Tel Aviv University
Materials Science & Engineering

Material World

The Department of Materials Science and Engineering will lead Israel's research activity in the coming materials science revolution. As a hub of interdisciplinary knowledge, it will train top engineers and create R&D infrastructure to drive Israeli industry and growth.

Material World

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Tel Aviv University

Biodegradable fiber with
a coating of drug-eluting cells
(Courtesy of Prof. Meital Zilberman)

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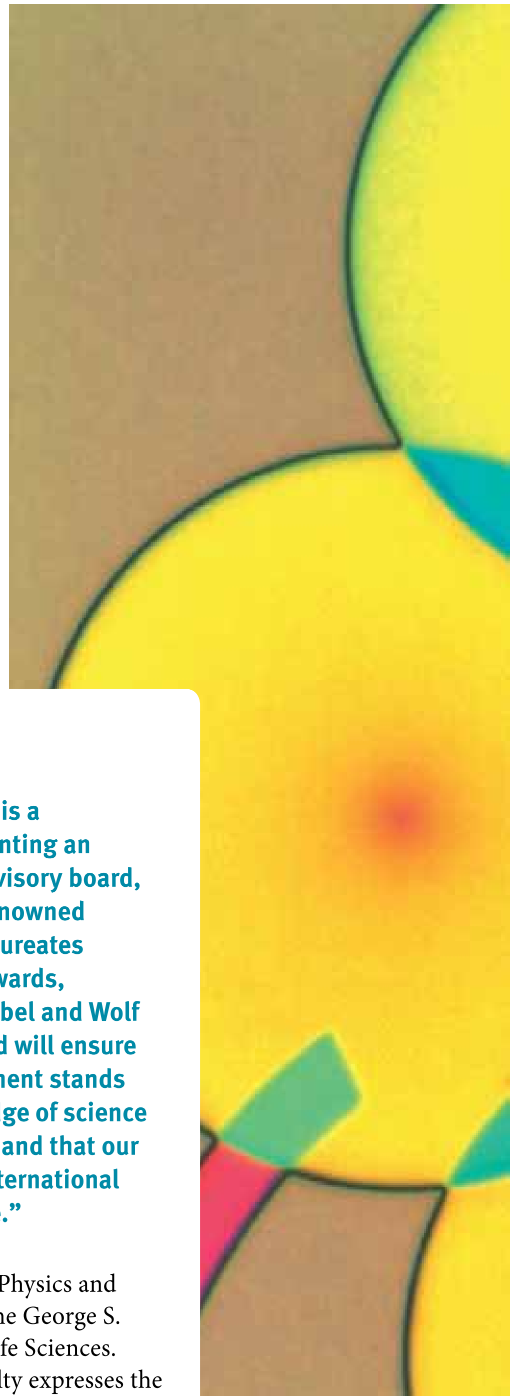

The Science of Materials

Prof. Noam Eliaz, Head of the new Department of Materials Science and Engineering, explains why it is unique, what its objectives are, and how it bridges past and future.

"The study of materials is the earliest field of science and technology," says Prof. Noam Eliaz, Head of the Department of Materials Science and Engineering at the Iby and Aladar Fleischman Faculty of Engineering. "We see the influence of materials on the development of humankind in the stages of history: the Stone, Copper, Bronze, and Iron Ages."

"Modern society is highly dependent on advanced materials for miniature components for micro-electronics, aviation turbine engines, energy production systems, and more. The field of materials is currently experiencing an upsurge, and will play a major role in future technology, including nanotechnologies and bioinformatics. Materials science will be a growth engine in the global economy, with a decisive impact on quality of life, health, security, and the environment."

When was the new department established, and what makes it special?

"The Department of Materials Science and Engineering was established in August 2013," says Prof. Eliaz. "The advanced degree program in Materials Science and Engineering comprises courses and research advisors from the new Department, as well as from other academic units in the faculties of Engineering, Exact Sciences, and Life Sciences. In the 2014-15 academic year, a new program for a combined BSc degree in Materials Science and Engineering and Chemistry, developed in close collaboration with the Raymond and Beverly Sackler School of Chemistry, will begin. This is a young department, and we are happy to rise to new challenges.

"In addition to core faculty members, whose number will grow in coming years, 11 affiliated faculty members have been appointed from the School of Electrical Engineering, School of Mechanical Engineering, Department of Biomedical Engineering, Raymond and Beverly Sackler School of Chemistry, Raymond and Beverly

"The Department is a pioneer in appointing an international advisory board, comprising 11 renowned scientists—all laureates of prestigious awards, including the Nobel and Wolf prizes. The board will ensure that the Department stands at the cutting-edge of science and technology, and that our degrees carry international value and repute."

Sackler School of Physics and Astronomy, and the George S. Wise Faculty of Life Sciences. Our blend of faculty expresses the multidisciplinary nature of the materials field in the modern era.

