



Tel Aviv University

Nano-Revolution

Nano-Revolution

Breakthroughs in nanoscience and nanotechnology possess the power to transform the way we live and how we fight disease • With 300 scientists and 50 new patents, Tel Aviv University's Center for Nanoscience and Nanotechnology pioneers Israel's nano-revolution • The Center is spearheading the development of smart drugs, and laying the groundwork for an innovative Israeli nano-medical industry





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Nano-Revolution

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Cover: Two nano-crystals. A dopant added to the crystal on the right altered its physical properties. Guy Cohen, Dept. of Physical Chemistry, Tel Aviv University

Breaking New Ground

The Center for Nanoscience and Nanotechnology—established at Tel Aviv University in 2000—has pioneered the field in Israel. The Center bolsters the connection between basic research, applied research, and industry. The Center boasts 300 researchers from various disciplines, 70 of whom are internationally recognized leaders in their fields.



“The establishment of the Center for Nanoscience and Nanotechnology at


Tel Aviv University reflects a governmental decision to support nanotechnology as the science of the future,” states Prof. Yael Hanein. Prof. Hanein, Head of the Center, recently took the reins from Prof. Ori Cheshnovsky, who led the Center’s successful growth for seven years. “The Center’s unique model strengthens the interface between basic research, applied research, and industry. We support basic research into the behavior of materials at the nanoscale of atoms and molecules; we encourage the development of scientific discoveries into useful applications; and we make our research infrastructure and scientific output accessible to Israeli industry. True to this principle, we recently launched an exciting national initiative: 11 research groups working together to create the technological foundations for an innovative

nano-medical industry within five years.”

CREATIVE COLLABORATIONS

In the spirit of 21st-century science, the Center supports a multidisciplinary approach. It currently brings together some 300 scientists—including 70 senior researchers who are international leaders in their fields—representing the gamut of disciplines: physics, chemistry, biology, engineering, and medicine. Cross-pollination and collaboration leads to surprising and innovative developments at the Center. A number of researchers are promising Israeli scientists recruited from leading research centers abroad, as part of a national effort to stem brain drain by bringing gifted young scientists home.

The Center is a hub for training a new generation of Israeli nanotechnology researchers who will help shape our world in coming decades. Hundreds



Prof. Yael Hanein:
“The Center is a hub for training a new generation of Israeli nanotechnology researchers.”

of advanced-degree students conduct their research utilizing Center infrastructure and grants. Many of them move on to enrich Israel’s flourishing high-tech and biotech industries.

During the past five years Center scientists were granted over 50 patents in fields such as nano-medicine, electronics, biotechnology, metallurgy, and optics—a number of which are in various phases of product development. Among these discoveries are drug delivery vectors that target injured sites in the body; highly-sensitive biological and chemical sensors;

transparent, flexible conductors for a new generation of electronic appliances; efficient energy storage devices; smart photo-voltaic cells for converting solar energy; and fuel cells that utilize green energy.

The Center welcomes members of industry and serves as a national nanotechnology knowledge base. Its cutting-edge research infrastructure, labs, and scientific developments are accessible to industry. More than 30 leading Israeli high-tech and biotech companies make use of Center services provided by a team of expert engineers and researchers. ●

★ **Prof. Yael Hanein** is Head of the Center for Nanoscience and Nanotechnology; Assoc. Prof., School of Electrical Engineering; and Assoc. Academic Director of TAU’s nano and micro infrastructure. Prof. Hanein, a physicist, leads a research group in neural engineering, developing brain-interfacing nano-devices. She serves as VP for the Israeli startup Nano Retina, developing artificial retinal implants. In 2009 Hanein was elected an outstanding young scientist at the World Economic Forum Young Scientists Conference. She is a member of the Global Young Academy since 2010. In 2012 Hanein was awarded a prestigious grant by the European Research Council (ERC), and appointed member of the Israeli Young Academy.

Five-Year Plan

Prof. Dan Peer, Head of the Laboratory of NanoMedicine, Dept. of Cell Research & Immunology, leads an innovative research effort to develop nanometric drug-delivery systems, designed to address a range of diseases. The project—comprising 11 labs—will build the technological infrastructure for commercial and industrial implementation within five years. The study is already sparking interest from leading pharmaceutical companies.

“Our project, launched in 2012, is an Israeli research effort of unprecedented focus,” states Prof. Peer. “Our goal is to establish the technological infrastructure for nano-medicine within five years—an extremely short period in terms of scientific research. Eleven specially selected research teams (eight from TAU) will develop strategies for a fascinating field: nanoparticles that guide drugs and imaging devices directly to targets inside the body.” The research groups specialize in chemical synthesis & polymers, antibody engineering, the immune system, cell biology, molecular imaging, and cardiology. They examine a wide range of diseases, primarily involving blood vessel deficiency or excess; immune system diseases, such as tumors and blood cancer; heart attacks, inflammatory processes, and viral immune system diseases such as AIDS. The project has received substantial support from the Israel National Nanotechnology Initiative (INNI), a governmental initiative to establish nano research centers in Israel.

Prof. Peer is partnering with TAU colleagues: Prof. Ehud Gazit, Chief Scientist, Ministry of Science, and faculty member, Life Sciences; Prof. Itai Benhar and Prof. Rimona Margalit, Life Sciences; Prof. Doron Shabat and

Prof. Moshe Portnoy, Chemistry; Prof. Ronit Satchi-Fainaro, Medicine; and Prof. Jonathan Leor, Medicine and Sheba Medical Center. Other project members: Dr. Galia Blum, Hadassah Ein Kerem Medical School; Dr. Ayelet David, Ben Gurion University Medical School; and Prof. Shulamit Michaeli, Bar-Ilan University.

DELIVERING DRUGS TO INTESTINAL INFLAMMATION SITES

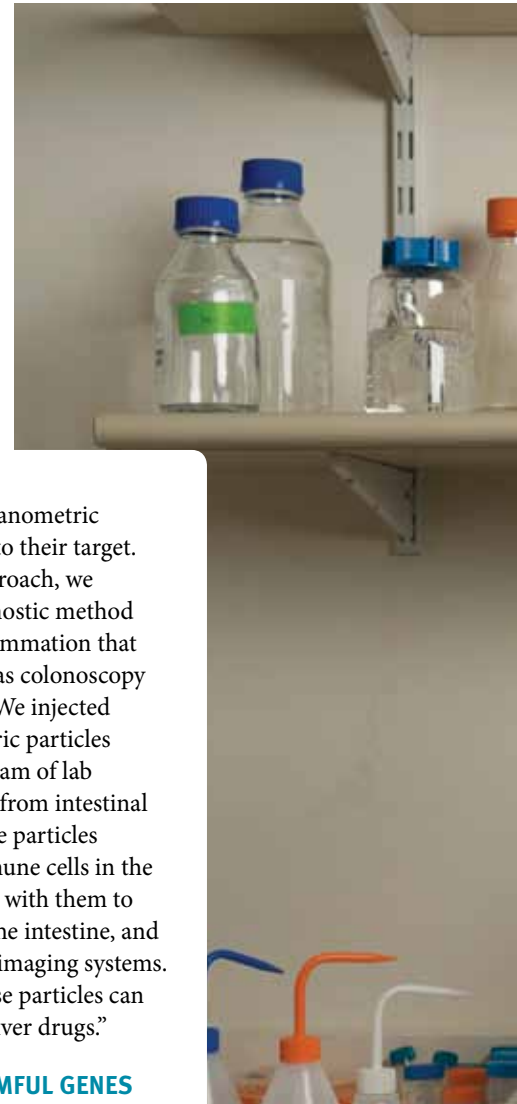
As part of the nano-medical project, Prof. Peer’s research group focuses on inflammatory intestinal diseases, such as Crohn’s disease and colitis. A multidisciplinary team of 22 researchers—engineers, biotechnologists, physicists, biologists, chemists, and a veterinarian—collaborates with doctors and surgeons at Sheba, Rabin, and Tel Aviv (Sourasky) Medical Centers, as well as Snyder Institute for Chronic Diseases, University of Calgary, Canada. “We are developing drug delivery strategies and nanometric diagnostic tools for intestinal inflammation,” explains Prof. Peer. “Our technology is based on antibody-coated nanoparticles. Antibodies recognize immune cells summoned in the bloodstream, and home in on a diseased site. These antibodies can be used as a GPS navigation

system to guide nanometric particles directly to their target. Based on this approach, we developed a diagnostic method for intestinal inflammation that is not as invasive as colonoscopy and gastroscopy. We injected marked nanometric particles into the bloodstream of lab animals suffering from intestinal inflammation. The particles homed in on immune cells in the blood, hitchhiked with them to diseased cells in the intestine, and marked them for imaging systems. By extension, these particles can transport and deliver drugs.”

