepatitis C Virus (HCV) Infection	ERC StG ¹ – 2 nd round	1.04.2010
Natalie Balaban	Genetic and phenotypic precursors of antibiotic resistance in evolving bacterial populations: from single cell to population analyses	ERC StG ¹ – 3 rd round	1.11.2010
Roie Yerushalmi	Large Scale Nanometric Architectures with Structured Interfaces for Charge Separation, Transport and Interception	ERC StG ¹ - 3 rd round	Still in negotiation
Uri Banin	Doping, Charge Transfer and Energy Flow in Hybrid Nanoparticle Systems	ERC AdG ² – 2 nd round	1.06.2010
Yechezkel Barenholz	Hydration lubrication: exploring a new paradigm	ERC AdG ² – 2 nd round	1.05.2010
Itamar Willner	Nanoengineered Nanoparticles and Quantum Dots for Sensor and Machinery Applications	ERC AdG ² – 3 rd round	Still in negotiation

¹ StG - ERC Starting Grant

² AdG – ERC Advanced Grant

K. Head of the nanocenter: recommendations, requests, comments

After nine years of acting as the center director since its foundation, with the intention of invigorating the center, I (Uri Banin) suggested to renew the center leadership. Prof. Danny Porath, writing the present report with me, is taking over the position of the center director and I wish him best of success in the future. The change will take place on January 1, 2011.

I wish to thank my colleagues at the center for their cooperation throughout these years. I would like to thank the staff of the central core facilities: the UNC staff headed by Dr. Inna Popov, and the UNF staff headed by Dr. Shimon Eliav, for their dedication and professional contributions. I am indebted to Mrs. Tirza Lavi, our administrative assistant, for her patience and hard work. I am truly grateful to Mr. David Shafranek, our managing director, for his on-going support, advice, and dedication. I also wish to thank the university management for its support. Last but not least, I am grateful to the members of the INNI and the INAB that are devoting significant efforts for the success of the Israel National Nanotechnology Initiative.

Both the present and new director of the center emphasize that within the past years it has become clear that the **existence of the Hebrew University Center for Nanoscience and Nanotechnology (HUCNN), with its core facilities, scientific/technical expert staff and scientific activity, is central and essential condition for creating and promoting an enabling and vigorous research environment at the Hebrew University.** This has created the environment for frontier world-class scientific achievements such as top level publications (see e.g., selected publications with 12 articles in Nature journals just last year). This also enabled recruitment of excellent young faculty, directly addressing the brain drain challenge of Israeli academia and high tech sectors.

We also point out the exceptional success in competitive grants awarded to the HUCNN members (e.g, 3 advanced and 4 young investigator awards of the ERC totaling over 11 million Euro). An additional major achievement, reflecting the interest and potential of nanotechnology, is manifested by the remarkable number of students studying towards advanced degrees in center member groups, three times more than the criteria set at the inception of the TELEM program. Moreover, in a period in which many other infrastructure facilities and the size of the supporting technical staff in the experimental faculties is significantly cut and reduced, the existence of the center core facilities has become a condition for the continuation of high level experimental activity and for further high level faculty recruits.

In a period in which the nearly immediate conversion of the nanoscience findings to technological applications is becoming a flagship, we note the numerous technological developments already achieved within the present program. 185 new patent applications were submitted surpassing by far the original goals, and 68 patents were granted. Cooperation with industry within various frames flourishes. Licensing agreements to industry are numerous. Several start-up companies have been launched. Let us also emphasize again, that our students are now graduating and fueling the high-tech sector with fresh concepts. We expect them to become the next leaders of nanotechnology companies and industry of the future. Clearly, these achievements are a direct outcome of the innovative and excellent basic nanoscience research and education, which is a condition for the development of new technologies.

These scientific and technological achievements point out without question that at a first tier, the essential principles of the first program, must be continued. This is necessary in order to fully capitalize on the many beginnings of the first program. Moreover, we expect and need a stream of new ideas and concepts arising from basic nanoscience, to stimulate the generation of nanotechnologies.

Based on this analysis we provide the following recommendations for the continuation of the second phase of the INNI program:

1. Support towards new recruits in nanoscience should be continued. These new faculty are the engine for the future and also this will address a major challenge facing Israeli academia in the next decade – the brain drain.
2. Support of highly qualified scientific/technical staff in nanotechnology to maintain the high level operation of the expensive, sophisticated and essential research infrastructure.
3. Funding for maintenance and service agreements is required.
4. Funding for new equipment and central core facilities and labs. While this component was emphasized in the first phase, its proportion indeed will decline in the second phase, but is still needed for updating the facilities with the latest equipment and for opening new research avenues.
5. In view of the large number of students for advanced degrees in nanotechnology, funding is needed for study programs and fellowships.
6. A new component, which we recommend to increase significantly in the next phase, is the funding of collaborative research and development programs. The most effective model for such programs is to establish national collaborative efforts in specific areas among the Israeli academic nanotechnology groups.
7. There is a need to simplify reporting, both scientific and financial, to assure efficient management of the program.

Our recommendations for enhancing the transfer of nanoscience to technological and industrial applications:

8. Further opening of center facilities towards start-ups. Allocating specific funds for this purpose can help to drive this direction.
9. Creating a forum at the center combining our principle investigators with R&D leaders from Israeli hi-tech sector, to identify and promote industrial applications.

L. Financial report for 2009-2010 and summary for 2006-10

The third budget report, for the year 2008-9, was approved by the official HU auditor (Kesselman & Kesselman, the PricewaterhouseCoopers Israeli branch) and submitted to the PBC in November 2010. The complete budget report (in Hebrew), including balance sheets for years 2006–2009 and comprehensive explanations, is available on request

Table 1 below follows the balance sheet #1 in the report to the PBC, which summarizes expenditures and income (in thousands of NIS) for the years 2005-2009 from the three sources participating in the budget: (1) government & PBC ("TELEM budget"), (2) donations and (3) HUI:

The Hebrew University in Jerusalem						
Table 1: Summary of expense and income in the TELEM program for nanotechnology (in 1,000 NIS)						
(1)	(2)		(3)	(4)	(5)	
	List of approved expenditures and income sources		1.1.2005 - 30.9.2009	1.1.2005 - 30.9.2009	1.10.2009 - 30.9.2010	1.10.2009 - 30.9.2010
			budget plan as submitted to PBC in 2007	implemetation (expenditures + liabilities)	budget plan as submitted to PBC in 2007	implemetation estimate valid July 2010
1	Total expenditures from all funding sources		100,180	170,445	23,830	40,996
	1.1.1	Salaries	14,360	21,222	6,450	7,550
	1.1.2	Other	85,821	149,222	17,380	33,446
	1.1.2.1	Equipment	50,750	53,370	11,200	12,326
	1.1.2.2	Establishing new labs	17,400	18,066		2,271
	1.1.2.3	Maintenance of labs & equipment	9,360	29,948	3,600	8,366
	1.1.2.4	Fund for maintenance after the project				
	1.1.2.5	Supporting graduate students	6,150	34,227	1,700	8,233
	1.1.2.6	Cooperations with other universities in Israel		1,133		250
	1.1.2.7	Construction works (up to 12% of the budget)				
	1.1.2.8	Building's adaptations				
	1.1.2.9	Re-qualification of the technical staff to nano		10,225		1,500
	1.1.2.10	Students qualification for academy and industry	750	1,306	300	
	1.1.2.11	Administration (= < 2% of the total budget)	1,410	947	580	500
2	Total income to the project, per funding source		100,180	189,102	23,830	41,732
	2.1.1	The government and PBC part	27,540	23,493	9,180	8,500
	2.1.2	Donations (approved between 1/1/05 - 31/12/06)	38,770	43,449	6,400	5,961
	2.1.3	The University resources	33,870	122,161	8,250	27,271

Explanations to Table 1:

- Column (3) summarizes the "budget plan" for the first three years (2006-9) of the TELEM triangle model project as submitted for approval by PBC in 2007.
- In column (4) we summarize the budget implementation (expenditures and standing liabilities) for the period 1.1.2005 - 30.9.2009, including expenses from the HUI sources only for the period of 1.1.2005 - 30.9.2006 (before the TELEM program begun) and three years of the TELEM project (2006-9). Income from donations reported in line 2.1.2 was accumulated until July 2009.
- The significant discrepancy between figures in columns (3) and (4) results from the original 5-yr budget proposal in which we planned the required HUI participation to 10 million \$ for the whole duration of the project, as elucidated in the **first** (2007-8) report.

Actually, all our cumulative expenditures for 2005-2009 **exceed by ~70% the estimated in the budget proposal** for this period, mainly due to the HUI matching line 2.1.3. As the HU matching approaches ~122M NIS (~30M USD) for the years 2005-2009, it is agreed with the PBC that this line will not be audited, starting from the 3rd budget report for years 2008-9.

4. Column (4) is the "budget plan" for the 4th year (2009-10) of the TELEM triangle model project as submitted for the PBC approval in 2007.
5. Column (5) presents the budget implementation (expenditures and standing liabilities) until July 2010, when we prepared the formal budget report to the PBC. We estimate an additional 0.5M NIS of expenditures and liabilities until the end of the 4th program year, at 30.9.2010.
6. As the project progresses, the deficit in the balance line of income from the TELEM budget part declines and it stands now on 8.5M NIS as compared with 12M NIS a year ago. The total of 23.5M NIS almost equals the expected 24M NIS income for the first three years of the project.

Table 2 below summarizes expenditures in the TELEM budget part (in the four allowable categories) and complies with our formal budget report to the PBC for 2008-9. The estimated budget implementation for 2009-10 reflects the actual implementation until July 2010, when the report was prepared for auditing, as 2009-10 has not been audited yet.

Table 2: Balance sheet for 4 years of the TELEM project (10.2006 - 7.2010), in NIS						
		Salary	Equipment	New laboratories	Core labs maintenance	Total
2006 - 7	Expenditures	207,026	474,825	1,026,179	93,704	1,801,734
2007 - 8	Expenditures	1,328,507	6,308,970	1,000,000	1,504,644	10,425,212
	Liabilities	-	277,450	-	5,641	
2008 - 9	Expenditures	1,633,947	5,121,366	365,292	1,494,128	8,850,662
	Liabilities	-	54,571	79,124	102,235	
2009 - 7.2010	Expenditures	1,245,143	1,730,061	269,577	1,321,842	10,522,698
	Liabilities	444,368	4,940,128	237,896	333,683	
Total performance		4,858,991	18,907,371	2,978,068	4,855,876	31,600,306

Actually, until September 30, 2010 our expenditures and liabilities for the year 2009-10 total over 11M NIS. Therefore, the accumulated expenses from the TELEM part of the project after the 4th year slightly exceed the total of 32M NIS (~8M USD), as planned.

Since the beginning of the project **60% of the TELEM budget were allocated for purchasing new equipment**, mainly for the core facilities, the UNC and UNF (~4.6M USD), and also for supporting new faculty start-up budgets (~0.4M USD).

About 10 % was allocated for establishing new laboratories for young faculty (0.65M USD) and for developing the UNF clean-room (0.15M USD).

During the last 2 years, the salaries paid from the TELEM budget reached a level of 1.7M NIS. In 2009-10 this amount was ~60% of the total salary cost paid to 14 scientific and technical employees in the Nano Center. The rest is funded by HUI regular budget (~ 1M NIS), and by research grants and donations (0.3M NIS).