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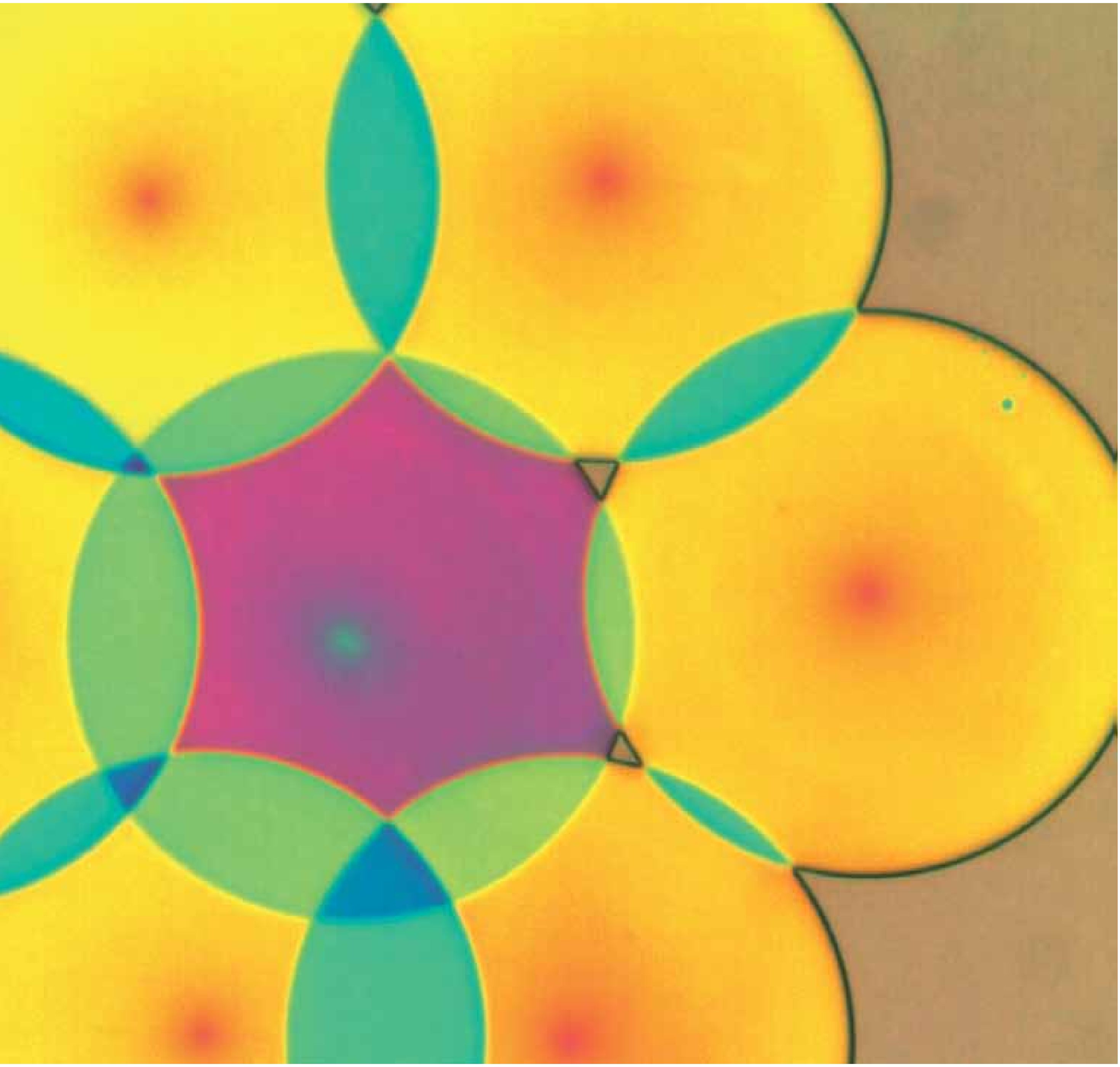


and that our degrees carry international value and repute."

How do you see the future of the Department? What goals have you set?

"We aim to achieve the highest international level of research in materials science and engineering, and to be a nucleus of interdisciplinary knowledge in the field at Tel Aviv University. We will build an infrastructure of knowledge and R&D services for Israeli industry, security, and governmental organizations, with our trained engineers leading the next technological breakthroughs. As the only such department in the center of Israel, we will fill a strategic national need." ●

Perspex heel shape created by electron beam energy changes (Courtesy of Dr. Yigal Lilach,Center for Nanoscience and Nanotechnology)

Capturing Cancer with a Magnet

Prof. Noam Eliaz and his group magnetize cancerous cells and create antibacterial implants in their laboratory—one of the world's leading laboratories for studying biomaterials and corrosion.

Prof. Noam Eliaz founded the Biomaterials and Corrosion Laboratory—today one of the world's leading laboratories in this field. Lab researchers investigate corrosion in environments such as aviation, space, sea, nuclear reactors, and the human body; biomaterials for orthopedic and dental applications; electrochemical coatings for aviation and space; ferrography and bio-ferrography for monitoring wear in plane engines and in biological and artificial joints, and for early diagnosis of cancer.

Ferrography—from the Latin *ferrum* or iron—was developed in the US in the 1970s to reveal the concentration, size, shape, and chemical composition of ferrous particles in lubricants such as grease in dynamic assemblies. Prof. Noam Eliaz co-led a project that applied ferrography to monitor wear in Israeli Air Force (IAF) helicopters—a project that in 2010 was ranked second in importance over the 60-year period of studying materials in the IAF.

"Lubrication fluid is sampled over time to determine the rate of wear, its mechanism, and its origin," explains Prof. Eliaz. "As the rate of wear increases, the gap between monitoring times is reduced, and a part requiring repair or replacement is identified before a general systems failure causes considerable financial damage and loss of life."