SILENCING HARMFUL GENES

Prof. Peer and his team are developing nanometric vectors of various types and sizes, adapted to different diseases. Lab-manufactured vectors are based on combinations of biological substances—lipids, sugars, and proteins. Lipids are effective for holding drugs and imaging agents, and a sugar coat prevents particles from sticking to each other. Proteins are used as antibodies and ligands that connect to particles’ surface, navigate to target cells, and assist with cell penetration.

But Prof. Peer is not stopping at smart drug delivery systems. “Many research groups worldwide are developing nanometric drug carriers. My lab is unique in that we





integrate technology *and* biology. A dedicated team of biologists is concurrently looking for the actual drugs. This model grants our research exceptional strength.” Prof. Peer’s biologist research partners are developing revolutionary medicines that, rather than destroying inflamed cells, attempt to transform them into anti-inflammatory cells. Another innovation utilizes highly advanced instruments available at TAU to examine patient tissue samples through deep genetic sequencing technique. They intend to locate damaged genes, examine their RNA, and develop a new kind of drug called small interfering RNA (siRNA) that can silence expression of damaged

genes. Prof. Peer’s group is a world pioneer applying siRNA molecules to manipulate immune cells. In the future, this system will make it possible to tailor personalized medication for individual patients.

Prof. Peer predicts that “based on our research, new technologies and drugs will treat a wide range of illnesses ranging from intestinal inflammations, psoriasis, and arthritis to different types of blood cancer—leukemia, lymphomas, and myelomas. Custom-tailored nano-particles will be created for each disease and each patient. Two startups are already established based on our work: Leuko Bioscience, a



Prof. Dan Peer was recruited from Harvard in 2008 to establish TAU’s Laboratory of NanoMedicine. He is a Visiting Scientist at Harvard Medical School, Boston, and a Senior Affiliate at Methodist Hospital Research Institute, Houston. Prof. Peer has published 60 papers, penned book chapters, and edited two books. He is Editor of three major periodicals on drug delivery systems, and sits on the scientific panel of five journals. He has applied for 40 patents, several of which are licensed by biotech companies. He is scientific advisor to startups and large pharmaceutical companies, in Israel and internationally, and has established two startups, Leuko Bioscience, Boston, and Quiet Therapeutics, Israel.

Boston-based spin-off, focuses on blood cancers and has conducted preliminary human clinical trials with impressive success; and Quiet Therapeutics, an Israeli company focusing on cancer, is expected to reach clinical trial phases in the next two years.” ●

On Target

Drugs we take are oftentimes double-edged swords. They fight the disease agent, but also flood the entire body, adversely affecting perfectly healthy parts of the system. Prof. Itai Benhar's Dept. of Molecular Microbiology & Biotechnology research team is developing targeted nanometric carriers that deliver drugs solely to the sites that need them.

“Targeted drug development is one of the most fascinating fields in medicine today,” says Prof. Benhar. Currently, physicians avoid using certain effective drugs because they are toxic to healthy cells. Targeted drugs will act on selected cells, curing disease with minimal side effects. Our lab is developing modular targeted carriers that can transport drugs to a wide variety of cells.”

TARGETING DISEASE

Prof. Benhar's drug carriers are based on bacteriophages—miniature viruses naturally present in bacteria. Bacteriophages are nanoparticles, which are easy to produce in a simple biological system at low cost, and easy to alter chemically and biologically. Antibodies, which home in on target cells, attach to the bacteriophage by means of genetic engineering. Drug molecules are

chemically and biologically bound to the phages, which are released under controlled conditions. The resulting high concentration of active drug at the diseased site ramps up treatment effectiveness, while minimizing adverse effects on other parts of the body.

INSPIRED BY A NOBEL LAUREATE

The first model for bacteriophages as nanometric targeted drug carriers was presented in 2006 by Dr. Itzhak Yacoby, at the time a doctoral student, and today a faculty member of TAU's Dept. of Molecular Biology & Ecology of Plants. Dr. Yacoby was inspired by a lecture by Prof. Ada Yonath—2009 Nobel Laureate in Chemistry—which addressed the lack of selectivity of drugs acting on the ribosome. Researchers were prompted to find a way to selectively deliver toxic molecules to pathogenic bacteria.

To test their method's efficacy, TAU researchers developed a range of test systems including the antibiotic chloramphenicol; a number of pathogenic bacteria (Staphylococcus aureus, Streptococcus pyogenes, and Escherichia coli); and antibodies that recognize these bacteria. They conducted experiments proving that the technology can treat a wide range of pathogenic target cells.



Our lab is developing targeted drug carriers with a modular structure to transport different types of drugs to a wide variety of target cells.

The Benhar research group—in conjunction with Prof. Nir Osherov, Dept. of Clinical Microbiology & Immunology, Sackler School of Medicine—has examined the method's efficacy with the pathogenic fungus Aspergillus Fumigatus, which causes severe pneumonia in patients with a compromised immune system. “We believe we will soon demonstrate the efficacy of nanometric targeted drug carriers in this model,” concludes Prof. Benhar. ●



Prof. Itai Benhar, faculty member and former Head (2007-11) of the Dept. of Molecular Microbiology & Biotechnology, currently heads the Laura Schwarz-Kipp Institute of Biotechnology. His research team develops technologies for isolating new and enhancing existing antibodies, and integrating them into advanced drug delivery systems and biological sensors. Prof. Benhar has published over 80 papers and book chapters, applied for 10 patents, and serves as scientific advisor to Israeli biotech companies.





Starving Cancer

Malignant tumors cannot develop and metastasize without a supporting network of blood vessels.

Prof. Ronit Satchi-Fainaro's research team at the Sackler School of Medicine is developing nanometric drugs to directly target blood vessels that nourish tumors.



“Angiogenesis—growing new blood vessels from preexisting ones—is a normal phenomenon of fetal development,” explains Prof. Satchi-Fainaro. “In a healthy adult new blood vessels form only under specific conditions, such as following injury, or during menstruation or pregnancy. However, there are at least 70 diseases associated with pathological angiogenesis, among them cancer.” New blood vessels are key to a tumor’s ability to develop and thrive. Blood vessels supply oxygen and nutrients, allowing cancer cells to infiltrate the blood stream, travel to other parts of the body, and metastasize. Studies show that in healthy adults of all ages there are microscopic

foci of dormant tumors, 1–2mm in size, most of which will not become malignant for the simple reason that they are unable to induce new blood vessel growth.

“Tumors remain dormant as long as they do not recruit blood vessels,” asserts Prof. Satchi-Fainaro. “Our core questions are: What causes the change? How does a tumor recruit blood vessels? Is the process reversible? That is, how can we halt blood vessel growth, and put the awakened tumor back to sleep, or, alternatively, how can we keep metastases in their dormant state?” These questions are pivotal to Prof. Satchi-Fainaro’s multidisciplinary group of 15 researchers in chemistry, biology,

engineering, materials science, and medicine.