In 2009-10 the Nano Center continued its support for new faculty members in purchasing equipment and establishing their own laboratories. We provided Dr. Roie Yerushalmi, who joined the Institute of Chemistry in 2008, with 250K USD. Dr. Yossi Paltiel, nominated in Engineering-Applied Physics in 2009, was supported with 300K USD.

Last year the Nano Center continued with 63 K USD matching from donations to fund the NanoSci ERANET research projects of Nano Center members. This was enabled by the generous donation of Kenneth L. Stein and the Goldie-Anna Charitable Trust.

Ten first year students of the new M.Sc. program, with specialization in nanoscience and nanotechnology, were supported with fellowships totaling 315K NIS, thanks to the generous donations of Ruthellen Toole, in the memory of the late Monte Toole (USA) and also by the Israeli Friends of the Hebrew University.

We continued in 2008-9 the Cambr Foundation scholarships for 4 excellent Ph.D. students thanks to the generous donation of Allen Skolnick (USA).

Plan for 2010-2011 academic year:

A. Milestones

1. Equipment:

In the coming academic year we intend to continue absorbing the systems purchased last year, bringing them into full functional use by the members and students. In the UNC, the new ultra-high resolution SEM that was installed in record time, will be put into full operation, through completion of training of the staff, and by training of students and other external users. In the UNF, the oxidation and doping furnaces will be installed and put into use.

A major activity in UNF these days is a selection process of a new Direct Laser Writer. This direct lithography system will allow users to create their own patterns directly on the photo-resist layer (without the use of masks) and to create simple masks. We expect the selection process (e.g., performing demos and evaluation of various tools provided by major manufacturers) to be completed by the end of 2010.

In addition supplementary equipment items for both the UNF and the UNC will be purchased. A detailed list of the specific equipment planned for 2009-10 is given in the Budget Plan paragraph below.

2. Students and study programs

The M.Sc. program in nanoscience and nanotechnology is running for second year. The first ten students will continue in the second year of studies, giving significant focus to research projects. 10 new students were selected and are beginning the second year of the program.

Aside from this special program, overall, we expect to maintain the steady-state record numbers of M.Sc. and Ph.D. students in member groups, especially as there was a surge in number of students in the past year.

3. International research programs

The center will continue to support the NanoSci ERANET program for two groups that are in the second year of their research grants.

The unique cooperative program for research incorporating a PI from Taiwan and co-PIs from HUCNN, will reach the end of the first year and continue to its second year. Further mutual visits are planned for the summer with the intention for continuing the program.

4. Scientific research activities

The research in the three major directions: nano-materials, nano-bio, and nano-electronics & optics, will continue in the different groups. Moreover, research towards four focal areas defined by the center will develop further. To achieve this, we have reviewed our focal areas and adjusted them further. Three of the areas are continuing essentially from the previous year, but a fourth area, on nano-biomaterials, has been formulated in part also to meet the vision of the Prof. Porath, the new director of the center. The focus on sensing is still present as a sub topic in the nanophotonics focal area, and also in the biomaterials

direction. A principle researcher was nominated to take lead of each area. The four focal areas as re-defined, and their leaders are:

1. Solar energy enabled by nanomaterials and devices – Prof. Micha Asscher
2. Nanophotonics for sensing, communications, and computing applications – Prof. Uriel Levy
3. Nanomedicine - drug delivery with nanosystems – Prof. Gershon Golomb
4. Nano-biomaterials for industrial and medical applications – Prof. Oded Shoseyov

In terms of publications, we expect to continue the impressive output, which has grown markedly last year. We hope it may intensify mildly as it is already very productive. Publications in the focal areas are expected to come out, reflecting enhanced activity in these directions.

5. Towards commercialization - patents, industrial ties, and licensing

Technological implementations already observed this past year, are expected to continue. We hope to continue the large number of new IP emerging from the research. Further licensing agreements are expected, working closely with Yissum, the technology transfer company of the Hebrew University.

6. Academic activities (seminar, workshop)

The Nanoseminar series will continue. The annual workshop of the HUCNN is planned for June 2011. Several international renowned scholars are expected to visit in addition, and will deliver lecture series for center members and students:

Prof. Shalom Wind (Columbia University, winter visit) – Nanofabrication

Prof. James Tour (Rice, summer visit) – Molecular- and nano-electronics, Nanomaterials and applications.

7. Center management

In January 2011, the center management will change, after 9 years under the present leading team. Prof. Danny Porath, an international renowned expert in electronic studies of molecular and nano-biosystems, will replace Prof. Uri Banin as the director of the center. He will be aided by Prof. Uriel Levy, widely recognized for his innovative research in nanophotonics, who will assume the position of the academic director of the center core research facilities, replacing Prof. Amir Sa'ar. The overlap period has already begun and we wish the new management best of success.

B. Recruitment of new faculty members

In the coming 2010-2011 academic year we are continuing the planned recruitments in nanoscience and nanotechnology. Another recruitment of an experimental scientist, the 13th faculty member, exceeding the goal of 12 recruits already, is going to take place. In addition, the center welcomes a new nomination of a theoretical physicist working on Graphene, bringing to 14 the total number of recruitments throughout the program.

Dr. Meital Reches is joining the HUJI faculty in 2010 as senior lecturer in Chemistry. Dr. Reches finished her Ph.D. with distinction in Biotechnology at Tel Aviv University in 2006. She did her postdoc at Harvard University with Prof. George Whitesides during the years 2006-2010. Meital arrived already in April 2010.

Her research interests focus on Biomolecular self-assembly, with particular emphasis on the design of self-assembled peptides and the design of novel composite materials. Meital is also interested in the challenge of Molecular recognition: specifically, how proteins interact with inorganic surfaces.

Dr. Doron Gazit joined the Hebrew University faculty in 2010 as senior lecturer in Physics. He finished his PhD in Physics at the HUJI under the supervision of Prof. Nir Barnea and did his postdoc at the Institute for Nuclear Theory, the University of Washington, Seattle, WA, USA.

His research focuses on graphene, the two-dimensional nanomaterial coined: "the new silicon", for which the Nobel prize in physics was awarded this year. Dr. Gazit focuses on the structure of graphene, and its interplay with the unique electronic properties, which are key elements for any future nanotechnological applications and scientific use of graphene.

C. Plan of acquisition of new equipment

Most of the equipment acquisitions planned for the 5th year of the TELEM program focus on enhancing the processing and characterization capabilities of the Unit for Nanofabrication.

The following equipment will be purchased from the TELEM part of the budget in 2010-11:

Direct Laser Writer	350K USD (matching to 115K USD from ISF)
Nano Spray Dryer	70K USD
Optical Profilometer.....	100K USD
Micro-Raman	200K USD
<u>Small equipment for UNF</u>	<u>100K USD</u>
	820 K USD (= ~3M NIS)

D. 2010-11 budget plan

Particular expenses from the TELEM budget, as per Table 2, are presented below:

Salaries (UNC & UNF staff)	1.7 M NIS
Equipment:.....	
for central units	3.0 M NIS
for new faculty (M. Reches)	0.9 M NIS
New labs for HUCNN core facility	0.8 M NIS
<u>Maintenance of equipment & labs.....</u>	<u>1,6 M NIS</u>
	8,0 M NIS

As noted above, there is an allocation of 250 K USD for Dr. Metal Reches, a new faculty recruit. After an intensive effort we will be able to add additional lab space for the HU CNN.

At the income side of the budget for 2009-10 we expect PBC to fulfill the 4 years budgeting of 32 M NIS (2006-2009) and provide the university with 4.0 M NIS prepayment for 2010-11.

On the side of expenditures, our plan for 2010-11 includes 8.0 M NIS from TELEM (as explained above). In addition 2.16 M NIS expenditures from donations are planned

1. Fellowships for 20 MSc students	1.00 M NIS
2. Fellowships for 4 PhD students.....	0.16 M NIS
3. Research funds matching	0.25 M NIS
4. Academic activities (annual conference, seminars, guests)	0.25 M NIS
5. Expanding central labs	0.50 M NIS
	<u>Total 2.16 M NIS</u>

The most significant expenditure from the donations will be the establishing of a "Maintenance Fund" – line 1.1.2.4 in Table 1 above (chapter L, Financial Report for 2009-10). The seed of this fund is the donation of ~ 1.26 M USD by Harvey M. Krueger which was invested by AFHU¹ in USA as a profitable fund until 2013. The fund raised from 2008 a net income of ~190 K USD to the Nano Center. In addition, we plan to allocate other income from donations to this maintenance fund.

¹ American Friends of the Hebrew University

Focal Areas

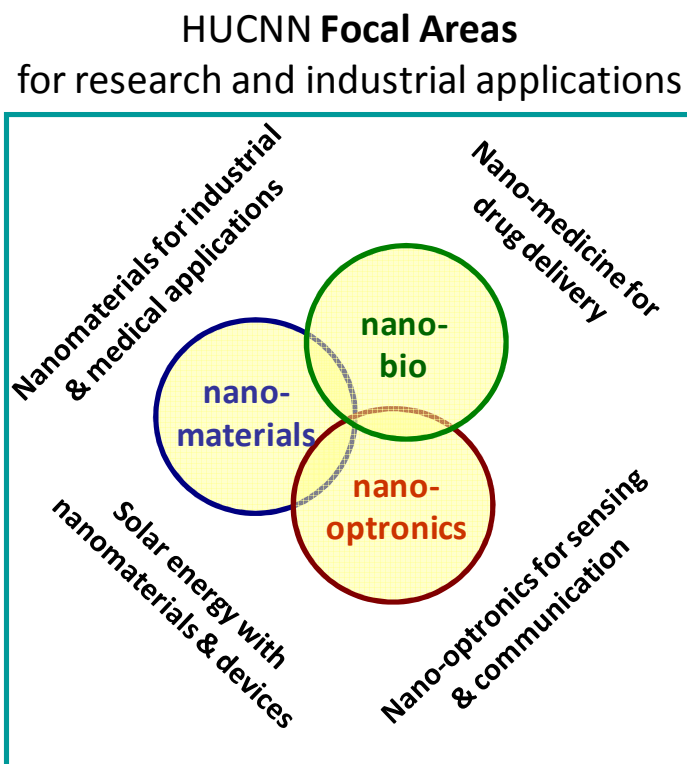
We have redefined and further formulated our four **main cross-platform focal areas** which on one hand reflect the existing strength of our activities, and on the other hand offer significant promise for future scientific discoveries and technological breakthroughs. We have also nominated a principle investigator to lead each of the focal areas.

The four focal areas are:

- A. Solar Energy enabled by Nanomaterials & Nanotechnology
- B. Nano-optonics for sensing and communication applications
- C. Nano Medicine for drug delivery.
- D. Nanomaterials for industrial and medical applications.

The alternative energy focal area of recent years, was focused further and defined to target the challenge of solar energy, where we find our impact to be most significant. The Nano Photonics focal area definition was modified towards myriad applications that are expected from this field, and in particular, with a focus on sensing. This is related to creating a new focal area on nano-biomaterials. This reflects the vision of the new center director, Prof. Danny Porath, aiming to intensify cross-disciplinary work between the exact and life-science wings of the center.