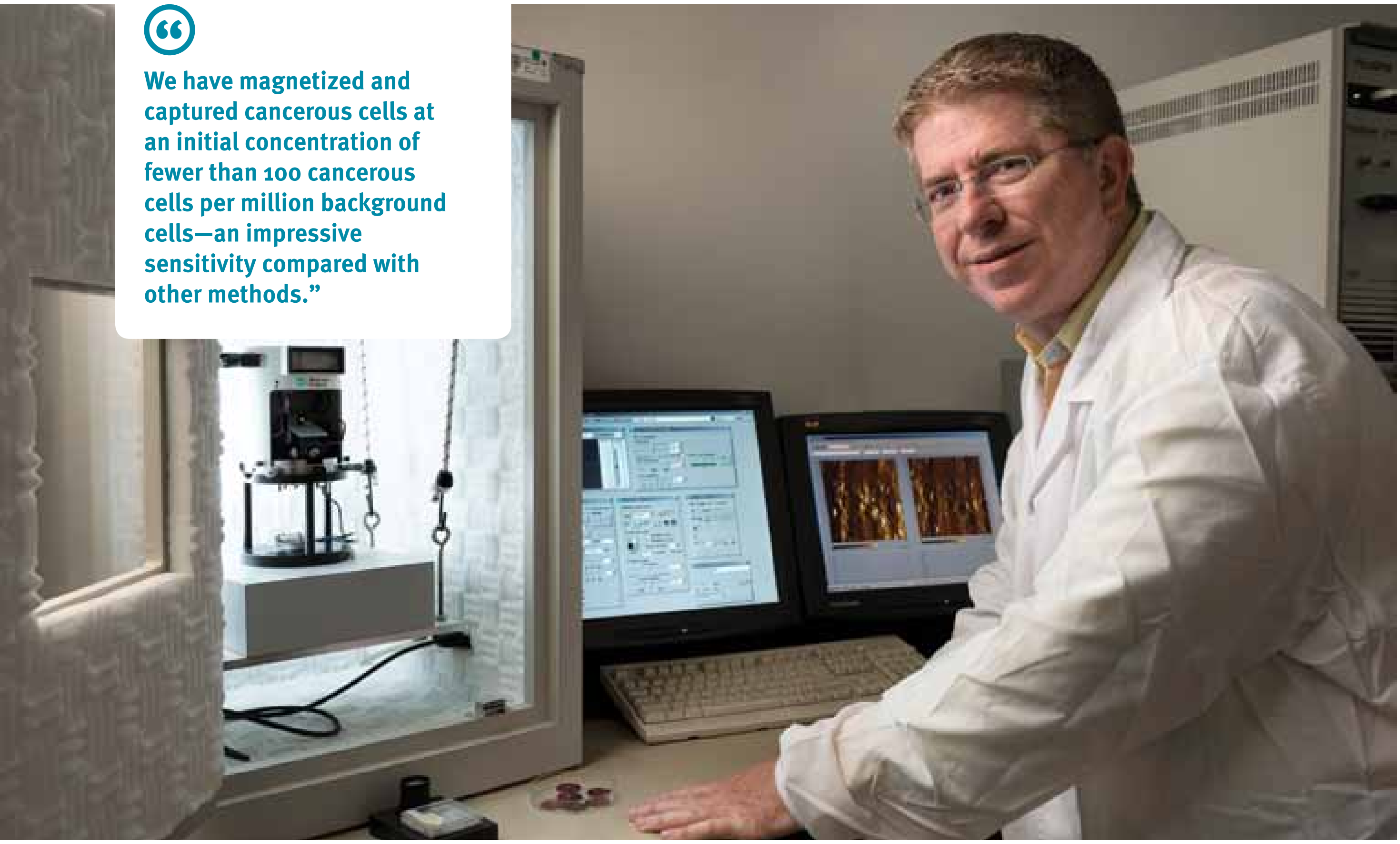
WORLD'S MOST ACTIVE LAB

In the 1990s, after his wife became ill with breast cancer, inventor of ferrography Vernon Westcott developed a new technology—*bio-ferrography*—to separate cells or tissues from body fluids such as blood, urine, and saliva. Today, four laboratories in the world possess bio-ferrographic capabilities, and Prof. Eliaz's laboratory is the most active of them all, and the only one outside the US.

The bio-ferrograph is a tabletop device that creates a magnetic field of about 1.8 Tesla. "After the cells or tissues we wish to separate have been magnetized, the fluid flows vertically across a thin glass assembled on the magnet," describes Prof. Eliaz. "The magnetic material sinks into collection strips on the glass, while remaining fluid flows to removal syringes. Only one microliter of fluid is sufficient to characterize it chemically and biologically."

The laboratory once focused on orthopedics, explains Prof. Eliaz: "We used bio-ferrography to determine severity of osteoarthritis. We separated bone and cartilage particles from synovial fluids, after magnetizing them using specific antibodies. By measuring the number and size of the particles, we determined the extent of the disease; on the basis of shape and chemical composition, we determined the originating layer of cartilage. We sampled the method's sensitivity and reliability relative to arthroscopy and radiography. We were even able to identify deterioration outset in a 13-year-old patient, where orthopedists had unanimously determined there was no cartilage damage."

Together with doctoral student Ofer Levi, Prof. Itai Benhar, and Dr. Assaf Shapira of TAU's George S. Wise Faculty of Life Sciences, and in collaboration with Prof. Nadir Arber, Head of the Integrated Cancer Prevention Center at Tel Aviv Sourasky Medical Center, Prof. Eliaz currently uses bio-ferrography to study colorectal cancer: "We have magnetized and captured cancerous cells at a concentration of fewer than 100 cancerous cells per million background cells—an impressive degree of sensitivity compared with other methods." The team now characterizes blood samples from patients suspected or known to be suffering from colorectal cancer using a cocktail calibrated at the University. A cocktail antibody reveals epithelial cells, whose presence indicates metastatic cancer. Initial results, examined by a Sheba Hospital pathologist, are promising.



We have magnetized and captured cancerous cells at an initial concentration of fewer than 100 cancerous cells per million background cells—an impressive sensitivity compared with other methods."

ANTIBACTERIAL IMPLANTS

Prof. Eliaz also studies electrochemical coatings of hydroxyapatite (HAp) and other bio-ceramic calcium phosphate compounds for orthopedic and dental implants. Since the 1970s, such implants are often coated with plasma spray. But only exposed surfaces are coated, and the coating is not chemically uniform and differs morphologically from biological bone mineral.

"Artificial hip joints are designed for a 10-year lifespan," explains Prof. Eliaz, "largely due to coating deterioration. This failure requires an additional operation, with lower success rates and additional suffering for the patient. Therefore, major implant companies are investing millions in developing alternative coating technologies to increase implant lifespan, reduce failure, and enable coating complex, porous shapes."