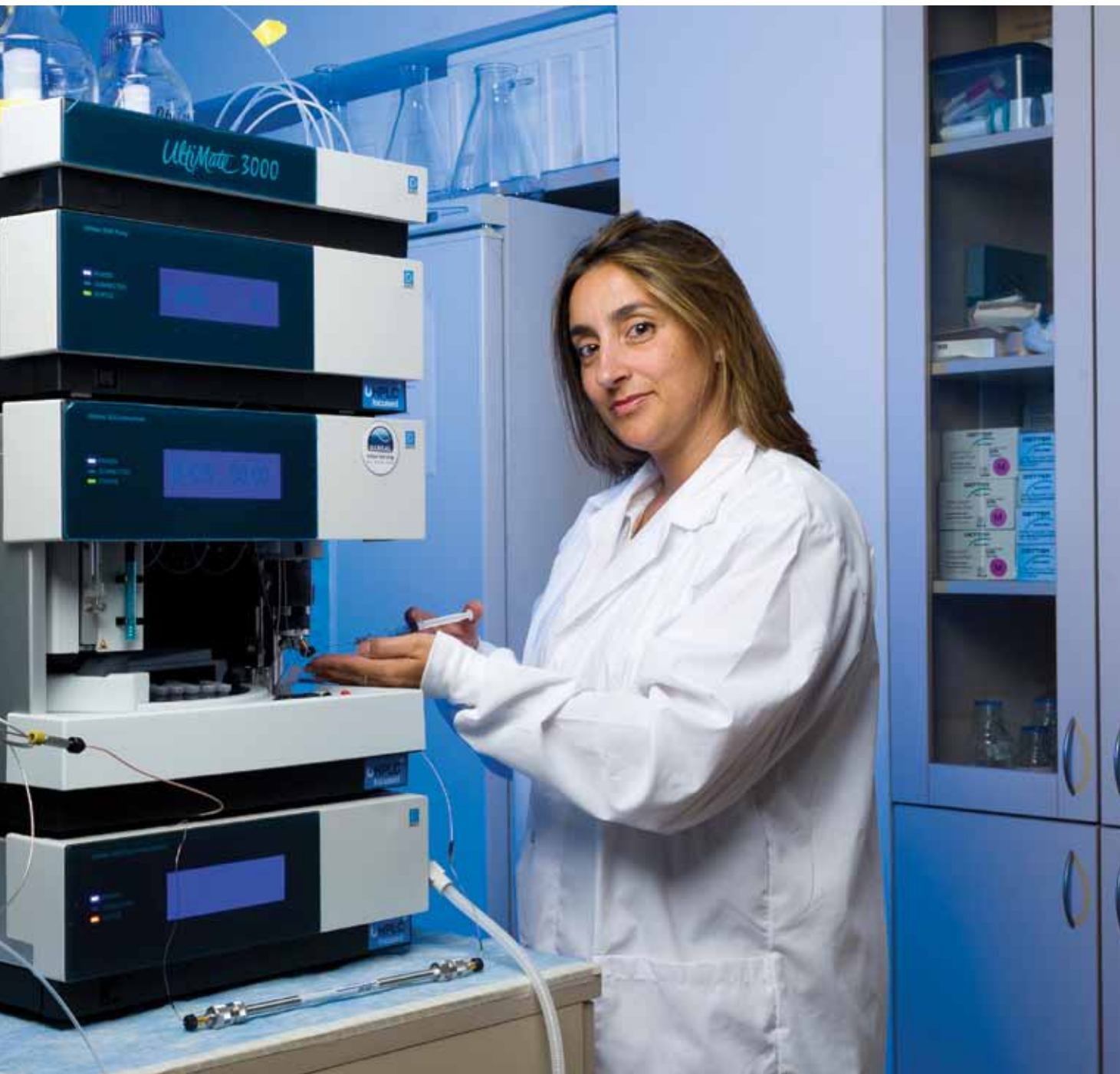
A NANOMETRIC TAXI TO THE TUMOR

Nanometric drug vectors can deliver effective substances directly to the malignant tumor. Nanometric polymer “taxis” roam the bloodstream; they cannot leak from normal blood vessels, however new blood vessels, quickly grown in the infected area, are porous. Vectors leak through, reaching the tumor with a cargo of drugs to inhibit new blood vessel growth; chemotherapeutics and anti-inflammatories; and novel biological substances like miRNA & siRNA to silence cancer-related genes.

Researchers have demonstrated the advantages of nanometrics. First, drug quantities are lesser than those used in chemotherapy—making treatments less toxic, minimizing side effects, and allowing longer periods of use. Second, due to the minute amount and unique mode of cell entry, the cancer is less inclined to develop resistance, so drugs remain effective for longer. Third,



Prof. Ronit Satchi-Fainaro is Head of the Cancer Angiogenesis & Nanomedicine Lab; Assoc. Prof., Dept. of Physiology & Pharmacology, Sackler School of Medicine; and Visiting Prof., Harvard Medical School and Children’s Hospital, Boston. She is an advisor to Israeli and international biotech companies, and President, Israeli Society for Controlled Release. Prof. Satchi-Fainaro is on the editorial board of scientific journals, and has published 50 papers, ten book chapters, and edited two books. She is named inventor on 20 patents, and was awarded prestigious grants and prizes, among them the Fulbright, Rothschild, Wingate, Alon, Young Investigator Award of the European Association for Cancer Research, and Juludan.



Researchers are making a collaborative, comprehensive effort to develop nanometric drug vectors that will deliver effective substances, in minute quantities, directly to the malignant tumor.

combining several drugs—using multivalent polymeric nano-carriers—is more effective than single drug treatment.

“Treatment employing nanometric technology can keep potential tumors in their dormant state, and prevent development of malignant tumors or metastases,” says Prof. Satchi-Fainaro. “This approach can

alter treatment of cancer. People in risk groups, and patients in relatively early stages of illness, or those concerned about recurrence, can receive treatment that is easier to tolerate and free of side effects. The treatment can prevent recurrence of cancer or transform it into a chronic illness that can be lived with, maintaining quality of life for many years.” ●

Marked for Removal

Residual cancer cells can initiate renewed cancerous growth even after the surgical removal of a tumor. Prof. Doron Shabat, Raymond and Beverly Sackler School of Chemistry, applies nanometric technology to develop sensors that will mark malignant cells, so the surgeon can remove each and every cancer cell.

➤ “Surgeons face tough questions when removing malignant tumors: Have they successfully excised all malignant cells? Have they accurately determined the borders of the tumor, so as not to endanger patients by removing healthy tissue?” explains Prof. Shabat. “We are developing diagnostic methods for marking malignant cells, and making them visible to surgeons through optical imaging.”

Prof. Shabat’s research group utilizes nanotechnology to create a unique organic molecule that will act as a sensor when injected into the patient’s body. The sensor will have a switch—a substance that identifies the disease agent, interacts with it, and impels it to emit light at a given wavelength. The surgeon, seeing the light, will be able to identify and completely remove malignant tissue.

The team faces two key challenges: (1) creating a switch that will emit light upon contact with the disease agent; (2) controlling light wavelength, which must be in a range not absorbed or emitted by surrounding tissue. (From 600–900 nanometers, close to

infrared range.) Dr. Shabat’s solution is based on an innovative chemical engineering design for fluorescent molecules. “Up until now, fluorescent molecules were built of two zones: an electron donor zone and an electron acceptor zone,” says Prof. Shabat. “We offer a different approach: we construct a triangle—a molecule with one donor zone and two acceptor zones. The defense team—the switch—is connected to the donor area, and as long as it is in place, no light is emitted. When the switch is removed, an electron passes from the donor to one of the acceptors, which then emits light.” In this manner it is possible to create a modular library of substances for a variety of applications.