The framework of the research map, including these focal directions, is presented in scheme 2.



A description of each of the focal areas is given below:

Focal Area: Solar Energy

1. Name: *Solar energy as an alternative, sustainable energy source of the future*

Focal area leader: Prof. Micha Asscher

Introduction:

Development of sustainable, new energy sources that do not depend on fossil fuels, at affordable cost, is perhaps the most important challenge for modern civilization in the 21st century. Solving the energy problem will simultaneously address other major problems of mankind such as diminishing supplies of clean water (e.g. solar energy driven desalination) and global warming. One simply cannot afford avoiding the stressing need to direct our focus to this topic.

A "democratic" source that is available and particularly abundant in Israel (and its surroundings) is solar radiation, which can be converted into (other) useful energy. It is impressive to realize that in one hour, planet earth absorbs solar radiation, its energy is equivalent to a year long consumption of the entire population on earth. It means that only 0.01% of this energy, if effectively utilized, can satisfy the need of humans worldwide. This is well understood in recent years within the western world. The market of photovoltaic (PV) applications alone is already more than \$10⁹ /year with anticipated annual growth rate of more than 25%. Thermal-electric applications are already in the market with two Israeli companies playing a major role in the global (power stations) market.

Knowledge that has already been accumulated within the HUCNN can provide unique opportunity to combine it with novel applications in solar energy related research. Discovery of new nano-materials with unique optical and electronic properties opens the way to new generations of solar energy solutions. Novel concepts in nano-photonics related to how light is guided on the nano-scale also contribute to this potential revolution. We expect that this will impact greatly the ability to improve photovoltaic cells to become more cost effective, opening new pathways to their wide spread utilization. Ground breaking innovation is directed towards the generation of solar fuels, which provide means of converting solar energy and store it within energetic chemical bonds, a way to address the obvious daily and yearly fluctuations in solar power (night time, cloudy days etc.). Finally, new theoretical approaches and concepts for efficient light handling through multiple excitation in nano-crystals may assist to achieve effective harvesting of solar energy as well as to address energy saving solutions for lighting. All these issues combine challenges in chemistry, in physics, in basic materials science, in nanotechnology and in innovative engineering.

2. Uniqueness

Research activity at HUJI's nanocenter will focus on what we identify as the main scientific and technological challenges regarding solar energy: Electrical energy generation and long term storage. These are areas in which scientists at HUJI have initiated basic science and applied research in recent years.

Three main themes were identified as unique, most important and appropriate:

a) Photovoltaics (emphasis on development of novel concepts of silicon based PV cells).

Silicon based photovoltaic cells is recognized as the main workhorse of the PV market and predicted to stay in its leading position for the coming 25 years. The most expensive part of manufacturing a working Si-PV is the silicon material itself. It is therefore, highly desired to explore new ways and concepts to reduce the need for Si. Three groups in Chemistry and Physics Institutes at HUJI already collaborate to develop novel nano-porous silicon (PS) based PV cell. The main issue is to drastically cut the amount of silicon per working cell. Insertion of conducting polymers together with metallic and semiconductor nano-crystals within the PS pores, will enable better absorption of solar light than that of pure silicon. Moreover, the critical understanding and development of procedures to improve front cell conducting contacts will be part of the silicon based cells. This research is based on the collaboration of five different research groups, all are active members at the Nano-center.

b) High temperature thermal electric (new materials that can sustain prolonged focused solar light, high temperature operation).

Thermal electric utilization of solar energy has been pioneered by the Israeli industry for the past thirty years. Currently the highest temperature of operation (e.g. the light absorber instrument at the top of a tower facility of BrightSource company) is 350-400°C, converting light to a steam turbine that generates electricity. Based on thermodynamic arguments, better efficiency can be gained by driving the operating temperature as high as 650-700°C. This is a major materials science challenge since most materials cannot sustain this high operation temperature for long time. Several HUJI groups are developing new materials while closely collaborating with BrightSource company.

c) Photo-catalysis as a means for long term, chemical energy storage.

A central issue in solar energy conversion to a stable, dependable source of energy, is the ability to store the energy at peak times of solar radiation and utilize it at later times. Among various ways to store solar energy, for particularly long times, is its conversion to chemical energy stored in chemical bonds of stable molecules such as hydrogen. This can generate also "solar fuels" that can be used for powering transportation needs. All this requires the development of efficient photo-catalysts that can convert other stable molecules, e.g. water and methane, to higher energy but stable molecules like hydrogen and methanol. Hydrogen can subsequently be used to generate clean electricity via fuel cells technology. At least three groups are involved and collaborate in such photo-catalysis studies. Photo-induced bio-fuel cells is another potential, novel way of reaching similar storage goals, explored by two other groups in HUCNN.

3. Participating groups:

Several research groups at the Institute of Chemistry (Asscher, Banin, Yitzchaik, Haas, Willner, Magdassi, Sasson, Baer, Ruhman), Physics (Sa'ar, Millo, Balberg) and Engineering (Levy), already perform research with various aspects of solar energy topics (see appendix I below for details on specific activity of each group). Young, recently recruited researchers, are also setting up to address these challenges (Yerushalmi, Paltiel), and we expect to recruit additional new faculty in these areas.

The table below summarizes the activities:

Name	Faculty/ Institute	Solar Energy Focal Area	Research Topics
Asscher Micha	Chemistry	PV and photocatalysis	1. Novel composite PS-PV 2. Photocatalysis over thin TiO ₂ film with Ag – Au NC – for chemical storage of energy
Banin Uri	Chemistry	PV and Photocatalysis	1. Semiconductor nanocrystals (SC-NC) for improved light harvesting in PV cells 2. Hybrid metal-NC for photocatalysis
Millo Oded and Balberg Isaac	Physics	Thin film PV	Photoconductivity in thin film SC-NC
Magdassi Shlomo	Chemistry	PV and Solar-thermal	1. Transparent top electrodes for PV cells 2. New high temperature materials for thermal-electric applications
Mandler Danny	Chemistry	Solar- thermal	Electrochemical coating of high temperature materials for solar-electric applications
Sa'ar Amir	Physics	Novel composite PV	1. Develop new composite PS-PV cell 2. Characterize conductivity of top PV-electrodes
Yitzchaik Shlomo	Chemistry	Novel composite PV	Grow conducting polymers within PS – for composite PV applications
Sasson Yoel	Chemistry	Chemical storage	1. Biofuels 2. Hydrogen storage as inorganic materials
Willner Itamar	Chemistry	PV and biofuel-cells	1. Functional electrodes for PV applications 2. Enzyme based bio-fuel cell
Levy Uriel	Applied Physics	PV	Nanophotonics for light focusing in PV cells
Baer Roi	Chemistry	Theory of PV	Multiexcitons in PV applications
Ruhman Sandy	Chemistry	Multiexcitons in PV	Multiexcitons in PV applications: A fsec time resolved study for basic PV applications

Significant publications in solar energy research in the past year:

1. "Can impact excitation explain efficient carrier multiplication in carbon nanotube photodiodes?", R. Baer and E. Rabani, *Nano Letters* Vol. **10**, Issue: 9, 3277-3282 (2010)
2. "Electrostatic Force Microscopy study of Single Au-CdSe Hybrid Nanodumbbells: Evidence for light Induced Charge Separation", R. Costi, G. Cohen, A. Salant, E. Rabani, Uri Banin, *Nano Letters* **9** (5), 2031-2039 (2009).
3. "Transparent conductive coatings by printing coffee rings arrays", M. Layani, M. Grouchko, O. Millo, I. Balberg, D. Azulay, S. Magdassi, *ACS Nano* **3** (11), 3537-3542 (2009).
4. "New Developments in Luminescence for Solar Energy Utilization", R. Reisfeld, Invited paper, *Optical Materials*, **32** (2010) 850-856.
5. "Integrated Enzyme-Based Biofuel Cells – A Review", I. Willner, Y.-M. Yan, B. Willner and R. Tel-Vered, , *Fuel Cells*, **9**, 7-24 (2009).
6. "An Ethanol/O₂ Biofuel Cell Based on an Electropolymerized Bilirubin Oxidase/Pt Nanoparticle Bioelectrocatalytic O₂-Reduction Cathode", Y.-M. Yan, I. Baravik, R. Tel-Vered and I. Willner, *Adv. Mater.*, **21**, 4275-4279 (2009).

7. "Control of Bioelectrocatalytic Transformations on DNA Scaffolds", G. Piperberg, O.I. Wilner, O. Yehezkeli, R. Tel-Vered and I. Willner, *J. Am. Chem. Soc.*, **131**, 8724-8725 (2009).
8. "Plugging into Enzymes with Light: Photonic "Wiring" of Enzymes with Electrodes for Photo Biofuel Cells", R. Tel-Vered, B.H. Yildiz, Y.-M. Yan and I. Willner, *Small*, **6**, 1593-1597 (2010).
9. "Quantum Dot Sensitized Solar Cells with Improved Efficiency Prepared Using Electrophoretic Deposition", A. Salant, M. Shalom, I. Hod, A. Faust, A. Zaban, U. Banin, *ACS nano*, **4** (10), 5962-5968 (2010).
10. "Xe interacting with porous silicon", A. Paldor, G. Toker, Y. Lilach, M. Asscher, *Phys Chem Chem Phys* **12**, 6774- (2010).
11. "Spectroscopic and electrochemical study of hybrids containing conductive polymers and carbon nanotubes", S. Ben-Valid, B. Botka, K. Kamaras, A. Zeng, S. Yitzchaik, *Carbon* **48**, 2773-2781 (2010).

Patents in the energy related field in the past year:

1. Patent on Solar Cells (see details in the report of J. Shappir) – Prof. U. Levy
2. S. Magdassi, M. Grouchko, and A. Kamyshny, Conductive Ink-Jet Printing for Flexible and Plastic Electronics, Prov. Patent Appl., submitted (2009).
3. M. Grouchko, A. Kamyshny, S. Magdassi, Obtaining conductive patterns by coagulation process at low temperatures, US Prov. 61/162,744 (2009).
4. M. Layani, M. Grouchko, and S. Magdassi, Transparent coatings for optoelectronic devices, US Prov. 61/257,139 (2009).
5. U. Banin, A. Zaban, A. Salant, M. Shalom, Novel quantum dot sensitized solar cells and a method for their preparation. (provisional filing 9/2010)
6. A. Sa'ar, S. Yitzchaik and M. Asscher, Composite porous silicon-conducting polymer solar cell, Patent application filed via Yisum.

4. Research infrastructure

Shared and individual equipment has recently been purchased with support of generous grant from the **Wolfson Foundation (UK)** and donation from **Mrs. Lillian Freedman (USA)**, that have recognized the importance of solar energy harvesting as a central research field.

A first level of indispensable shared equipment are the characterization tools at the UNC. The nanoscopic characterization is an essential element enabling the research in this focal area. These are essential for the characterization of the nanoparticles and nanowire building blocks incorporated in the respective devices. Also, coatings and matrices will be extensively characterized and studied. Similarly, nanofabrication capabilities at the UNF are essential for the construction of solar cells and other renewable energy devices.