Since 2001, Prof. Eliaz and his team have employed electrochemistry to develop innovative coatings. They are considered world leaders in this field today. "In animal trials, our coatings exhibit 33% of the cracking found in leading commercial implants," says Prof. Eliaz. "Because our coatings are closer in morphological terms to bone mineral, we have succeeded in increasing the quantity of bone that the body builds around the implant." SGS, an international dental implant company, has recently purchased the know-how for Prof. Eliaz's coatings through Ramot, the University's commercial transfer company. As Chief Scientist, Prof. Eliaz is currently supervising the set up of the first production line in Hungary.

Prof. Eliaz is already working on the next generation of coatings for implants. "Today we know how to coat at the temperature and pH level of the body, which enables us to integrate drugs or biological materials into coatings. We are developing antibacterial implants and integrating growth factors that encourage bone to build around the implant." ●

Prof. Noam Eliaz is the founding Head of the Department of Materials Science and Engineering. He is Director of the Biomaterials and Corrosion Laboratory, and leads a large, successful research group. He has published over 300 research publications, and is Editor-in-Chief of *Corrosion Reviews*. To date, Prof. Eliaz and his colleagues have raised over $3.2 million for research and equipment. He has won many prestigious grants and awards, including the Fulbright and Rothschild Foundation scholarships; Eshkol and Dan David scholarships; Eshbach Scholarship, Northwestern University; JSPS fellowship, Japan; and the leading NACE International's Uhlig, Fellow, and Technical Achievements Awards in corrosion.

Force of Attraction

Prof. Ilan Goldfarb employs magnetic nanostructures to pave the way to smaller memories and thus larger storage capacities.

Gordon Moore, Intel's first CEO, made a prediction in 1965 that would come to be known as Moore's Law: the number of transistors on industrially produced chips will double approximately every 18–24 months. Moore's Law has proven true over decades, and is a basis for electronics industry development. As dimensions of transistors shrink, manufacturers pack more and more onto each chip. Consumers benefit from the continuing process of miniaturization, enhanced efficiency, and ever-lowering prices of electronics. Illustrating this principle is the flash drive—a device the size of a finger whose capacity for storing information has tripled within just a few years.

Longstanding technology has served us well, but a question hovers: When will we achieve saturation and no longer be able to increase the number of transistors on an electronic chip? Well, it turns out that the moment of truth is upon us. The size of chips today is already in the nanometer range, and in these minuscule dimensions, quantum effects may prevail and violate known laws of physics. Prof. Ilan Goldfarb and his group in the Department of Materials Science and Engineering are developing alternatives based on nanostructures—crystals built from a small number of atoms in a variety of shapes and arrangements.

SHAPING NANOSTRUCTURES

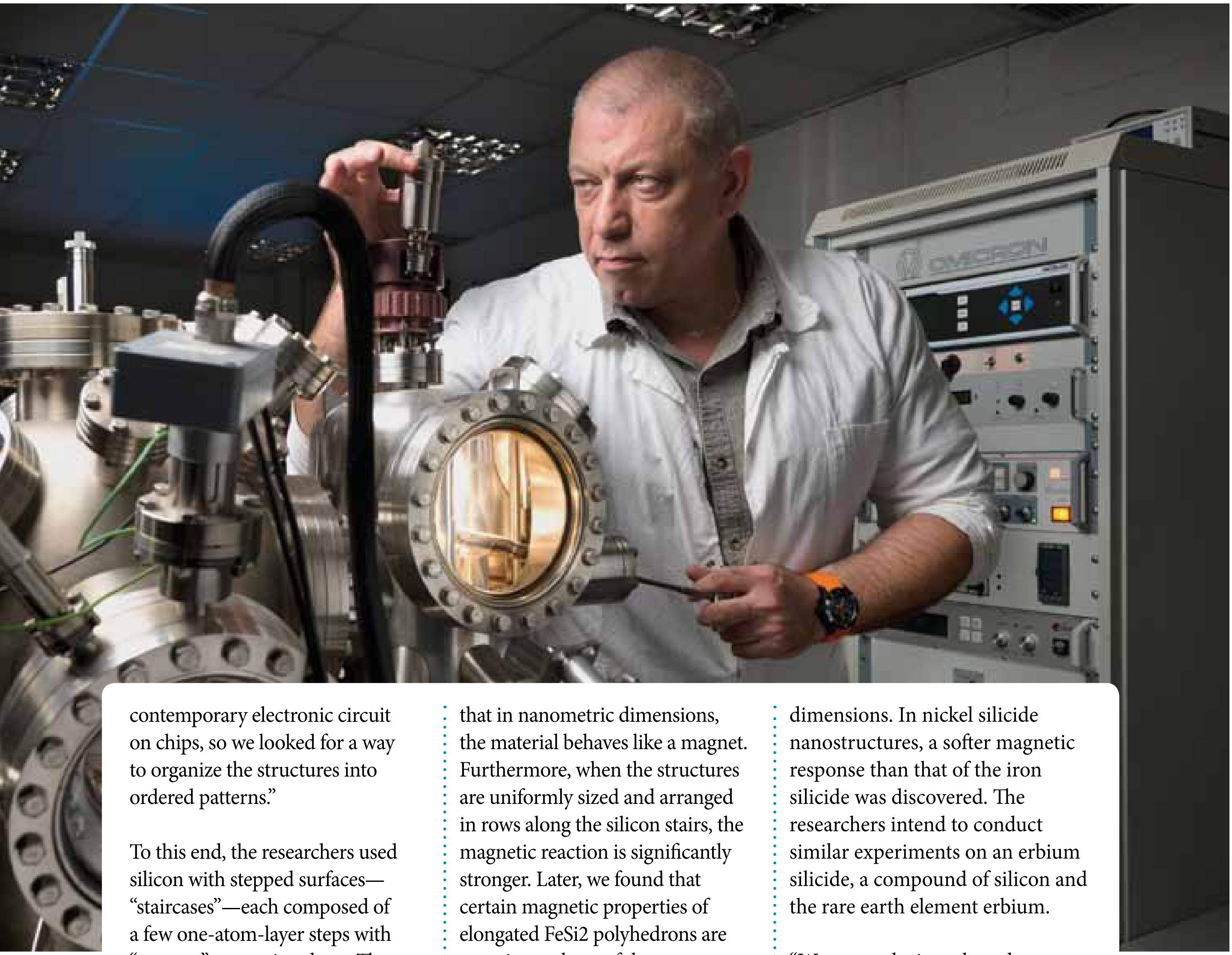
"Our laboratory specializes in creating novel nanostructures," explains Prof. Goldfarb. "We utilize sophisticated equipment to place atoms of a material onto wafers of another material, usually silicon, that serves as a substrate. The atoms attach to the substrate surface, arranging themselves in a natural process known as self-organization, and creating nanostructures with a shape dependent on the grown material—pyramid, box, ring. This is a natural process, with Mother Nature determining exactly how and where the atoms self-organize. We use physics to control these organizational mechanisms and create nanostructures for specific purposes. This is the essence of nanotechnology."