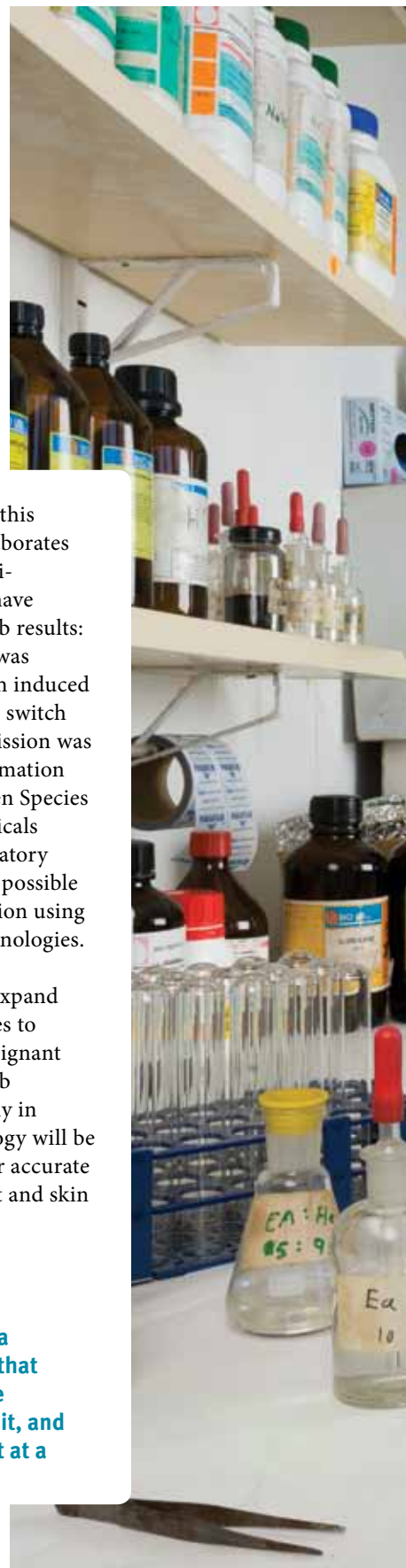
Nanometric carriers are needed to deliver marker molecules

“ Prof. Shabat’s research group utilizes nanotechnology to create a unique organic molecule that will act as a sensor when injected into the patient’s body.

to diagnostic sites. To this end, Prof. Shabat collaborates with Prof. Ronit Satchi-Fainaro. Researchers have obtained significant lab results: a switched-off sensor was injected into mice with induced inflammation, and the switch that prevents light emission was removed at the inflammation site by Reactive Oxygen Species (ROS)—oxidizing radicals typical of the inflammatory condition. It was then possible to view the inflammation using available imaging technologies.

Prof. Shabat seeks to expand the system’s capabilities to identify and mark malignant tumors—initially in lab animals, and eventually in humans. This technology will be particularly helpful for accurate identification of breast and skin cancer cells. ●

“ The sensor will have a switch—a substance that identifies the disease agent, interacts with it, and impels it to emit light at a given wavelength.





Prof. Doron Shabat, Raymond and Beverly Sackler School of Chemistry, leads a research group in bioorganic chemistry. His research has been key to the development of innovative molecular systems for control-release drugs at target sites, biomedical diagnostics, and identifying disease-causing agents. Prof. Shabat has published over 70 scientific papers and has contributed chapters to select books.





Dr. Oded Hod, Raymond and Beverly Sackler School of Chemistry, heads the research team investigating computational nanomaterials. Dr. Hod's group explores physical properties of materials at the nanoscale, and develops computational methods that will make it possible to accurately describe the structural, electronic, and conduction properties of these materials. Dr. Hod is a member of the Lise Meitner-Minerva Center for Computational Quantum Chemistry, Global Young Academy, and Israeli Young Academy. He serves as Israeli team coordinator for the European Graphene project, and TAU's coordinator at CECAM, the Centre Européen de Calcul Atomique et Moléculaire.



Nano-Diamonds and Other Treasures

Substances display surprising physical properties at the nanometric scale. Dr. Oded Hod, Raymond and Beverly Sackler School of Chemistry, applies these properties to a variety of futuristic developments, such as a highly sensitive electronic nose, super-efficient solar devices, and a minuscule guiding system in a mosquito-sized drone.



“At the nanometric scale, substances display surprising physical

properties that fascinate me as a scientist, and that can be applied in innovative ways,” says Dr. Hod. “In my lab, we study minute structures from the single-atom level up to the few-hundred-atom scale. We examine a gamut of materials’ properties, including mechanical, electronic, magnetic, optic, and electrical conductivity.”

Researchers utilize a cluster of more than 300 compute cores to perform complex precision calculations of properties of substances at the nanometric level.

AN ELECTRONIC NOSE

Dr. Hod’s group is developing an ultra-sensitive chemical sensor using graphene—a nanometric carbon structure in the form of a single-atom-thick sheet. This sensor can act as an electronic nose, able to identify airborne substances. An explosives detector of this kind could sniff out a single molecule of TNT, and indicate its presence through changes in conductivity. Researchers are attempting to calculate the precise changes in properties of

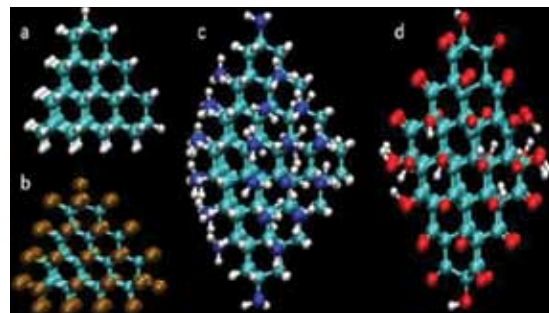
graphene, such as conductivity, which result from the absorption of foreign molecules.

NANO-DIAMONDS

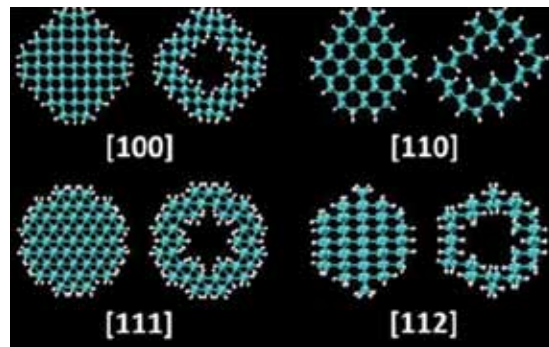
The team examines how to control electrical properties of minuscule structures—silicon nanotubes and nano-diamonds—by chemically binding atoms or molecules to their surface. Silicon nanotubes allow solar devices to utilize a broader range of radiation than existing technologies, thus increasing efficiency. Nano-diamonds can function as precision biological markers, producing imaging and diagnostics with unprecedented quality. Another innovation involves advanced methods for calculating electrical conductivity of individual molecules, paving the way for molecular electronics—a technology in which a handful of molecules replace familiar silicon-based components.

Dr. Hod, in collaboration with Prof. Ernesto Joselevich and Prof. Leeor Kronik, Weizmann Institute, is investigating mechanical properties of boron-nitride nanotubes measuring a few atoms,

in a bid to understand how torsion affects electronic properties of the micro-tube. Their findings can aid in the development of a nanometric gyroscope in mosquito-sized drones. ●



Nano-diamonds with different chemical coatings produce medical imaging & diagnostics of unprecedented quality.



Silicon nano-wires and nanotubes exploit a broader range of solar irradiation.

Physical Reality of Proteins

“Everything is physics,” says Dr. Roy Beck-Barkai. In his lab at the Center, he has built one of the world’s most sophisticated x-ray small angle scattering systems. The goal: discovering simple physical formulae to describe the enormous diversity of biological phenomena. This knowledge will help us to understand disease mechanisms, and develop effective drugs and nanometric drug carriers.



“The world of biology poses a great challenge to physicists,” says Dr. Beck-Barkai, Raymond and Beverly Sackler School of Physics & Astronomy and Raymond and Beverly Sackler Institute of Biophysics. “The physics toolbox was originally defined for relatively simple molecules, whereas biological structures are large, complex, and highly diverse. In our lab we tackle a mission once considered impossible: finding simple physical formulae with a minimal number of parameters to describe the immense diversity of biological phenomena. Our research overlaps between biology and physics, integrating materials engineering, chemistry, and medicine.” Dr. Beck-Barkai’s multidisciplinary group collaborates with TAU researchers, among them Prof. Dan Peer and Dr. Joel Hirsch, Life Sciences; Dr. Yael Roichman, Chemistry; and Dr. Uri Nevo, Engineering.