A second level of shared equipment relates to specific aspects of this focal area. First, a Solar Simulator (Newport) where calibrated irradiation simulates uniform solar spectrum over 4"x4" area on which photovoltaic cells can be characterized and measured. In addition, a high performance UV-VIS-NIR spectrophotometer that includes an integrating sphere for light reflection measurements (in addition to standard absorption). This is important to define the spectral response of non-uniform, hybrid materials such as porous silicon thin films and colloidal solutions. In addition, within the basic infrastructure of the

nano-center, smaller irradiation station, equipped with four-point probe for resistivity-photocurrent measurements is used to characterize smaller, model PV cells.

Other individual lab equipment enable electrochemical studies to prepare porous silicon and thin film materials deposition for high temperature light absorption studies (for thermal electric applications), ultra high vacuum systems and GC for photo-catalysis studies.

5. Collaborations / external grants

The importance of solar energy research has been recognized already a few years ago by members of the Center who initiated together with colleagues at Bar-Ilan University, a major Academia-Industry consortium ("Solar Energy Solutions - SES" MAGNET), funded by the Israeli Ministry of Industry and Commerce (TAMAT) at annual levels of about 20 Million NIS. This initiative has been approved and started operating on May 2009, where 8 different Israeli Industrial firms and more than 10 groups from academia (5 from the HUCNN) closely collaborate. Cooperations with academic partners have been established, for example, with Bar Ilan University and with Ben Gurion University.

Major industrial partners include Tower Semiconductors, Orbotech, Hanita coatings, Ricor, Actar, BrightSource and more.

Equipment grant from the Wolfson Foundation and donation from Mrs. L. Freedman are acknowledged as well, see infrastructure section above.

6. 2011 plan: targets, milestones

Collaboration with Industry:

- 6.1 Collaboration with industry will continue within the MAGNET platform for the coming 2-3 years. Tower Semiconductors, Orbotech, Hanita Coatings, Aktar, Bright Source
- 6.2 Developing cooperations with several companies in this area;
 - Dani Mandler with Bright Source on thermal resistive coatings
 - Shlomo Magdassi with Xjet on transparent coatings
 - Uri Banin with 3GSolar on quantum dot sensitized solar cells

Future concepts: Specific areas of planned activity in 2011

- 6.3 Basic research of novel photovoltaic cells and concepts will be emphasized. It will include the hybrid porous silicon / conducting polymer cell with emphasis on the insertion of nano-clusters (semiconductor and metallic). In addition, theoretical study of multiple excitation within semiconductor quantum dots, coupled with femtoseconds time resolved experimental studies will be conducted.
- 6.4 Sol-gel based methods with electrochemical control will be employed for novel thin film coatings operating at extremely high temperature solar-thermal applications.
- 6.5 Semiconductor nano-crystals and hybrid metal-semiconductor structures will be developed and studied in solution and under UHV conditions for their photo-catalytic activity with emphasis on hydrogen generation for chemical storage and fuel cells applications.

Focal Area: Nano-optonics

1. Name: *Nano-optonics for sensing and communication applications*

Focal area leader: Prof. Uriel Levy

Introduction:

Nanophotonic concepts and components are finding myriad applications in communication, information science, health care, lighting, sensing and security. Nanophotonics research involves studying the properties of light on the nanometer scale as well as the interaction of light with matter on the nano and the subwavelength scale. The interaction of light with nanoscale features opens new opportunities for the design and realization of miniaturized components with performance exceeding conventional photonic devices and going beyond what was thought to be the fundamental limits in optics and photonics.

The rapid progress in nanofabrication techniques and in computational capabilities is of major importance in advancing the field forward. Nanophotonic components and devices are based on large variety of material platforms, including dielectrics, semiconductors, and metals. The latter are widely used in recent years for the realization of plasmonic and metamaterial based devices, in which light can be localized at the nanometric scale, much below the limit of diffraction.

Within the last few years, the nanophotonics related activity at the HUCNN is flourishing. With a combination of young and senior faculty members, new base of knowledge was created and several internal and external collaborations were initiated. We identify a unique opportunity to direct this activity towards making nanophotonics an enabling technology with novel applications. Nanoscale confinement of light may provide enhanced light-matter interaction leading to improved light emission and detection, as well as enhanced resolution in imaging systems. The use of silicon as a photonic material paves the way for the dense integration of electronics and photonics on a single chip. Introducing new materials, e.g. quantum dots, into optical structures provides new opportunities for optoelectronic devices geared towards chip-scale light sources, and biosensing applications. Merging the concepts of nanophotonics with microfluidics technology may give rise to the construction of integrated photonic devices oriented for “lab on chip” applications. Plasmonic concepts can be used for nanoscale confinement of electromagnetic waves with optical frequencies and short U.V wavelengths, providing further enhancement of light-matter interaction. Finally, Novel concepts in nano-photonics can support future activities in quantum communication and computation.

2. Uniqueness

Research activity at HUJI's nano-center will focus on our strengths and in directions we deem as the main scientific and technological challenges regarding nanophotonics: nanophotonics for sensing applications and nanophotonics for communication applications. These are areas in which scientists at HUJI have initiated basic science and applied research in recent years.

Nanophotonics for sensing applications – Recent advancements in plasmonics and silicon photonics provide versatile means for developing new optical platforms that are geared towards mitigating the application of sensing on a chip. The construction of high Q

resonators and their integration with microfluidic platform give rise to the concept of label free biosensing and chemical sensing where the sensitivity is based on detecting minute variations in refractive index. This, together with the property of specificity, which may be the result of surface chemistry or multi-wavelength measurement, may provide sensitivity down to the single molecule level. In parallel, the integration of nanophotonic structures with advanced optical materials, e.g. quantum dots/rods, may allow the realization of chip-scale optofluidic lasers for spectrometer on chip applications. Plasmonic assisted nanoscale confinement of electromagnetic modes by the use of plasmonic lenses and plasmonic antennas may lead to a significant increase in the local density of states. This in turn improves the performance of chip-scale nanophotonic sensing by increasing the interaction of light with the analytes to be detected and by improving the resolution of imaging systems.

Nanophotonics for communication applications – Photonics is being used for long haul communication for a long time, as it offers important advantages in bandwidth, delay, cross-talk and power. Owing to these important features, and taking into account the growing demand for higher data rates and information capacity, photonics is now being also considered as a potential solution for much shorter range communication, at the chip to chip and board to board level, and even for chip scale communication. This transition will be supported by the enabling technology of nanophotonics. For example, silicon photonics will be used for dense integration of photonic and electronic components on a chip. It will also support the confinement of electromagnetic modes down to the ~100-300 nanometer scale. Further “squeezing” of the optical mode may become possible by the integration of plasmonic structures on chip. Plasmonic devices and structures may also become valuable for the construction of logic operators and processing units on chip, with the ultimate goal of inventing new types of electronic transistors.

3. Participating groups

Several research groups at the school of engineering (Agranat, Levy, Lewis, Marom, Paltiel), physics (Sa’ar, Rappaport and Eisenberg), and the Institute of Chemistry (Baer, Banin,), already perform research with various aspects of nanophotonics (see appendix I below for details on specific activity of each group). We expect to recruit new faculty members in the area of nanophotonics. The table below summarizes the activities:

Name	Faculty/ Institute	Nanophotonics Focal Area	Research Topics
Agranat A.	Applied Physics	Sensing/communication	Refractive Index Engineering, Optical crystals, EM wave propagation in soft condensed matter
Baer R.	Chemistry	communication	Theory of plasmonic structures
Banin U.	Chemistry	Sensing/communication	Science and technology of nanocrystals
Eisenberg H.	Physics	Communication	Quantum optics
Levy U.	Applied Physics	Sensing/communication	Subwavelength optics, Plasmonics, Optofluidics, Nanophotonic devices
Lewis A.	Applied Physics	Sensing	Near field optics, Bio photonics
Marom D.	Chemistry	Communication	Integrated optics
Paltiel Y.	Chemistry	Sensing/communication	Quantum nano engineering Nanophotonic devices
Rappaport R.	Physics/Applied Physics	Communication	Nonlinear Plasmonics
Sa’ar A.	Physics	Sensing/communication	Science and technology of silicon nanostructures, Photonic crystals

Selected publications in nanophotonics research in the past year:

1. "Scale-free optics and diffractionless waves in nano-disordered ferroelectrics", E. Del Re, E. Spinozzi, A. J. Agranat, and C. Conti, *Nature Photonics*, Accepted for publication (2010).
2. "Collective Effects in Charge Transfer within a Hybrid Organic-Inorganic System", Y. Paltiel, G. Jung, T. Aqua, D. Mocatta, U. Banin, and R. Naaman, *Physical Review Letters* **104**, 016804 (2010).
3. "Nanoscale Mode Selector in Silicon Waveguide for on Chip Nanofocusing Applications", B. Desiatov, I. Goykhman and U. Levy, *Nano Lett.* **9**, 3381–3386 (2009).
4. "NAD⁺/NADH-Sensitive Quantum Dots: Applications to Probe NAD⁺-Dependent Enzymes and to Sense the RDX Explosive", R. Freeman and I. Willner, *Nano Lett.*, **9**, 322-326 (2009).
5. "Demonstration of Nanofocusing by the use of Plasmonic Lens Illuminated with Radially Polarized Light," G. M. Lerman, A. Yanai and U. Levy, *Nano Lett.*, **9**, 2139-2143, (2009).
6. "Nanoscale Near-Field Imaging of Excitons in Single Heterostructured Nanorods", E. Yoskovitz, G. Menagen, A. Sitt, E. Lachman, U. Banin, *Nano Letters* **10** (8), 3068-3072 (2010).
7. "Biosensing and Probing of Intracellular Metabolic Pathways by NADH-Sensitive Quantum Dots", R. Freeman, R. Gill, I. Shweky, M. Kotler, U. Banin and I. Willner, *Angewandte Chemie International Edition* **48** (2), 309-313 (2009).
8. "Fine Structure and Selection Rules for Excitonic Transitions in Silicon Nanostructures", M. Dovrat, Y. Shalibo, N. Arad, , S.-T. Lee, and A. Sa'ar, *Phys. Rev. B.* **79**, 125306 (2009).
9. "Tunable Optofluidic devices", U. Levy and R. Shamai, (invited review paper) *Microfluidics and Nanofluidics* **4**, 97-105 (2008).
10. "Strong emitting sol-gel materials based on interaction of luminescence dyes and lanthanide complexes with Silver Nanoparticles", R. Reisfeld, Ts. Saraidarov V. Levchenko, *J Sol-Gel Sci Technol*, DOI 10.1007/s10971-009-1892-7 (2009) 50: 194-200.
11. "Photoluminescence from Silicon Nanostructures: The mutual role of quantum confinement and surface chemistry ", A. Sa'ar, *J. Nanophoton.* **3**, 032501 (2009).
12. "Photoluminescence from Silicon Nanostructures", A. Sa'ar, chapter 25: "*Handbook of Nanophysics*", Vol. **6** (Nanoelectronics and Nanophotonics), K. D. Sattler, Ed., Taylor & Francis Publisher (CRC Press), October 14, 2010.
13. "A tunable channel waveguide array fabricated by the implantations of He⁺ ions in an electrooptical KLTN substrate", A. Gumennik, G. Perepelitsa, A. Israel and A. J. Agranat., *Optics Express* **17** (8), pp: 5919-6251 (2009).
14. "Semiconductor nanocrystals in organic-inorganic Sol-Gel composite for optical gain applications", M. Kazes, T. Saraidarov, R. Reisfeld, U. Banin, *Advanced Materials* **21**, 1716-1720 (2009).