At present, a central objective of the laboratory is to create nanometric structures to replace the transistors and circuits that crowd chips today. This will help solve the looming saturation problem, and enable manufacturers to develop next-generation electronics. "We received a grant from the Israel Science Foundation to investigate the magnetic properties of nanostructures," says Prof. Goldfarb. "Magnetism is a key factor in electronic device memory, and magnetic nanometric structures can be the basis for creating tiny memories with huge storage capacity."

MAGNETIC MOMENT

Experiments at the lab focus on silicides—metal-silicon compounds. Researchers place metal atoms on a silicon surface, with Mother Nature choreographing the rest: Metal and silicon atoms join together to create silicide nanostructures that organize into characteristic shapes and exhibit unique physical properties, including conductivity and magnetism. One of the materials is the silicide FeSi2, an iron-silicon compound containing one iron and two silicon atoms per formula. "This material produces polyhedron-shaped nanostructures that look like flat-top pyramids," elaborates Prof. Goldfarb. "Without our intervention, the process creates polyhedrons of various sizes, randomly scattered over the silicon surface. Such a random arrangement cannot replace a

Prof. Ilan Goldfarb is a senior faculty member of the Department of Materials Science and Engineering, and Head of TAU's Wolfson Applied Materials Research Center. He conducted his doctoral research in Prof. Dan Shechtman's laboratory at the Technion–Israel Institute of Technology, Haifa; was a Research Fellow in the Department of Materials at Oxford University, UK; and was a member of Hewlett-Packard Laboratories' leading research team in nanoelectronics. He served as Head of the TAU Materials and Nanotechnologies Graduate Program and currently serves on the editorial board of the scientific periodical *Applied Physics A*.



contemporary electronic circuit on chips, so we looked for a way to organize the structures into ordered patterns."

To this end, the researchers used silicon with stepped surfaces—"staircases"—each composed of a few one-atom-layer steps with "terraces" separating them. They have found that on such a stepped surface, metal atoms tend to preferentially react with silicon atoms on the steps rather than on the terraces, producing a continuous line of FeSi2 nano-polyhedrons of uniform size and shape formed along the steps. Later, they examined the magnetic attributes of the ordered nanostructures.

"In larger dimensions, while iron possesses magnetic properties, the concentration of iron in FeSi2 is insufficient and therefore this silicide is not magnetic," explains Prof. Goldfarb. "But when we activated a magnetic field on the nanostructures at an extremely low temperature (4° K) we discovered that in nanometric dimensions, the material behaves like a magnet. Furthermore, when the structures are uniformly sized and arranged in rows along the silicon stairs, the magnetic reaction is significantly stronger. Later, we found that certain magnetic properties of elongated FeSi2 polyhedrons are superior to those of the more compact ones. We propose the following explanation for the observed phenomenon: Magnetism is a property that stems from the magnetic moment of each individual atom, called spin. When nanostructures are arranged in rows, individual moments inside them are preferentially oriented along one direction, thus all contribute to the joint magnetic force, and the magnetic response is intensified."