For Dr. Beck-Barkai, “everything is physics.” Physical forces and laws are responsible for the motion and interactions of all systems in the universe, from galaxies down to the atom. To unlock the properties and behavior of biological materials,

he examines the physical forces operating inside and between them on the nanometric level. “The nanometric world of biology is characterized by spontaneous organization into clusters or complexes composed of biological molecules such as proteins, fatty acids, and genetic material,” he explains. “We gauge physical



Fundamental physical understanding of biological mechanisms on the nanometric level will eventually make it possible to identify the primary cause of disease, and find an effective, targeted treatment, custom-designed for each patient.

mechanisms and intermolecular forces responsible for various phenomena—how molecules communicate, and how they assemble and form new structures. We measure, quantify, and map forces; locate dominant mechanisms; and formulate physical-law systems describing the behavior of materials and explaining biological processes.”

A COMPLEX TECHNOLOGICAL CHALLENGE

To examine the behavior of biological molecules, Dr. Beck-

Barkai faces complex technological challenges: optical microscopes are insufficient for observing such minuscule structures; yet to use tools with nanometric resolution, the biological substance’s environment must be altered to such a degree that the material’s original properties are lost. Researchers now use advanced

nanotechnology techniques to measure the x-ray scattering of biological materials. This allows observation of nanometric clusters inside fluids that simulate the natural environment of the living cell. Dr. Beck-Barkai’s laboratory x-ray scattering system is one of the most sophisticated and advanced of its kind.

Lab researchers examine forces affecting self-assembly of nanometric structures and clusters of proteins, fatty acids, and genetic material. They focus on the physics



Physical forces are responsible for the motion and interactions of all systems in the universe, from galaxies down to the atom.



Dr. Roy Beck-Barkai, Senior Lecturer, Raymond and Beverly Sackler School of Physics & Astronomy, specialized in solid-state physics, and superconductors and physical phenomena in strong magnetic fields as a TAU graduate student. As a research associate of the prestigious Human Frontier Science Program, his interests evolved towards biological substances with the goal of understanding their physical properties. In 2010, upon his return from UC–Santa Barbara as part of the national program to recruit young Israeli scientists, he established an advanced biophysics laboratory at TAU.

of intrinsically disordered proteins. “Most familiar proteins have a typical folding process responsible for their functionality,” explains Dr. Beck-Barkai, “but approximately half of the proteins in our body have functional regions that are not folded. The activity of these proteins is garnering interest, and we are hoping to develop analysis methods to best describe their function in the biological context.” Their work is a basis

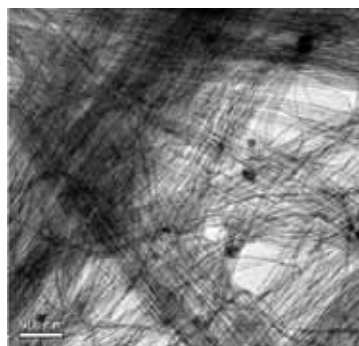
for understanding the clusters of biological molecules associated with disease, and may become a basis for nanometric drug and drug carrier development. “Fundamental physical understanding of biological mechanisms on the nanometric level will eventually make it possible to identify the primary cause of disease, and find an effective, targeted treatment, custom-designed for each patient,” predicts Dr. Beck-Barkai. ●

Absolute Transparency

Imagine flexible monitors that roll up for storage and unroll for use, or solar cells that fold and unfold like camping gear. These ideas may soon materialize thanks to the vision of Prof. Gil Markovich and his Raymond and Beverly Sackler School of Chemistry research team.



“Monitors today are composed of several layers, one of which is a transparent electrode—a conductive layer of a glass-like brittle material,” explains Prof. Markovich, a physical chemist investigating electrical, magnetic, and optical properties of nanomaterials. “The current trend is to create electronic appliances from flexible materials such as polymers (plastic)—which will require transparent, flexible, cost-effective conductors. Research in this field is conducted worldwide and there have been a number of advanced discoveries. But we are developing a conductor that boasts several advantages over the competition, and is designed to



Electron-microscope image: metallic nano-fiber layer that is conductive and almost completely transparent. Fiber thickness is 2-3 nanometers—each fiber contains a mere 10-15 atoms of gold!

precisely answer industry’s evolving needs.”

NANO-SPAGHETTI

Prof. Markovich and his team’s transparent electrodes are fashioned from a web of fine silver and gold nano-fibers—*nano-spaghetti*. Utilizing wet chemistry manufacturing methods, a substrate is dipped in a solution containing gold nanoparticles, which self-align and connect into fibers over the entire surface. This process, termed self-assembly, is typical of certain materials on the nanoscale. The technique’s ease of use—dipping, spreading, or spraying—is its advantage.

“Other technologies, based on graphene or carbon nanotubes, call for separate manufacture of transparent flexible conductor components, after which the components are transferred onto the surface on which the electronic device is built,” says Prof. Markovich. “This is a complex process with many technological hurdles. Our technique is a one-step process, with the conducting mesh self-assembling on the surface.” The technology works for large surfaces, such as wide screens or solar panels. And it is cost-effective: the process occurs on the nanometric

scale, using minute quantities of gold and silver, and is less expensive than existing methods for manufacturing transparent conductors.

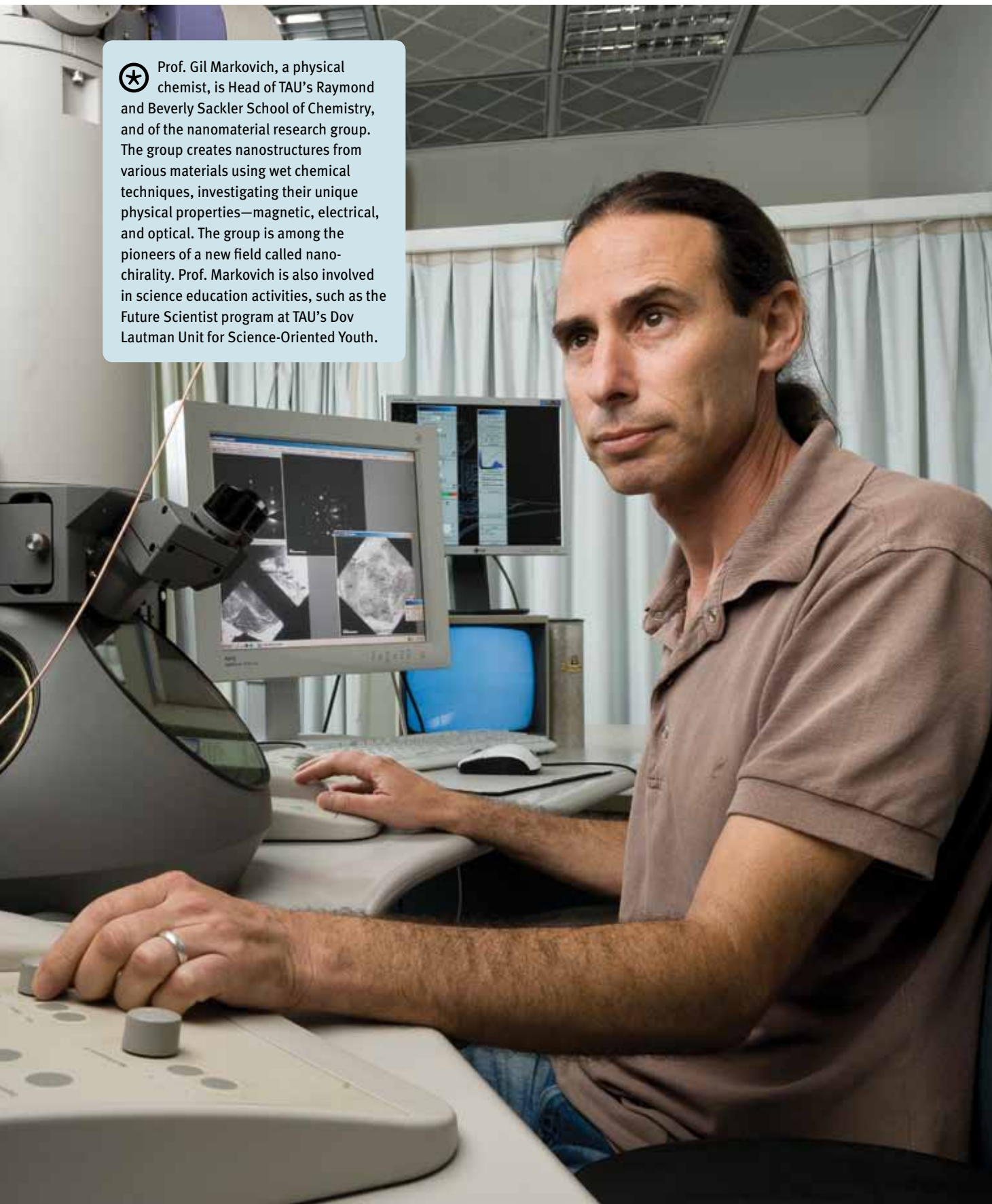
Prof. Markovich is also investigating the optical properties of metal nanostructures. “Light is a form of electromagnetic radiation in a nanometric-scale wavelength. That is why metal nanostructures can serve as nanoantennas that receive and concentrate light waves,” explains Prof. Markovich. Thus nano-spaghetti—employed as antennas on the large surface of a solar panel—can significantly improve solar-cell efficiency.