4. Research infrastructure

First levels of indispensable shared equipment are the nanofabrication tools at the Unit for Nanofabrication (UNF). These nanoscale fabrication tools are essential elements enabling the research in the nanophotonics focal area. E-beam lithography is used to define the nanoscale features of the nanophotonic structures and devices, whereas photolithography is primarily used to connect these structures to the outside world. Layers are being constructed using either PECVD (plasma enhanced CVD), sputtering or E-gun evaporator. Patterns are being transferred from resist to the substrate by the use of RIE (Reactive Ion Etching). RTA (Rapid Thermal Annealing) and ovens are used for doping and annealing of silicon nanostructures. Bottom-up approaches are supported by an advanced glove box. Also available are inspection tools (microscopes, surface profiler, etc.) and a wire bonder. The facilities at the Unit for Nanocharacterization (UNC) are also of great importance. SEM is used on a regular base both for observing the final structures as well as a tool for process development. AFM provide additional information, primarily about cross sections. TEM is used for the characterization of hyper-fine structures and nanoparticles.

In parallel, individual lab equipment enable the experimental measurement and characterization of nanophotonic devices. A major strength of the nanocenter members is near-field measurements, with various NSOM tools allowing to measure structures in free space and guided wave configurations, using both aperture and apertureless approaches. Large variety of lasers, detectors, cameras, microscopes, equipment for ultrafast measurements and spectroscopic measurements (including in cryogenic temperatures) facilitates the research in this focal area.

5. Collaborations / external grants

During the TELEM program, we have constructed various internal collaborations to address the topics of nanophotonics for sensing, and nanophotonics for communication applications. For example, following an initial support from ISF converging technologies program, Banin, Willner and Levy collaborated on a project aiming at developing chip scale nanophotonic platform by combining concepts of plasmonic focusing, integration of quantum dots in optical resonators and surface functionalization for enhancing the specificity of the sensing. In parallel, Levy, Agranat and Feldman are collaborating on a project where the integration of microfluidic and nanophotonics is used for trapping cells on chip and their characterization using terahertz signals. This project is supported by the ministry of science and technology. Sa'ar and Lewis are collaborating on the development and study of biosensors in photonic crystals platform. Levy and Marom are collaborating on developing a chip scale communication systems operating at a speed of about terabit per second within the framework of the TERASANTA Magnet, which has been recently launched and involves extensive cooperation with industry as well. Paltiel, Rapaport and Eisenberg are collaborating on developing on chip single photon sources using concepts of plasmonic concentration. This effort is supported by a recent grant from Bikura. Levy, Paltiel, Rapaport and Eisenberg are also working on the system level aspects of these sources, with the ultimate goal of developing an on chip communication and computation system that is operated by single photons. This effort is supported by the ministry of defense.

6. 2011 plan: targets, milestones

Collaboration with Industry:

- 6.1 Collaboration with industry will continue within the TERASANTA MAGNET environment for the coming 2-3 years. This includes close collaboration with ECI, Finisar, and Efdon.
- 6.2 We will maintain and increase the collaborations of individual researchers with industry. For example, Banin is involved in a start-up company (Q-light) generating advanced nanoscale lighting solutions. Levy has an ongoing collaboration with Rafael on the infrastructure of silicon nanophotonics. Marom is collaborating with Xtellus on nanoscale optical switches.

Future concepts: Specific areas of planned activity in 2011

- 6.3 Basic and applied research of plasmonic lenses and plasmonic antennas in “free space” and guided mode configurations. The incorporation of active nanoparticles into such structures will be investigated. We will also study the coupling between plasmonic structures and emitters/detectors with the goal of enhancing spontaneous emission and quantum efficiency. This platform will be used for the generation of efficient light sources (both classic and quantum sources), and efficient detectors. We will also study the role of these plasmonic structures in obtaining super-resolution down to the nanoscale due to the short plasmonic wavelengths at optical frequencies.
- 6.4 The research in silicon photonics will be geared towards the realization of on-chip systems for sensing and communication. We will make progress in advancing the platform of porous silicon towards the construction of light sources and sensing devices. Nanoscale silicon diode-like structures will be used for the construction of compact electro-optic devices with ultrafast operation speed and low power consumption. CMOS compatible resonant structures will be investigated, with the goal of facilitating on chip refractive index sensing capabilities. These structures will be integrated with microfluidic channel network used as a delivery mechanism for the analytes to be detected. This platform will bring together researchers from applied physics, physics, chemistry and biology to work on problems with common interest.
- 6.5 Polymer nanophotonic structures will be studied and developed with the ultimate goal of developing a flexible nanophotonic platform in which nanocrystals are being introduced to photonic nanostructures with the goal of developing optoelectronic devices in polymeric materials.

Focal Area: Nanomedicine

1. Name: *Nanomedicine for drug delivery and tissue regeneration*

Focal area leader: Prof. Gershon Golomb

Introduction

The development of a wide spectrum of nanoscale technologies and their incorporation into top-level conventional technologies is beginning to change the foundations of disease diagnosis, treatment, and prevention. These technological innovations, referred to as nanomedicines by the National Institutes of Health (Bethesda, MD, USA), have the potential to turn molecular discoveries arising from genomics and proteomics into widespread benefit for patients. For the sake of clarity, we define the term nanomedicine as **‘the science and technology of diagnosing, treating and preventing disease and traumatic injury, of relieving pain, of preserving and improving human health, and molecular knowledge of the human body, using molecular and other tools arising from the wider field of nanoscience and nanotechnology’**. Nanotechnology is beginning to change the resolution, scale and methods of vascular imaging and drug delivery. Indeed, the NIH Roadmap’s ‘Nanomedicine Initiatives’ envisages that nanoscale technologies will begin yielding more and more medical benefits within the next 10 years. The National Cancer Institute has related programs too, with the goal of producing nanometer scale multifunctional entities that can diagnose, deliver therapeutic agents, and monitor cancer treatment progress. Based on these applications, three categories²⁻⁴ can be defined: “Biopharmaceutics”, “Implantable materials” and “Diagnostic tools”.

2. Uniqueness

For the full in vivo potential of nanotechnology in targeted imaging and drug delivery to be realized, nanocarriers have to get smarter and more specific. Pertinent to realizing this promise is a clear understanding of both physicochemical and physiological processes. These form the basis of complex interactions inherent to the fingerprint of a nanovehicle and its microenvironment.

During the past years HUCNN has established a critical mass of researchers with widely recognized achievements in the application of nanotechnology for drug delivery. Their research includes carrier stability, extracellular and intracellular controlled drug release in different pathologies, interaction with biological milieu, and other barriers en-route to the target site, be it anatomical, physiological, immunological or biochemical, and exploitation of opportunities offered by disease states (e.g., tissue-specific receptor expression and escape routes from the vasculature). Inherently, carrier design and targeting strategies may vary in relation to the type, developmental stage and location of the disease.

a) Biopharmaceutics

The first area of application is drug delivery, that is, the optimization of drug delivery. New technologies developed at HUJI influence the rate of absorption, distribution, metabolism and excretion of a drug in the human body. Nanotechnology offers new delivery solutions in two areas: drug encapsulation and target oriented functional drug

carriers. The advantage of using encapsulation materials at the nanoscale is that they present better solutions for the delivery of certain drugs and for control of drug release in specific times, locations and doses, thus increasing efficacy and reducing side effects. Functional drug carriers are another type of drug delivery that uses nanomaterials to carry drugs to a particular location in the human body. Major areas at HUJI include Targeted delivery of gene and drug NP in cancer and NP for immuno-modulation and anti-inflammatory disorders (see Table and appended reports).

b) Implantable materials

The possibility of repairing and replacing human tissues is another remarkable application of nanotechnology in the biomedical sciences. Scientists are developing a new generation of nanoscale biostructures to solve some of the problems related to the repair and replacement of tissues in the body (the most common problems are immune rejection and invasive surgery). Nanotechnology offers new biocompatible nanomaterials and coatings that should increase the adhesion, durability and lifespan of implants. Other areas of application of nanoscale biostructures include bone repair, bioresorbable materials and smart materials. Finally, some nanodevices are being developed to restore vision and correct hearing dysfunctions. These types of devices are built to collect and interpret information and transform them into electrical signals transferred directly to the nervous system of an individual. Retinal implants use nanodevices to stimulate the functional neurons in the retina electrically. Major areas of research at HUJI include Coating of medical devices, Self-assembled biomolecules, and Microdevices for liver tissue engineering (see Table and appended reports).

c) Diagnostic tools

Included in this category are surgical aids of nanodevices that would enable greater precision, better monitoring of physiological and biomechanical parameters and safer and potentially less expensive (because they are less invasive) surgical procedures. When we turn to diagnostic devices, nanotechnology offers new technologies that enable the monitoring and collection of data in a more efficient way. Devices can also be implanted in the human body for specific medical applications. For instance, very small implantable fluid injection systems can be placed in the body to dispense drug on demand for the treatment of diseases such as cancer. Finally, nanotechnology offers new applications in the area of genetic testing. In particular, these innovative solutions can increase speed and accuracy in the process of identifying genes and genetic materials either for treatment-oriented applications or for the development of new drugs. Thus far, various new technologies have been developed. They include, for example, the use of gold nanoparticle probes that are coated with chemicals that enable them to stick to and to target genetic materials.

3. Participating groups

As can be seen from the appended activity reports a critical mass of research activities in the 3 areas of Biopharmaceutics”, “Implantable materials” and “Diagnostic tools” has been established at HUJI:

Name	Faculty/ Institute	Nanomedicine Focal Area	Research Topics
Barenholz Y.	Medicine	Biopharmaceutics/ Implantable materials	1. Liposomes in cancer therapy 2. Liposomes for anti-inflammatory disorders
Benita S.	Pharmacy	Biopharmaceutics	1. Targeted NP in cancer therapy 2. Ocular gene and drug delivery by NP 3. NP for enhanced oral absorption
Domb A.	Pharmacy	Biopharmaceutics/ Implantable materials	NP for enhanced oral absorption
Golomb G.	Pharmacy	Biopharmaceutics/ Implantable materials	1. Targeted drug and gene NP in cancer therapy. 2. NP and liposomes for immuno-modulation 3. Targeted NP for brain delivery
Magdassi S.	Chemistry	Implantable materials/ Diagnostic Tools	Functional organic NP for drug delivery
Mandler D .	Chemistry	Implantable materials/ Diagnostic Tools	Drug eluting stents
Nahmias Y.	Engineering	Implantable materials	Microdevices for liver tissue engineering
Rubinstein A	Pharmacy	Biopharmaceutics/ diagnostics	1. Real time detection of cancer biomarkers by nano-biomaterials 2. Targeting inflammation by nano-immunoliposomes
Shoseyov O.	Agriculture, Food & Environment	Implantable materials/ Diagnostic Tools	Nano bio-composites for intervertebral disc repair