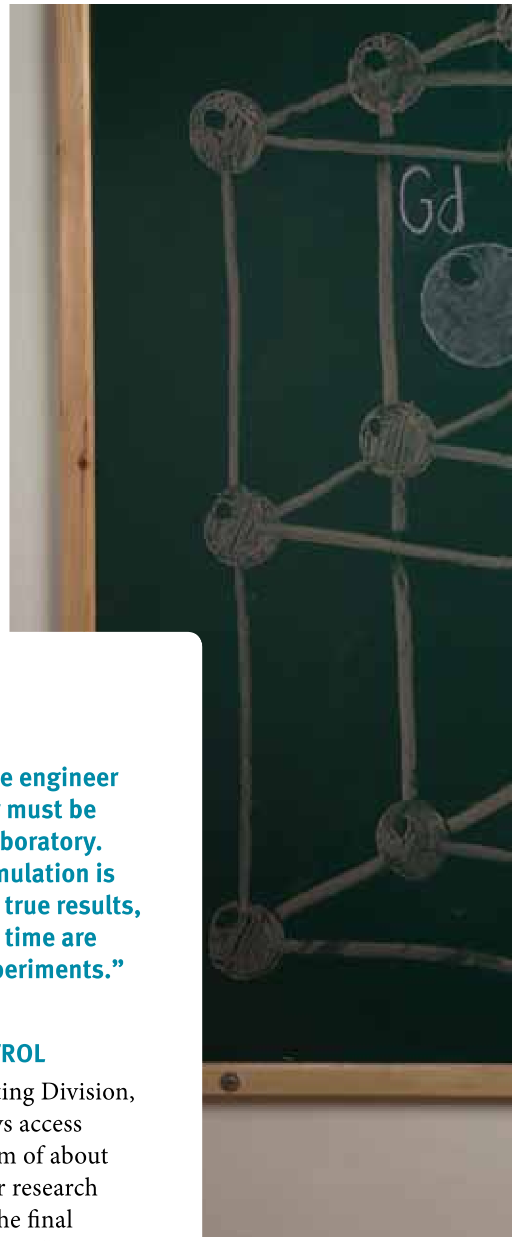
NANO-TAILORING

Prof. Goldfarb and his group also examine magnetic properties of other silicides, such as silicon compounds with cobalt, titanium, and nickel of nanometric dimensions. In nickel silicide nanostructures, a softer magnetic response than that of the iron silicide was discovered. The researchers intend to conduct similar experiments on an erbium silicide, a compound of silicon and the rare earth element erbium.

"We are exploring a broad range of silicides to elucidate different magnetic properties for various applications," sums up Prof. Goldfarb. "Hard magnetism can be utilized for advanced, nanotechnology-based memory. In contrast, the core of electrical transformers requires softer magnetism. Beyond magnetism, this method has huge potential for other applications including lasers and LED screens, markers for monitoring cancer, electrical engineering, and more. Our role is to tailor the right nanostructure out of a suitable material, with the required shape and arrangement. Having achieved that, the applications are virtually endless."

Virtual Laboratory

Dr. Oswaldo Dieguez makes do without materials for his experiments. His laboratory is a computer, and his field of research is simulations.



Compared with other laboratories in the Department of Materials Science and Engineering, Dr. Oswaldo Dieguez's laboratory is miraculously tidy. "My field of research is computational simulation of materials," explains Dr. Dieguez. "Unlike my colleagues, I do not conduct experiments with materials, and that is why my room is so clean and small," he laughs. "Other researchers need sophisticated laboratories, while my group works in a virtual laboratory. Every test that we perform, every new material that we engineer, and every new discovery that we make are possible thanks to the power of modern computers, which carry out millions of mathematical operations per second."

Dr. Dieguez and his colleagues use atoms as the building blocks of their simulations. "In Richard Feynman's wonderful teachings on physics," says Dr. Dieguez, "he explains that the most useful physical theory expressed in the smallest number of words is the atomic hypothesis: Everything is made up of atoms—small particles in constant motion, attracting each other when apart but repelling each other when together. Thanks to quantum mechanics, we know the mathematical equations describing the interactions between atoms. Solving these equations with a computer allows us to discover, for example, whether a material is hard or soft, at what temperature it will melt, and whether it will conduct electricity."

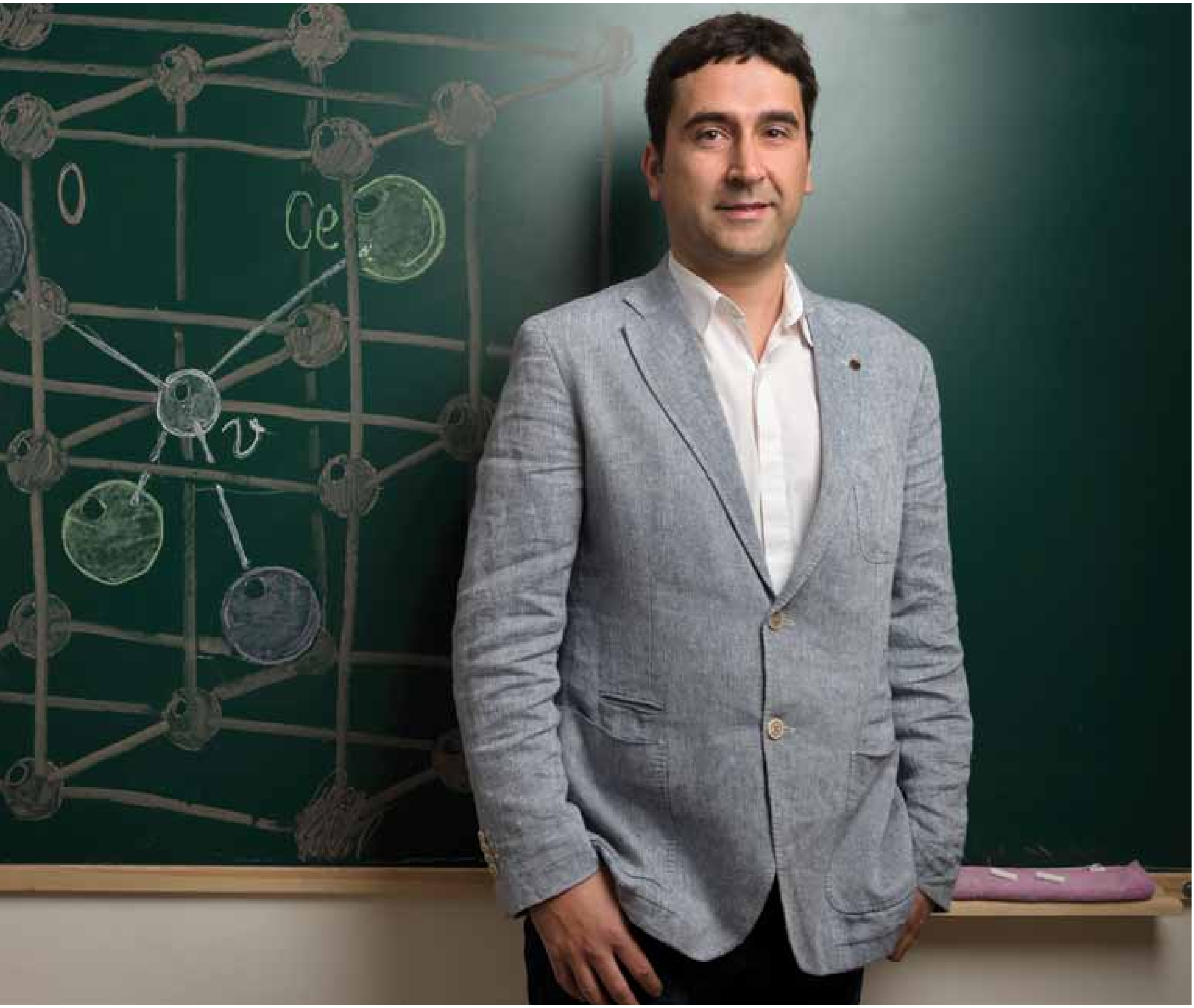
"Materials that we engineer on the computer must be verified in the laboratory. Yet computer simulation is edging closer to true results, which time after time are confirmed in experiments."