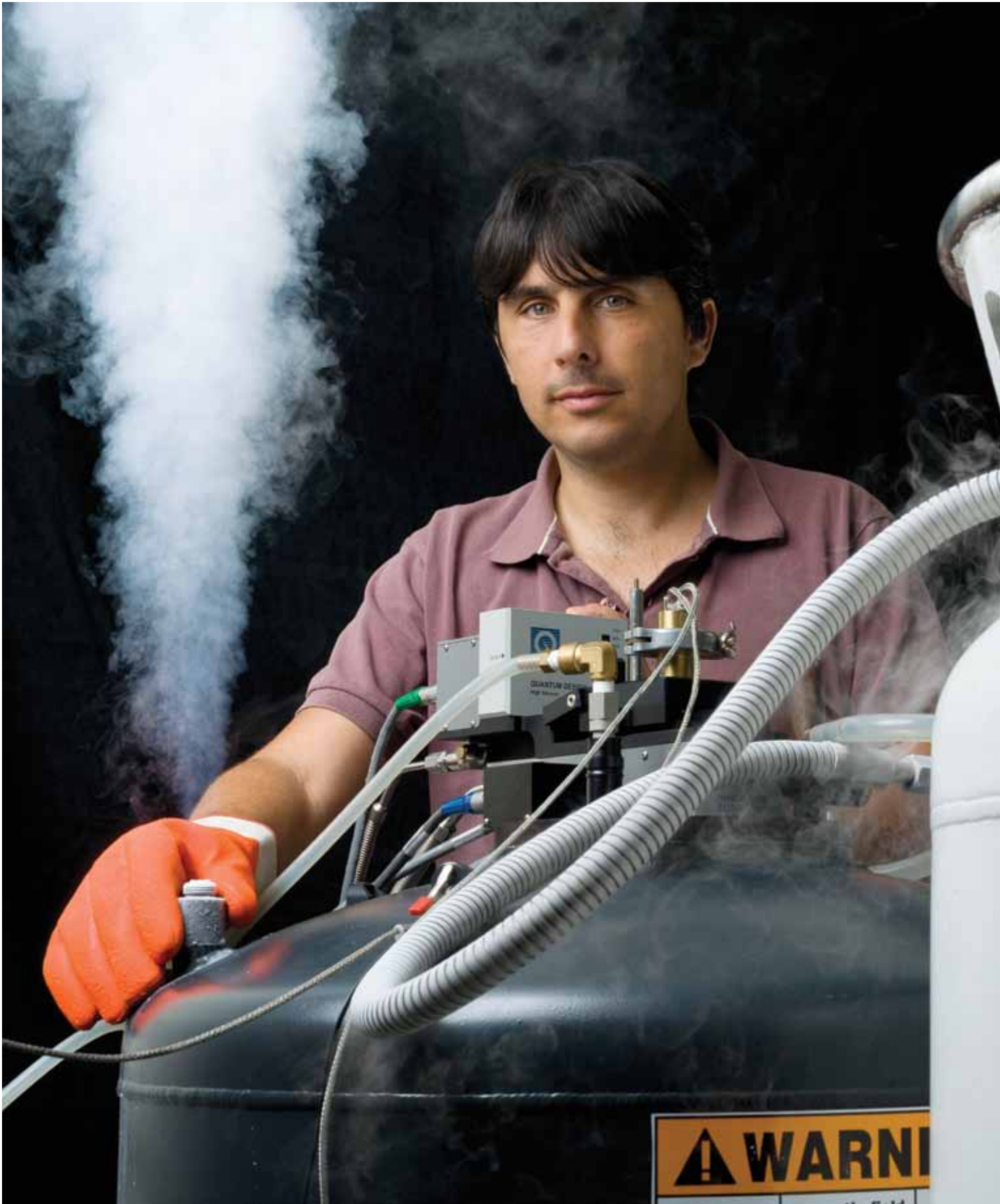
PROMISING APPLICATIONS

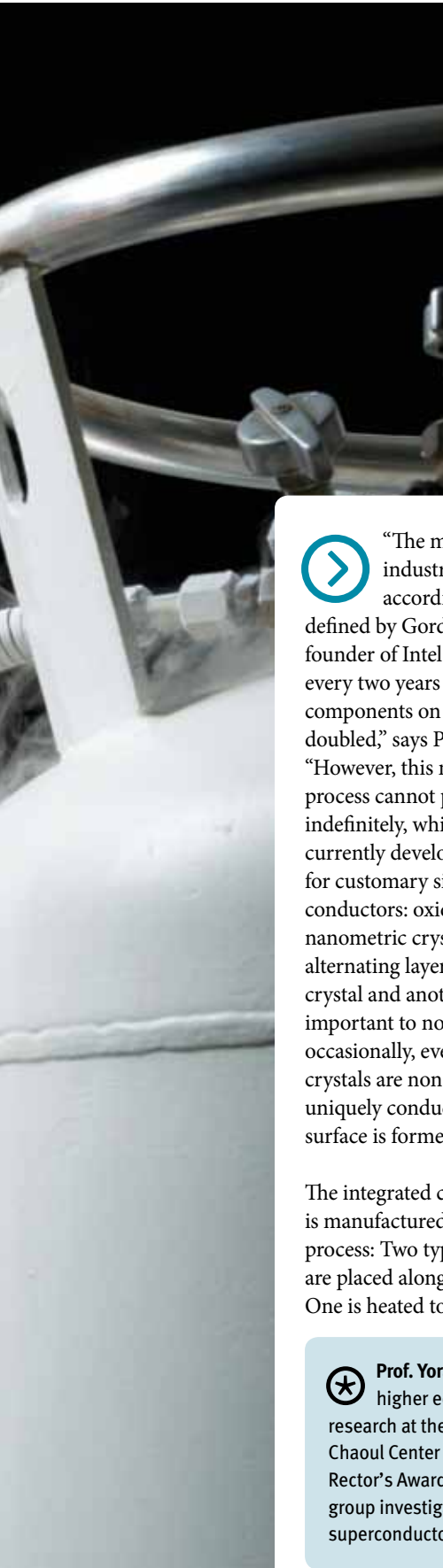
There is a current effort to apply and commercialize nano-spaghetti technology in collaboration with PV Nanocell, Israel. The first phase involves manufacturing sheets of polymer solar cells to be used by campers to produce electricity. In the future, similar sheets could be mass-produced to coat surfaces, walls, etc. Each of the layers, including Prof. Markovich’s transparent conductor layer, will be applied to the sheets using advanced printing methods. Possible future applications include wide, foldable LCD screens. ●



Prof. Gil Markovich, a physical chemist, is Head of TAU's Raymond and Beverly Sackler School of Chemistry, and of the nanomaterial research group. The group creates nanostructures from various materials using wet chemical techniques, investigating their unique physical properties—magnetic, electrical, and optical. The group is among the pioneers of a new field called nano-chirality. Prof. Markovich is also involved in science education activities, such as the Future Scientist program at TAU's Dov Lautman Unit for Science-Oriented Youth.