Publications in Nanomedicine in the past year

1. "Spatiotemporal controlled delivery of nanoparticles to injured vasculature", J.M. Chan, L. Zhang, R. Tong, D. Ghosh, W. Gao, G. Liao, K.P. Yuet, D. Gray, J. Rhee, J. Cheng, G. Golomb, P. Libby, R. Langer, and O.C. Farokhzad, Proc. Natl. Acad. USA, **107**, 2213-2218 (2010).
2. "Novel Double Coated Nanocapsules for Intestinal Delivery and Enhanced Oral Bioavailability of Tacrolimus", T. Nassar, A. Rom, A. Niska and S. Benita, a P-gp Substrate Drug, J. Control. Rel., **133**, pp 77-84 (2009).
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4. "A new double emulsion solvent diffusion technique for encapsulating hydrophilic molecules in PLGA nanoparticles", E. Cohen-Sela, M. Chorney, N. Koroukhov, H D. Danenberg, G Golomb, J. Controlled Rel., **133**, 90-95 (2009).
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9. "Oxygen-mediated enhancement of metabolism, functional polarization, gene expression, and drug clearance in co-cultures of primary hepatocytes", S. Kidambi, R. Yarmush, E. Novik, P.B. Chao, M.L. Yarmush, Y. Nahmias, *Proc Natl Acad Sci USA* **106**(37):15714-9 (2009)
10. "Organ Engineering: Decellularized Liver Matrix and the Generation of a Transplantable Recellularized Graft", B. Uygun, A. Soto-Gutierrez, H. Yagi, M.L. Izamis, C. Shulman, J. Milwid, Y. Nahmias, A. Tilles, F. Berthiaume, M. Hertl, M.L. Yarmush, K. Uygun. *Nature Medicine* accepted
11. "Sustained delivery and efficacy of polymeric nanoparticles containing osteopontin and bone sialoprotein antisenses in rats with breast cancer bone metastasis",V. Elazar, H. Adwan, T. Bäuerle, K. Rohekar, G. Golomb, M.R. Berger. *Int. J. Cancer*, **126**, 1749–1760 (2010).
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 24. "Electropolymerized tricopolymer based on N-pyrrole derivatives as a primer coating for improving the performance of a drug-eluting stent", Okner R, Shaulov Y, Tal N, Favaro G, Domb AJ, Mandler D. *ACS Appl Mater Interfaces*. 2009;**1**(4):758-767.
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 27. "Solution X-Ray Scattering Form Factors of Supramolecular Self-Assembled Structures", Szekely P, Ginsburg A, Ben Nun T, Raviv U. *Langmuir*. 2010;**26**:13110-13129.

Patent applications in the drug-delivery related field:

1. "pH sensitive biodegradable polymeric particles for drug delivery", A.F. Radovic-Moreno, R.S. Langer, W. Gao, G. Golomb, O.C. Farokhzad, M. Tanner, H. Lockhart, (US patent application 61/212,989, 2009).
2. "Microspheres Comprising Nanocapsules Containing a Lipophilic Drug", S. Benita, A. Rom, T. Nasser, EP Pat 2026771; US app 12/219,540; Canadian app 2,639,921 ; AU app 2007206582; Japanese app 2008-551954; Israeli app 192998; Indian app
3. "Nanoparticles for targeted delivery of active agents to the lung", J. Borlak, S. Benita, O. Harush-Frenkel, N. Debotton, N. Karra EP application 08075267.8. (April 2008) + PCT app PCT/EP2009/002513 (March 2009)

4. "Methods for selecting cationic or anionic liposomes for a treatment of mucosa membrane and kit comprising the same", Barenholz Y., Rubinstein A. and Jubeh T., EP Patent 1694298, 2010, US Patent application 10/578,090. Enabled.
5. "Device for in vivo detection of a cancer biomarker", Rabinovitz E., Rubinstein, A., Khazanov E., Azab A., Yavin E., Barenholz Y. and Emmanuel N., US Application, 2009.
6. "NIR fluorescent nanoparticles for targeted in vitro, ex vivo, in situ and in vivo imaging applications", L. Larush, E. Portnoy, P. Lazarovich, S. Lecht, and S. Magdassi, Preparation of FDA-approved US Prov. 61/240,367 (2009).
7. "pH sensitive biodegradable polymeric particles for drug delivery", A.F. Radovic-Moreno, R.S. Langer, W. Gao, G. Golomb, O.C. Farokhzad, M. Tanner, H. Lockhart, (US patent application 61/212,989, 2009)

4. Research infrastructure

Researchers and laboratories involved in the Nanomedicine focal area are distributed in the 3 campuses of Faculty of Medicine (Ein Kerem), Faculty of Science (E. Safra, Givat Ram) and Faculty of Agriculture (Rehovot). Thus these researchers enjoy the top facilities of the HUJI. Nanomedicine focal area researchers participate in the steering committees of the The Harvey M. Krueger Family Center for Nanoscience and Nanotechnology (E. Safra, Givat Ram), and use the cutting edge facilities for forefront research. A central focus in the coming years activity will be to enhance the joined and collaborative activity among these top level groups.

5. Industrial Collaborations / external grants

The scientific activity in this focal area is constantly feeding up and being quickly transferred to technology and commercial applications. HUCNN researchers are playing a major role in emergent areas of nanoscale drug delivery platforms. Liposomes containing a cytotoxic drug - Doxil®, was invented by Profs. Barenholz and Gabizon. This drug is considered to be the first nanotechnology drug carrier system worldwide. Another example is Cationorm®, a cationic nano-emulsion invented by Prof. Simon Benita for moderate dry eye treatment. In Shoseyov group, the biosynthesis and production of collagen in plants has emerged into a public company (CollPlant). A large number of clinical trials are underway and are raising the interest in drug nano-delivery systems. An Israeli biotech company has been established based on Golomb's IP (Biorest), and the novel nanomedicine is under phase II clinical studies (BLAST). Furthermore, investigators are attempting to reformulate and add new indications to existing blockbuster drugs to maintain a reasonable scientific and economic growth rate. The research groups in the focal area of Nanomedicine outlined above are supported by prestigious international grants.

6. 2011 targets in Nanomedicine

Research will continue in the 3 major sub-areas of Biopharmaceutics, Implantable Materials and Diagnostic Tools (see researchers' reports, below). The strongest and particular focus is on the targeted drug delivery aspects. The future of nanomedicine will depend on rational design of nanotechnology materials and tools based around a detailed and thorough understanding of biological processes rather than forcing applications for

some materials currently in vogue. This is the basis of Nanomedicine research at HUJI. A central emphasis will be on the quick transfer of scientific discoveries to patents, companies and commercial applications.

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1. Foundation ES. ESF Forward Look on Nanomedicine. *European Science Foundation* 7 2005.
2. Farokhzad OC, Langer R. Nanomedicine: developing smarter therapeutic and diagnostic modalities. *Adv Drug Deliv Rev.* 2006;58(14):1456-1459.
3. Jotterand F. Nanomedicine: how it could reshape clinical practice. *Nanomedicine (Lond).* 2007;2(4):401-405.
4. Moghimi SM, Hunter AC, Murray JC. Nanomedicine: current status and future prospects. *Faseb J.* 2005;19(3):311-330.

Focal Area: Nanomaterials

1. Name: *Nanomaterials for industrial and medical applications.*

Focal area leader: Prof. Oded Shoseyov

Introduction:

Biomaterials can generally be produced either naturally by living organisms, by genetically engineered organisms, or be synthesized in the laboratory using a variety of chemical approaches utilizing metallic components or ceramics. Biomaterials are often used and/or adapted for a medical application, and thus comprise whole or part of a living structure or biomedical device which performs, augments, or replaces a natural function. Such functions may be benign, like being used for a heart valve, or may be bioactive with a more interactive functionality such as hydroxy-apatite coated hip implant. Biomaterials are also used every day in dental applications, surgery, and drug delivery. Biomaterials in different form and shape often contain active pharmaceutical that can be placed into the body, which permits the prolonged release of a drug over an extended period of time. A novel direction of biomaterials is their use in non-conventional functions. A first direction for such applications is the use of bio-organic/inorganic hybrids as components of electronic circuitry, various sensors (gases, homeland security, bio-sensors), a field termed nano-bioelectronics. Another direction is the development of bio-inspired systems and processes for the synthesis and production of composite materials in military as well as textile industries, for various coating applications.

At the Hebrew University HUCNN, biologists, physicists, materials scientists, chemists and engineers are currently focused on studying the nanostructure and assembly of biomaterials in natural and synthetic conditions. Understanding the processes in which living organisms are capable of regulating the growth and assembly of biomaterials from the nano to the macro-scale will lead to significant scientific advances, development of novel synthesis and fabrication technologies for nano-structured biomaterials and biocomposites that will find applications in the medical and industrial arena.

2. Uniqueness

Research activity at HUJI nano-center will focus on development of novel methods to produce, assemble and characterize nano-structured biomaterials for industrial and medical applications. Members of the center combine unique know-how and intellectual property position in composition of matter, synthesis, fabrication and use of certain biomaterials, and medical devices. Among others it includes polymeric proteins such as recombinant collagen, gelatin, resilin, spider silk, cellulose nano-crystals, thermo-responsive polymers, conductive polymers, fluorescent nano-crystals, nano-liposomes, and nano-capsules.

There are many promising applications in use of nano-biomaterials as instruments for analysis (lab-on-the-chip approach). Major areas of research at HUCNN include microbial-based nanosensors, functional organic NP for metallic devices, electrochemical coating of metallic devices, microdevices for liver tissue engineering, supramolecular self-assembled nanostructures of biomolecules, genetic engineering of self-assembled proteins for displaying NP, nano bio-composites for intervertebral disc repair, and neuro-electronic hybrid systems.

These activities benefit from the expertise of HUCNN members in advanced methods to study nano-biomaterials self assembly such as X-ray scattering, AFM, and high-resolution EM. The strong existing collaboration between, biologists, chemists, physicists and engineers at the HUCNN is a strong point for the success of interdisciplinary research in biomaterial science. Indeed, some of the members already demonstrated their ability to lead such interdisciplinary research to successful companies (i.e. CollPlant, Fulcrum Materials) and products (i.e. DoxilTM, Glass inkjet inks).

The enhancement of the collaborations and joint activity between the exact sciences wing (physics-chemistry-engineering) of the center and the life sciences wing (biology-medicine-pharmacy-agriculture) of the center will be a major flagship for this focal area in the coming years.

Three central directions compose the activity within this focal area:

1. Biomaterials for industrial applications: composite materials with enhanced functionality and bio-compatibility.
2. Diagnostics and sensing using bio-materials.
3. Nano-bioelectronics: non-conventional integration of biomaterials as bio-templated systems for electronic application, bioelectronics sensors, and for interfacing with neurons.