ULTRAFINE CONTROL

At TAU's Computing Division, Dr. Dieguez enjoys access to a computer farm of about 400 processors for research simulations. "In the final analysis," he clarifies, "materials that we engineer on the computer must be verified in the laboratory. Yet computer simulation is edging closer to true results, which time after time are confirmed in experiments."

Dr. Dieguez is primarily interested in ferroelectric materials. "These materials possess an asymmetrical distribution of positive and negative charges, which can be controlled by an external electrical field," he explains. "This property is useful for

Dr. Oswaldo Dieguez is a member of the new Department of Materials Science and Engineering, where he heads a group involved in atomistic simulation of materials. Dr. Dieguez holds a PhD in Physics from the University of Santiago de Compostela, Spain, and post-doctorates from the University of Cambridge, Rutgers University, and MIT. Dr. Dieguez was a researcher at the Institut de Ciencia de Materials de Barcelona before joining TAU.

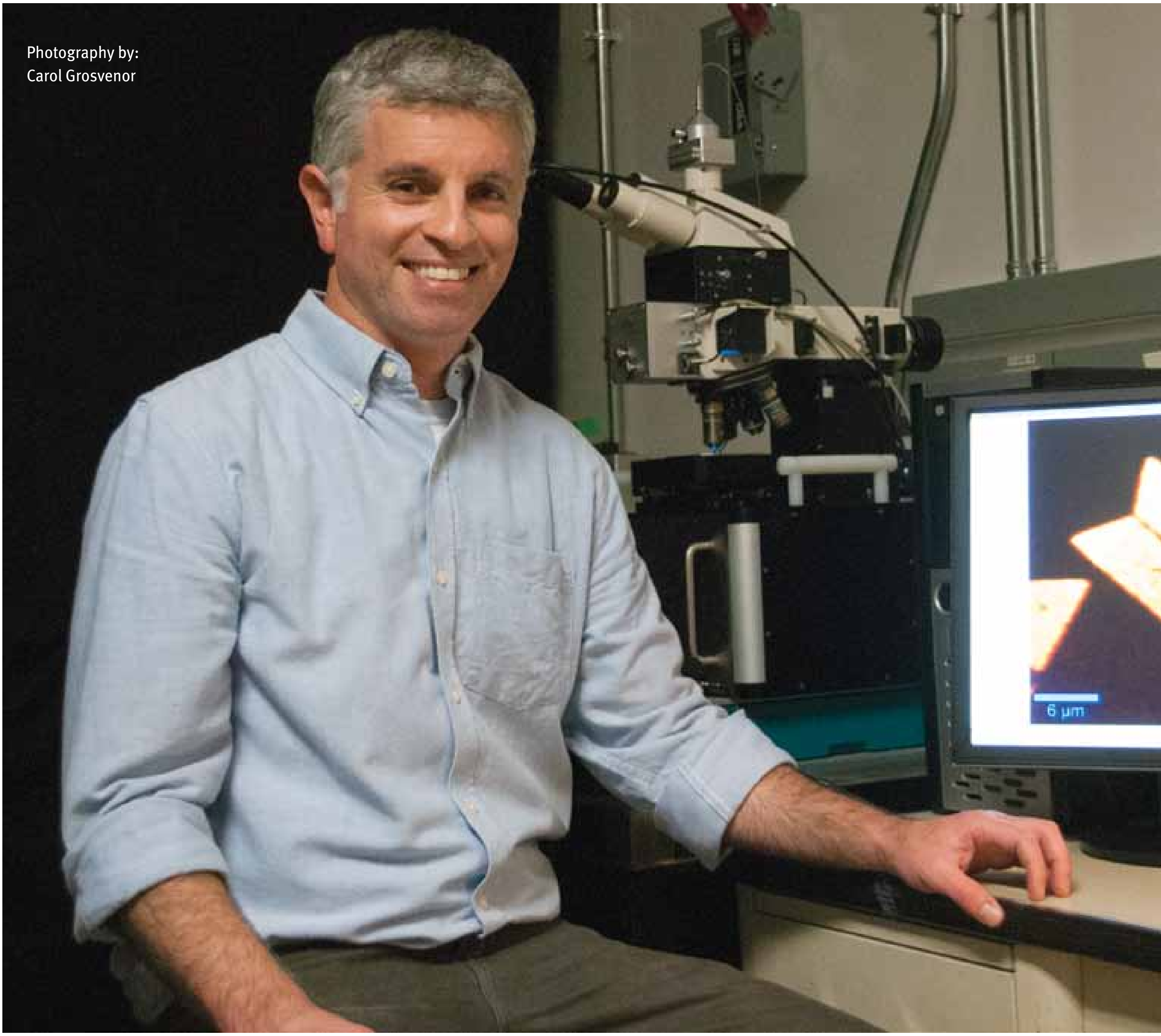


building computer memory cells. Ferroelectric materials are also used in devices requiring ultrafine control of movement, such as camera lenses. We seek to understand the behavior of ferroelectric materials at the atomic level, and use this knowledge to engineer materials for technological applications."