Electron's Spin

Prof. Yoram Dagan, Raymond and Beverly Sackler School of Physics and Astronomy, bombards one crystal with a laser and heats another to 800°C to create a one-molecule-thick nanometric layer as a possible replacement for silicon. “The electronics of the future will use electron spin properties to store double the amount of information in a single electronic base unit,” he estimates.

➤ “The microelectronics industry has progressed according to principles defined by Gordon Moore, a founder of Intel: approximately every two years the number of components on a given area is doubled,” says Prof. Dagan. “However, this miniaturization process cannot proceed indefinitely, which is why we are currently developing a substitute for customary silicon-based semiconductors: oxide-based nanometric crystals, composed of alternating layers of an insulating crystal and another crystal. It is important to note that, occasionally, even when both crystals are non-conductive, a uniquely conductive nanometric surface is formed between the two.”

The integrated crystal structure is manufactured in a complicated process: Two types of crystals are placed alongside each other. One is heated to 800°C, while the

other is kept at room temperature. Ultra-violet laser signals beam onto the unheated crystal and loosen atoms. The loosened atoms stick to the heated, receiving crystal and assume its structure. A one-molecule-thick surface is obtained. It is essentially a third material integrating properties from the two



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original substances. That is, atoms of one material arrange in a pattern typical of the other material.

“If we wish to create a magnetic, high-polarity layer of atoms, we match a magnetic material with a ferro-electric crystal—a substance with high polarity that is retained even if the external electric field is removed,” explains Prof. Dagan. “My lab is focusing on a pair of

insulating crystals—lanthanum aluminum oxide and strontium titanium oxide—chosen because the surface separating them is, surprisingly, both a superconductor and magnetic.”

As nanometric structures are based on a single layer of atoms,

investigators can observe physical phenomena and effects existing solely on this tiny scale; wave phenomena that effect electron conductivity; and quantum phenomena from theoretical physics, translated into actual behavior of the material (at extremely low temperatures). Prof. Dagan focuses, among other subjects, on magnetic phenomena occurring in the integrated material, particularly spin-orbit interaction. Controlling electron spin by changing its velocity can alter the face of electronics. Prof. Dagan estimates that “electronics of the future will use electron spin properties to store double the amount of information in a single electronic base unit.” ●



Prof. Yoram Dagan is a solid-state physicist. He completed his higher education at TAU, and in 2005, after four years of post-doctoral research at the U of Maryland, joined the TAU faculty. Prof. Dagan directs the Chaoul Center for Nanoscale Materials and Systems and has received the Rector's Award for Excellence in Teaching, among other awards. His research group investigates strong-correlation electronic systems, such as superconductors, magnetic materials, and oxide interfaces.

Quanta on the Nanometric Scale

What transpires in a transistor on the nanometric scale? How can conductivity be controlled in a tiny electronic device? How can nanoparticle-based solar cell efficiency be doubled? Prof. Eran Rabani, Dept. of Chemical Physics, explains: “In the minuscule dimensions of the nanometric world, many effects depend on quantum phenomena.”



“At the close of the 19th century, physicists believed that the basic laws of nature had already been discovered,” explains Prof. Rabani. “Then, in the 20th century, quantum mechanics opened a window onto a new world: that of the smallest scale, that of molecules, atoms, electrons. Quantum mechanics rejuvenated physics, and inspired some of the great 20th-century scientists. Today, we understand that many effects in the nanometric world depend on quantum phenomena. Modern technology, in its drive to minimize electronic components, will face quantum effects. We search for an accurate description of quantum phenomena and their role in nanometric devices.”

A MOLECULAR TRANSISTOR

What happens in a transistor—a basic component of any electronic device—at the scale of a single molecule? How does an electron flow through a molecule? To answer, one must explore and understand the complex problem of conductivity of single-electron devices. Prof. Rabani developed an innovative computational method—based on the path-integral approach

of nanotechnology visionary, Richard Feynman—which accurately predicts a material’s conductivity on the nanometric scale.

NANOMETRIC DOPING

Today’s electronic devices are based on doped semiconductors (e.g., doped silicon). By doping semiconductors, device developers gain optimal control of electronic properties, and adapt them to various applications. But what happens to semi-conductors and dopants on the nanometric scale? “For many years scientists tried unsuccessfully to add impurities to nanoparticles. Without dopants, it is very difficult to apply nanometric semi-conductors to manufacturing minute devices,” says Prof. Rabani.

Prof. Rabani’s research group, together with a group from Hebrew University, has found a solution to this problem. TAU researchers developed a theoretical model explaining the electronic properties of impurities trapped inside a nanometric semi-conductor; their Hebrew University colleagues have put the innovative doping process into practice. New developments grant optimal control of the electronic and optical properties



Prof. Eran Rabani is a faculty member, Raymond and Beverly Sackler School of Chemistry, and was Vice President, TAU R&D. A trailblazer in nanometric complex system theory, he studies self-organization of nanoparticles; energy & charge transfer in nanometric scale; molecular conductivity; and many-body quantum dynamics. Prof. Rabani is active in European & US scientific organizations and a visiting scientist at leading universities, including Harvard, Columbia, Berkeley, and École Normale, Paris. His studies appear in prestigious scientific journals. He is recipient of the Clore, Alon, Rothschild, Fulbright, Berkeley Miller Institute, Yad Hanadiv’s Bruno, Israeli Chemical Society, Friedenberg Fund, Bergmann, Patai, and Elving scholarships and prizes.

of nanometric semiconductors—providing a basis for a variety of applications.

DOUBLING EFFICIENCY

According to Prof. Rabani, “Solar cells work in the following way: When a material absorbs sunlight, electrons shift into an excited state. Each absorbed photon (light particle) excites one electron, and the excited electron leaves a hole behind it. Separating the electron from the hole creates an electric charge, and electrodes connected to the cell collect these charges to create electric current.” A solar cell operating in this manner utilizes



up to 31% of the solar energy it absorbs. The cost of manufacturing solar cells is high compared to the derived benefits; scientists seek to increase efficiency and decrease cost.

“Many scientists attempted to increase cell efficiency using a method called carrier multiplication,” explains Prof. Rabani. “Each photon absorbed

creates two charge carriers instead of one. The theory predicts that the efficiency of such a cell could approach 46%. We have investigated the process of carrier multiplication in nanoparticle-based solar panels and have reached interesting conclusions.” While the carrier multiplication method is inefficient when employing commonly used nanotechnology base panels, researchers enjoyed



In the 20th century, quantum mechanics opened a window onto a new world: that of the smallest scale, that of molecules, atoms, electrons.

success by modifying physical elements. Rabani’s team proved that it is possible to construct solar cells with an efficient carrier multiplication process. ●



Prof. Koby Scheuer, School of Electrical Engineering, is a leading scientist in the area of optics and nano-optics. His research areas are sensors, renewable energy, and optical communications. Prof. Scheuer is a core member and representative of the Iby and Aladar Fleischman Faculty of Engineering in the scientific committee of the Tel Aviv University's Center for Nanoscience and Nanotechnology. He has published over 60 papers and books, and has been granted ten patents.