3. Participating groups:

The table below includes participating groups and their activities in the Biomaterial focal area:

Name	Faculty/ Institute	Biomaterials Focal Area	Research Topics
Avnir D.	Chemistry	Biomaterials for industrial applications	1. Sol-gel biomaterials for cosmetics 2. Bioactive enzyme-metal composites
Balaban N.	Physics	Diagnostics and sensing	1. Microfluidic devices for analysis of single cells 2. Automated analysis systems for single bacteria
Barenholz Y.	Medicine	Biomaterials for industrial applications	Liposomes for articular joints
Banin U.	Chemistry	Diagnostics and sensing	Fluorescence tagging of biomaterials with nanocrystals
Belkin S.	Life Science	Diagnostics and sensing	Microbial-based biosensors
Domb A.	Pharmacy	Biomaterials for industrial applications	1. Antimicrobial NP 2. NP for metal devices coating
Golomb G.	Pharmacy	Biomaterials for industrial applications	NP and liposomes for immuno-modulation
Magdassi S.	Chemistry	Biomaterials for industrial applications and diagnostics	Functional organic NP for bio imaging and cosmetics
Mandler D.	Chemistry	Biomaterials for industrial applications and diagnostics	Electrochemical coating of metallic and medical devices
Nahmias Y.	Engineering	Biomaterials for industrial applications and diagnostics	Fabrication of engineered biostructures on microfluidic devices
Raviv U.	Chemistry	Biomaterials for industrial applications	1. Supramolecular self-assembled nano-structures of biomolecules

			2. Bio-molecular structure and intermolecular interactions
Shoseyov O.	Agriculture, Food & Environment	Biomaterials for industrial applications/ bio-inspired composites	1. Genetic engineering of self-assembled proteins for displaying NP 2. Production of human recombinant Type I collagen in transgenic plants 3. Production and polymerisation of recombinant resilin 4. Production and fiber assembly of recombinant spider silk 5. Production and assembly of composites made of nano-crystalline cellulose.
Paltiel Y.	Engineering	Nano-bioelectronics	Self assembly of nano-biomaterials for non-invasive optical implant detection.
Porath D.	Chemistry	Nano-bioelectronics	1. Bio-templated systems for nanoelectronics: Protein/DNA/nano-particle hybrids 2. Investigation of bioprocesses using physical tools
Spira M.	Life Sciences	Nano-bioelectronics	Neuro-electronic hybrid systems
Vaknin A.	Physics	Diagnostics and sensing	Biological sensors
Willner I.	Chemistry	Nano-bioelectronics/ diagnostics and sensing/ biomaterials for industrial applications	1. Biocatalytic growth of nanoparticles 2. DNA nanostructures for machinery, logic and sensing
Yitzchaik S.	Chemistry	Nano-bioelectronics	Conducting polymers coated carbon nanotubes

Publications in biomaterial research in the past year

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26. "A Comprehensive, Computationally Accelerated, Structural Analysis Tool of Solution X-ray Scattering from Supramolecular Self-Assemblies", T. Ben Nun, A. Ginsburg, P. Szekeley and U. Raviv 2010. X+ :. *J. Appl. Cryst.* **43**, Advanced online.

Patents in the Biomaterial related field in the past few year:

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2. Lapidot S., Meirovich S., Siegel D. and Shoseyov O. (2008). Composites made of polymeric proteins and polysaccharides. US Patent 61/071,968 pending
3. Shoseyov O., Baneth G. and Lapidot S. (2008). Resilin and Tick Cuticular Protein as Targets for Vaccination Against Ticks US Provisional
4. Shoseyov O. and Dgani, O. (2008). Methods to process collagen. US provisional patent application.
5. Cohen Ben-Lulu G., Grimberg E., Heyman A., Medalsy I., Porath D., Shoseyov O. and wolf A. (2009). Use of SP1 in generating composite materials. US provisional patent application.
6. Shoseyov O. and Yaari A. (2009). Ordered fibers made of liquid crystals. US provisional patent application.
7. Spira, M., Yitzchaik, S., Shappir, J., Bartic, C., and Borghs, G., "Micro-nails for use in electrical interaction with cells" Application Serial No. PCT/IL2008/000313 (March 09, 2008).

4. Research infrastructure

The laboratories of the PIs in this focal area have advanced equipment and infrastructure to conduct modern biomaterial research. The infrastructure of the HUCNN adds an important source that will assure state of the art research in this focal area.

5. Collaboration with Industry:

CollPlant Ltd was established on a technology developed at the laboratory of Shoseyov. The company develops implants made of bio-materials and its proprietary human recombinant type I collagen for orthopedic, and wound healing.

Fulcrum Materials Ltd. was established on a technology (self assembled stable ring protein- SP1) developed at the laboratory of Shoseyov. The company produces SP1-carbon nanotube grafted fabric for the defense, transportation and aviation industry.

6. 2011 plan: targets, milestones

We aim to develop novel nano structured biomaterials for medical and industrial applications.

1. Nano crystalline cellulose (NCC) will be used to make foams and aerogels. These materials may be used to prepare bio-composite materials for the transportation, air and space, construction and medical industries.
2. Recombinant polymeric proteins (collagen, gelatine, resilin, spider silk) will be used to develop new scaffolds for drug delivery and regenerative medicine (orthopaedic, wound healing, cardio-vascular).
3. Protein-NP hybrid molecules will be developed for imaging applications.
4. Conducting bio-polymers and implantable electrodes.

Appendix A

Nanoscience and Nanotechnology TDM Program, fourth year

INDICATORS¹

		Since 1.1.10	Since beginning of TDM Program 1.1.07	Planned for 2011
1	Number of world-class leading scientists recruited as faculty members	2	12 ²	2
2	Number of fellow scientists/post-docs (steady state ³)	66	56	~ 55
3	Number of Ph.D students (steady state ³)	173	159	~ 160
4	Number of M.Sc. students (steady state ³)	185	169	~ 160
5	Number of published scientific articles (no redundancies, please)	183	740	~ 180
6	Number of published articles resulting from cooperation between the universities	48	185	40
7	Number of cooperation projects with the industry: Magnetons, Nofar, participation in MAGNET consortia, defense projects, with industries in Israel and abroad, etc. (steady state ³)	42	40	~ 40
8	Number of applied patents	75	185	50
9	Number of approved patents	24	68	15
10	Number of "success stories": patents licensed, patents/IP applied by start-ups, etc.	14	52	10
11	Investment in basic nano-equipment (\$ K ⁴) (ordered)	3,000	16,500	2,000
12	Investment in new facilities (\$ K ²)	575	5,050	720
13	Number of recruited nano-equipment operators/technicians	2	10 ²	0
14	Average use of equipment (price above \$500 K) by institute members, % of 24 hrs ⁵	33%	26%	~ 30%
15	Average use of equipment (price above \$500 K) by outsiders, % of 24 hrs	8%	5%	~ 10%
16	External grants obtained for NN R&D (in K NIS)	51,000	160,000	55,000

¹ All figures in this table are based on 44 personal activity summaries for 2010, provided by the HUCNN members, as compared with the data used in the 2008-9 Activity Report which was based on 42 summaries.

² Since the beginning of the project in 2005

³ Steady state figures are for 2nd column reflect the numbers reported last year

⁴ Expenses and liabilities converted from NIS at the rate of 4 NIS/\$

⁵ For the period of 1.10.2009 – 30.9.2010, mean value for the UNC HR-SEM and for the UNF e-Line system, based on 230 working days/year for 12 month. Summary of hours charged, doesn't include hours of training, consulting, method's development, sample preparation, etc. Most of the heavy equipment requires operator's assistance.

Appendix B

Members of the Center for Nanoscience and Nanotechnology

	Name & e-mail	Faculty/Institute	Research Interests
1	Abu-Reziq Raed raed@chem.ch.huji.ac.il	Chemistry	Design and construction of nano-catalytic systems; sol-gel processes for delivery of active chemicals, for pharma and agriculture applications.
2	Asscher Micha asscher@fh.huji.ac.il	Chemistry	Nano catalysis: size dependent thermal and photo-induced catalysis over nanometer-range; metallic clusters over well defined oxide surfaces
3	Avnir David david@chem.ch.huji.ac.il	Chemistry	Nanoporosity; hybrid nanocompositions and nanoparticles; very thin films in sol-gel based functional materials and their industrial applications
4	Baer Roi roi.baer@huji.ac.il	Chemistry	Theoretical studies of electron dynamics in molecular electronics and small metallic nanoclusters
5	Banin Uri banin@chem.ch.huji.ac.il	Chemistry	Nanocrystals: synthesis, basic science and applications in materials, energy, optics, electronics and biology.
6	Blum Jochanan jblum@chem.ch.huji.ac.il	Chemistry	Organometallic catalysis
7	Friedler Assaf assaf@chem.ch.huji.ac.il	Chemistry	Protein-Protein Interactions Using Peptides: A Basis For Drug Design.
8	Lev Ovadia Ovadia@vms.huji.ac.il	Chemistry	Sol-gel chemistry; small molecule organogels; hydrogen peroxide induced gelation
9	Magdassi Shlomo magdassi@cc.huji.ac.il	Chemistry	Synthesis and stabilization of metallic and organic nanoparticles
10	Mandler Daniel mandler@vms.huji.ac.il	Chemistry	Localized chemistry and electrochemistry
11	Marom Gad gadm@vms.huji.ac.il	Chemistry	Graphite nanoparticle-based polymeric nanocomposites
12	Porath Danny porath@chem.ch.huji.ac.il	Chemistry	DNA-based and SP1-based nanoelectronics
13	Raviv Uri raviv@chem.ch.huji.ac.il	Chemistry	Bio-molecular structure and intermolecular interactions
14	Reches Meital mreches@chem.ch.huji.ac.il	Chemistry	Biomolecular self-assembly for design of self-assembled peptides and composite materials.
15	Reisfeld Reneta renata@vms.huji.ac.il	Chemistry	Science and technology of sol-gel based glasses
16	Sasson Yoel ysasson@vms.huji.ac.il	Chemistry	Stabilized metallic nanoparticles as process and environmental catalysts
17	Shenhar Roy roys@chem.ch.huji.ac.il	Chemistry	Design of specialized block copolymers for nanotechnological application
18	Willner Itamar willnea@vms.huji.ac.il	Chemistry	Nanobiotechnology and nanoparticle-functionalized surfaces
19	Yerushalmi Roie roie@chem.ch.huji.ac.il	Chemistry	Synthesis of nanostructures and understanding of unique reactivity characteristics related to the nanoscale
20	Yitzchaik Shlomo sy@cc.huji.ac.il	Chemistry	Science and technology of nanolayers
21	Balaban-Questembert Nathalie nathalieqb@phys.huji.ac.il	Physics	Soft lithography microfluidics for the quantitative study of single cell
22	Balberg Isaac balberg@vms.huji.ac.il	Physics	Nanostructured semiconductors and metal/insulator composites
23	Eisenberg Hagai hagaie@huji.ac.il	Physics	Quantum optics with multi-photon states
24	Felner Israel israela@vms.huji.ac.il	Physics	Superconductivity and magnetism of amorphous carbon; Fe-As superconductors

Members of the Center for Nanoscience and Nanotechnology

	Name & e-mail	Faculty/Institute	Research Interests
25	Gazit Doron doron.gazit@mail.huji.ac.il	Physics	Nanostructure of Graphene – a monolayer of Carbon atoms – and its implications. Structure of physical crystalline membranes in condensed matter and bio-physics
26	Katz Nadav katzn@phys.huji.ac.il	Physics	Superconductivity at the nano-scale; material research into dielectrics at ultra-low temperatures
27	Millo Oded milode@vms.huji.ac.il	Physics	Nanostructured semiconductors, superconductors and composite materials
28	Rapaport Ronen ronenr@phys.huji.ac.il	Physics & Engineering	Nanophotonics
29	Sa'ar Amir saar@vms.huji.ac.il	Physics	Science and technology of silicon based nanostructures
30	Schiller Avraham avraham@phys.huji.ac.il	Physics	Strong electronic correlations in semiconductor nanostructures and on metallic surfaces
31	Vaknin Ady avaknin@phys.huji.ac.il	Physics	Biological sensors
32	Agranat J. Aharon agranat@cc.huji.ac.il	Applied Physics & Engineering	Optoelectronic computing laboratory
33	Feldman Yuri yurif@vms.huji.ac.il	Applied Physics & Engineering	Dielectric response of complex systems at mesoscale
34	Levy Uriel ulevy@cc.huji.ac.il	Applied Physics & Engineering	Nanophotonics and optofluidics
35	Lewis Aaron lewisu@vms.huji.ac.il	Applied Physics & Engineering	Confining, manipulating and analyzing light materials in nanometric dimensionalities
36	Marom Dan danmarom@cc.huji.ac.il	Applied Physics & Engineering	Waveguides, nano-optics
37	Nahmias Yaakov ynahmias@cs.huji.ac.il	Bioengineering	Biomedical engineering: Microdevices for Liver Tissue
38	Paltiel Yossi paltiel@cc.huji.ac.il	Applied Physics & Engineering	III-V semiconductors; device nano physics ; nano process; MOVPE and MBE growth; optoelectronics; single photon detector
39	Rubinsky Boris rubinsky@cs.huji.ac.il	Bioengineering	Bioengineering, heat transfer material processing, biotechnology and cryogenics
40	Shappir Joseph shappir@cc.huji.ac.il	Applied Physics & Engineering	Physics and technology of electronic and electro-optic silicon devices with nanoscale dimensions
41	Barenholz Yechezkel yb@cc.huji.ac.il	Medicine	Encapsulation into nanoscale liposomes: from basic research to applications
42	Belkin Shimshom shimshon@vms.huji.ac.il	Life Science	Microbial-based biosensors
43	Benita Shimon benita@cc.huji.ac.il	Pharmacy	lipid colloidal carriers for drug targeting and improved drug delivery
44	Domb Abraham adomb@md.huji.ac.il	Pharmacy	Molecularly imprinted polymeric nanotechnology
45	Gazit Dan dgaz@cc.huji.ac.il	Dental Medicine	Nanostructured scaffolds and nanobiomechanics in stem cell-based tissue engineering
46	Golomb Gershon golomb@cc.huji.ac.il	Pharmacy	Drug and gene delivery by nanoparticles
47	Rubinstein Abraham avrir@huji.ac.il	Pharmacy	Drug delivery by immunoliposomes
48	Shoseyov Oded shoseyov@agri.huji.ac.il	Agriculture, Food & Environment	Enzymes and proteins that modify and bind to polysaccharides; plant cell wall synthesis; plant biotechnology
49	Spira Micha spira@cc.huji.ac.il	Life Sciences	Neuro-electronic hybrid systems
50	Navon Oded oded@vms.huji.ac.il	Earth Sciences	Nano and micro inclusions in natural diamonds: a key to diamond formation in the Earth's mantle

Appendix C

Scientific and technical staff of the central research units

Name Title	Area of specialization	Phone	e-mail
Unit for Nanocharacterization			
Dr. Inna Popov , Head of UNC <i>Staff Scientist</i>	HRTEM; E-SEM HR-SEM	02 6584808	innap@savion.huji.ac.il
Dr. Vitaly Gutkin <i>Staff Scientist</i>	XPS/ESCA E-SEM; SEM	02 6584799	vitalyg@savion.huji.ac.il
Dr. Anya Radko <i>Staff Scientist</i>	SPM TEM	02 6585212	annar@savion.huji.ac.il
Dr. Vladimir Uvarov <i>Staff Scientist</i>	XRD	02 6586761 02 6584889	vladimiru@savion.huji.ac.il
Evgenia Blayvas <i>Research Engineer</i>	HR-SEM E-SEM	02 6584879	evgeniab@savion.huji.ac.il
Nadya Zaharov (retired 2008, partial) <i>Engineer</i>	sample preparation laboratory	02 6586023	zahaovn@savion.huji.ac.il
Avi Ben-Hur <i>Technical Manager</i>	EM, EDS	02 6584815	avib@savion.huji.ac.il
Moty Levy (partial) <i>Technician</i>	ICT support	02 6584428	motyl@savion.huji.ac.il
Unit for Nanofabrication			
Dr. Shimon Eliav , Head of UNF <i>Staff Scientist</i>	Clean Room Management, Thin Film Process	02 6584062	shimonel@savion.huji.ac.il
Dr. Yigal Lilach <i>Staff Scientist</i>	e-Beam Lithography, Characterization	02 6585249	yigall@savion.huji.ac.il
Noa Mazursky <i>Process Engineer</i>	Photolithography, Chemical Processes	02 6586200 02 6586127	noam@savion.huji.ac.il
Rami Gabay <i>Technician</i>	Thin Film Process, Clean Room Maintenance	02 6585249	ramig@savion.huji.ac.il
Sharon Aharon , M.Sc. student <i>Research Assistant</i>	PECVD	02 6586127	sharon.aharon@mail.huji.ac.il
Doron Greental , M.Sc. student <i>Research Assistant</i>	RIE, RTA, Thin Film Deposition	02 6586127	doron.greental@mail.huji.ac.il

E. Basic Equipment

1. Acquisition of equipment for the Nano Center:

The development of central research infrastructure in nanoscience and nanotechnology, to serve as multi-user facilities for the center members and students, for the university researchers and for industry users, has continued. The facilities are organized in two units:

- The Unit for Nano-characterization (UNC), opened in 2002
- The Unit for Nanofabrication (UNF), opened in 2007.

This year we have upgraded the equipment and the research facilities in both units of the Nano Center. A major research tool that has been purchased and already been installed in the UNC is the **FEI Magellan 400L Ultra-High Resolution Scanning Electron Microscope (UHR-SEM)** combined with the **Oxford Inca 450 Energy Dispersive Spectrometer** (with 20 mm² Si detector, LN free). This system provides a major upgrade to the imaging and analytical capabilities of the UNC, particularly in terms of highly improved resolution at SE (secondary electrons) and BSE (backscattered electrons) modes, and also provides new modes of operation: STEM, low-voltage ($\geq 50V$) imaging, integrated CryoCleaner and PlasmaCleaner, etc). We expect the Magellan system to be another workhorse of the UNC, to be used by many students and researchers for their research needs. In addition, we expect the system to reduce the heavy load on the HR-SEM (the Sirion system) thus shortening the wait time and increasing the availability of these tools. An **additional Oxford Inca 450 EDS** replaced the old EDAX system on the Sirion HR-SEM.

This year we continued to equip the UNF with basic equipment required to address emerging needs of researchers and young PIs recruited under the present program. Many of those young PIs and their students are frequent users of UNF. Major equipment, that has already been purchased and is expected to be installed these days, is a system of atmospheric pressure, high-temperature **furnaces** for oxidation (dry and wet), diffusion and annealing processes. The system will complement the existing thin-film etching and deposition facilities of the UNF (such as RIE, PECVD, evaporator and the E-beam lithography system) to provide a complete line of fabrication tools to create modern electronic, photonic and mechanical devices, from diodes and transistors to optical waveguides, MEMS membranes etc. Few additional tools that have been installed in UNF this year are **wafer dicing** machine, a new **chemical hood for acids**, **vacuum oven** and **ellipsometer**. In addition we have upgraded the **sputtering system** and installed it in the clean room.

2. Extent of use of equipment (by institute members and others)

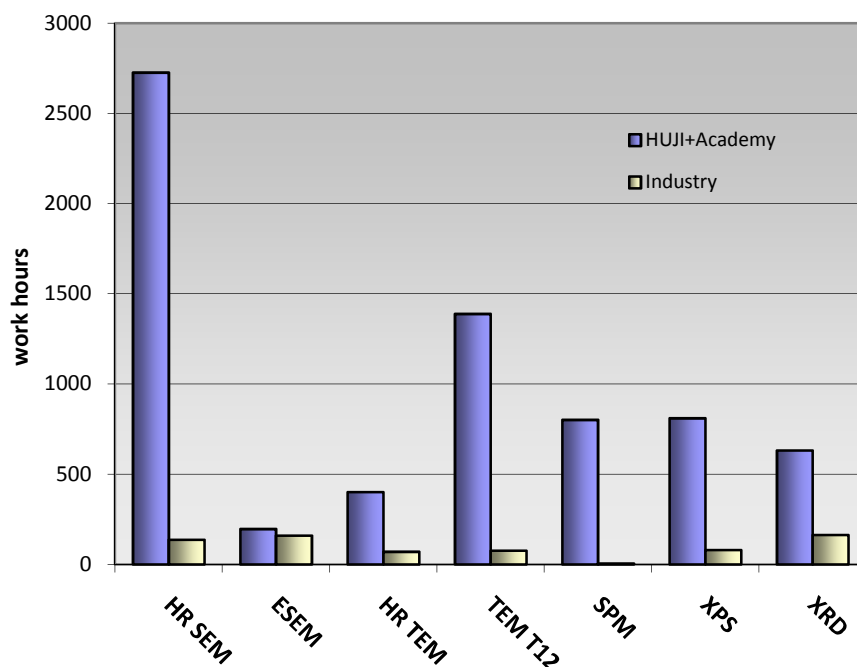
We continued the focus on increasing use of the central equipment. We emphasize training of a large number of independent users, especially in the instruments where this is required and feasible. Notably this includes the SEMs, TEM, AFM, and most of the UNF equipment. This also serves an important educational purpose of the program. Next, we have opened more and more facilities for use over extended hours in the evenings. An additional category of over 20 "super-users" was defined and allowed to work in the center overnight. Finally, we have continued the aggressive pricing scheme to encourage after-hour use by students, offering substantial discounts for evening operation.

At the beginning of 2009, when the wave of the global financial crisis arrived Israel, we decided to cut significantly service tariffs for industry. Our aim was to help industry users, and especially start-up companies, to tide over the financial difficulties and be able to benefit from fruits of the TELEM project. We established very convenient and simple formal agreements, solving the NDA, IP and insurance issues. This provides industry users with easy access to the Nano Center infrastructure (fast-track training, overnight hours, etc.) and the Givat Ram Campus amenities (e.g. lodging in the Faculty Club).

Below we include the summary of usage hours in the UNC and UNF.

The Unit for Nanocharacterization (UNC) activity data presented below covers a 12 months period of November 2009 – October 2010:

UNC - use of equipment, 2009-10



Remarkably, we have witnessed a continued increase in the use of most instruments, thanks to efforts of the UNC staff, headed by Dr. Inna Popov. For example, the use of the HR-SEM has increased from about ~ 2,300 hours in 2009 to more than 2800 hours in 2010 (a growth of about 20%). This substantial rise in use of the microscope (which reflects the increasing number of young faculties and their students, who work in the field of nanoscience and nanotechnology and use these facilities) has led to substantial longer wait time for the HR-SEM. We expect to a significant improvement after the completion of the installation and training period of the new UHR-SEM (Magellan).

Concerning industrial users, in 2009-10 **forty** companies from all over Israel have used the services of the UNC. Among these are well established companies such as TEVA, Freescale Semiconductor, Siemens Solar Systems, Ahava, AVX, Ophir Optronics, Tempo Ceramics and many start-up companies such as Piercell, Acktar, Atlantium, Cima Nano Tech, Xjet Solar, QLight Nanotech.