Luminescent Waves

Nanometric devices can harness light to produce electricity from solar energy, locate pollution sources, and even identify forgeries. **Prof. Koby Scheuer's Nanaphotonics Lab, Dept. of Physical Electronics, School of Electrical Engineering, develops applications for this novel technology.**

“We explore nanophotonics—the interaction of light and particles of matter on the nanometric scale,” explains Prof. Scheuer. “Light-related properties, such as color, change significantly in nanoscale: A solution of gold particles measuring 20 nanometers looks red to us, but reducing the size of the particles would change the solution's color to blue.”



A miniature precision optical gyroscope with navigation capabilities—not in the air or across oceans but in the human body—can steer a drug directly to a particular site in a patient's body.



We examine materials and their properties in nanoscale, and discover a wide range of applications—some are interesting, and some are *even more* interesting.

Geometric shape of particles also affects behavior of nanometric material. We examine materials and their properties in nanoscale, and discover a wide range of applications—some are interesting, and some are *even more* interesting.”

NANOANTENNAS RECEIVE LIGHT WAVES

Among the important developments emerging from Prof. Scheuer's lab, in partnership with Prof. Yael Hanein and Prof.

Amir Boag, is the nanoantenna. This tiny antenna matches the size of wavelengths of infrared to visible light. “An antenna is a metal wire of specific length that receives electromagnetic waves with a suitable wavelength. Electromagnetic waves create an electric current in the wire,” says Prof. Scheuer. “The length of radio waves, for instance, is measured in meters, and antenna size is proportional. The wavelength of visible light, however, is in the nanometric range, and we are developing nanoantennas for light waves.”

Nanometric antennas, measuring between one-half to one micron, are highly efficient: their dimensions allow for the reception of a broad range of visible and infrared light. They can utilize a far greater percentage of solar energy than existing technologies—up to 85% versus 30%. An array of nanoantennas deployed over a large area can create a significant amount of renewable electricity.

NANOSENSORS TO DETECT EXPLOSIVES

Prof. Scheuer and his team are developing super-sensitive detectors that can sense a foreign substance in extremely small quantities. This type of nanometric sensor is itself a light-source—a laser with an extremely low threshold sensitivity that changes color as a result of contact with the substance it is to detect.

Nanometric sensors have many applications such as early detection of water pollution, of minute amounts of explosives, and of chemical and biological toxins.

GYROSCOPE IN A CAPSULE

The gyroscope, invented in the 19th century as a large mechanical form, was utilized to maintain compass stability in seafaring ships. Its range of applications expanded, and today gyroscopes are deployed in aircraft, rockets, tanks, stunt-bikes, and even sophisticated cameras and mobile phones. Researchers in Prof. Scheuer's lab, together with Prof. Benny Steinberg's School of Engineering group, are developing a miniature precision optical gyroscope with navigation capabilities—not in the air or across oceans, but rather, in the human body. Implanted in a capsule, it can steer a drug directly to a particular site in a patient's body.

MINUSCULE DEVICES THAT CAN PREVENT FORGERIES

Another project involves miniature structures that are simple and cheap to mass-produce, and that could potentially be used to prevent forgeries of currency, medications, and more. The nanometric structures, invisible to the naked eye, can be attached to paper currency and identified using a suitable optical reader. A specific reaction of the nanometric structure to the reader's light beam would confirm the authenticity or validity of the product. ●

Energy in the Miniature

As appliances and devices shrink in size, the need for efficient miniature batteries grows. Prof. Emanuel Peled and Prof. Diana Golodnitsky, Raymond and Beverly Sackler School of Chemistry, are developing tiny batteries to be lodged in ingestible capsules for medical use, or in minuscule sensors for security purpose.

Scientists are attempting to develop long-life, high-current micro-batteries needed today for a range of novel applications. “Commonly available batteries are built of layers—cathode, anode, electrolyte, and current collector—which together carry out an electricity-producing electrochemical reaction,” explains Prof. Golodnitsky. “When we reduce the quantity of matter to construct a smaller battery, the amount of energy produced drops accordingly, and the battery is inefficient. For medical use inside the body, traditional batteries are unsuitable because of the danger of toxic electrolyte fluid leaking. In addition, small batteries with thin layers of solid electrolyte, which were developed 15 years ago, must be recharged frequently. Prof. Menachem Nathan of the Iby and Aladar Fleischman Faculty of Engineering has come up with a brilliant solution: a perforated silicon chip that carries many nanoscale batteries.

Our group is developing miniature batteries based on Prof. Nathan’s idea.”

Miniature batteries are built into a three-dimensional silicon chip. Its surface area is less than one square centimeter, it is 500 microns thick, and has 20,000–30,000 fine holes measuring 30–50 microns in diameter each, approximately 10 microns apart. Using smart wet chemistry methods—a variety of coating processes in solutions—researchers place thin layers that form independent nano-batteries into each hole. The chip offers 10–40 times more active material for electricity production per surface unit, compared with other micro-batteries.

“We are developing nanomaterial batteries that supply voltage according to need and application,” says Prof. Golodnitsky. “For example, solar cells require a voltage of 1.5–2 volts, whereas batteries for medical use usually operate

Prof. Emanuel Peled, Raymond and Beverly Sackler School of Chemistry, is world-renowned in the field of fuel cells and batteries. He was a founder of Chemtronics and EnStorage—start-ups based on technologies developed in his lab. His group’s unique fuel cells have achieved world records in electricity output. Prof. Peled has been Head of TAU’s Wolfson Center for Applied Materials Research, and Gordon Center for Energy Studies, and director of the Ministry of Science & Technology knowledge center for fuel cells & batteries. He has published more than 150 papers, registered over 40 patents, and won awards in Israel and worldwide.

on 3 or more volts.” Potential applications range from implants with controlled-release drugs; micro-cameras for internal imaging of the digestive tract (endoscopy); implanted hearing aids, pacemakers, blood-pressure or insulin-level sensors; collection and storage of solar energy with small solar cells; environmental-monitoring sensors and atmospheric-pressure gauges; outdoor sensors for defense purposes; and so forth.

GREEN FUEL CELLS

Researchers create clean, green fuel cells using nanotechnology. “A fuel cell is an electrochemical device that continuously converts chemical energy from a fuel (such as hydrogen) and an oxidant (such as oxygen or air) into electrical energy,” explains



We are developing nanomaterial batteries that supply voltage according to need and application...ranging from implants with controlled-release drugs; micro-cameras for internal imaging of the digestive tract (endoscopy); implanted hearing aids, pacemakers, blood-pressure or insulin-level sensors; collection and storage of solar energy with small solar cells...and so forth.



Prof. Peled. “Green fuel cells are environmentally friendly because they release only water and heat to the atmosphere. They have garnered interest as a means of producing and storing energy in general, and particularly clean energy. They can store energy produced from wind or sun, and supply energy to the grid, individual homes, or mobile devices; but their most promising application today is powering electric vehicles.” Important

components of fuel cells are the catalysts—nanometric particles that facilitate redox processes taking place in the fuel cell. Catalysts are made of nanoparticles of platinum—a prohibitively expensive metal. Currently, the cost of the catalysts is approximately half the cost of the entire fuel cell. Prof. Peled’s team has developed a new type of catalyst: a nanometric core made of a less costly metal, encased in a thin coat or sub-coat of platinum or platinum alloy.

★ **Prof. Diana Goldodnitsky**, Raymond and Beverly Sackler School of Chemistry, specializes in electrochemistry, lithium batteries, and electrochemical storage of energy. She has published more than 90 scientific papers and penned three book chapters. She holds 12 patents and was a founder of DEVIS Electroscopy. Prof. Goldodnitsky collaborates with leading scientists in the US and Europe, and sits on the editorial board of *The Open Electrochemistry Journal*.

Such catalysts are more easily manufactured by non-electrical deposition, at room temperature. They significantly reduce the cost of fuel cells without compromising their performance, and even improving it. ●



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