SIESTA

Dr. Dieguez's research group is also interested in developing simulation software. "After completing my doctorate, I contributed to SIESTA—the Spanish Initiative for Electronic Simulations with Thousands of Atoms. This program has more than 100,000 lines of code to model materials, such as DNA molecules, that are made up of many atoms. In September 2014, we are organizing the first SIESTA tutorial here at the University, so that researchers from Israel and abroad can learn to use this program for modeling materials."

In Dr. Dieguez's opinion, computing will play a central role in engineering new materials in the future: "There are around 80 stable elements in the periodic table. The number of materials that can be formed from different combinations of these elements is vast, and many combinations can be successfully modeled on the computer before trying them in the laboratory. Computational modeling is an important tool for discovering the materials of the future." ●



Photography by:
Carol Grosvenor

Atomic Layers

Dr. Ariel Ismach grows two-dimensional atomic layers. He investigates and manipulates their properties to create new layered materials.

"When writing with a pencil, thousands of layers of graphite separate from the pencil point," explains Dr. Ariel Ismach, Department of Materials Science and Engineering. "Materials such as graphite are made up of layer upon layer of atoms: The atoms in each layer are interconnected by a strong bond, while the bonds between the layers are weak, so they can be separated. The scientific community is

Dr. Ariel Ismach immigrated to Israel from Argentina. He holds a BEng in Materials Engineering from Ben Gurion University of the Negev, and an MA and PhD in Materials and Surfaces from the Faculty of Chemistry, Weizmann Institute. He was awarded a prize from the Israel Chemistry Society for his doctoral thesis. Dr. Ismach was a post-doctoral fellow at the Department of Electrical Engineering, University of California–Berkeley; at the Materials Science Division of the Lawrence Berkeley Laboratory; and as part of a leading group studying two-dimensional materials at the Department of Mechanical Engineering, University of Texas–Austin. Owing to his outstanding research, he was recruited by Tel Aviv University to establish a laboratory for growing and characterizing atomic layers.

interested in isolating a single two-dimensional layer of atoms. Such a layer possesses very special mechanical, electronic, thermal, chemical, and optical properties—substantively different from those of three-dimensional material. My research group develops nanotechnological methods to produce atomic films of different types of layered materials, and to study their properties."

TRANSPARENT & THIN

Researchers see a promising future for atomic materials. "Atomic layers are characterized by stability and strength," says Dr. Ismach. "Because the chemical bonds between the atoms are saturated, the material does not seek out external supplements. Atomic layers possess a high degree of mechanical strength, unique electrical and optical properties, and are heat-resistant. Being just one atom thick, they are naturally transparent and thin."

Atomic layers will drive the production of smaller, faster, more efficient, and much more economical electronic devices. Some materials will even meet the latest requirement of the next generation: flexibility. Other applications are super-thin solar cells; medical devices; light, chemical, and biological sensors; powerful batteries for renewable energy technologies; innovative complex materials; and smart windows that control light quantity.

NOVEL MATERIALS

Despite their great promise, there is still a long way to go. "Our main challenge is to find consistent, efficient methods of growing individual atomic layers of diverse materials and properties," says Dr. Ismach. "So far, such a technique exists for only one material—graphite. The single-atom layer produced from it is graphene. Graphene possesses excellent electrical and thermal conduction, mechanical strength, and flexibility, and it is already grown for commercial applications, such as touch screens, and transparent, flexible conductors."

Dr. Ismach's current research deals with another atomic material, hexagonal boron nitride (h-BN), known as white graphene. He explains: "White graphene could be a platform for nanometric electrical devices. Because white graphene is very stable in chemical terms and atomically flat, it will not scatter the flow of electrons. Experiments have proven that a platform of white graphene significantly improves electrical properties of graphene laid over it, compared with electronics platforms used today." White graphene has another important property: unlike most insulating materials, it is an excellent heat conductor. Therefore, according to Dr. Ismach, it is likely to support vital heat removal functions—e.g. in flexible plastic polymer electronic devices that are liable to heat up considerably.

"We will chemically modify two-dimensional material layers in order to dictate their physical, mechanical, electrical, and optical properties. In this way we can create novel families of materials."

In his new laboratory at the University, Dr. Ismach will produce atomic layers from a range of materials. His group will then investigate and develop techniques for transforming layer properties. "We will chemically modify two-dimensional material layers in order to dictate their physical, mechanical, electrical, and optical properties. In this way we can create families of novel materials," explains Dr. Ismach."

The jellyfish is mainly made up of water. By straining the water and injecting nanoparticles with electrical conductivity or antibacterial properties into the remaining mucous material, we can transform jellyfish byproducts into smart plastic.”

Organically Smart

Prof. Shachar Richter and his colleagues develop nanotransistors that harness the electrical properties of organic molecules. They also utilize natural materials for a range of technological uses.

Contrary to popular belief, electronic components do not only exist in computers. These components can be introduced into the human body. Prof. Shachar Richter and his colleagues in the molecular bioelectronics research group have a revolutionary proposal: To utilize the electrical properties of organic molecules to create electronic components. Blood, saliva, and milk would be used to produce a new generation of transistors—not harmful to the body or the environment.

EXPANDING MEMORY

Prof. Richter began his nanoelectronic research developing tools to create smaller than small nanotransistors. "Our invention—*molecule-based memory*—is a carbon nanotransistor, the width of a single-molecule layer, which multiplies computer memory many times over," says Prof. Richter. "Commercial applications are vast, and we are involved in negotiations with major companies. At the same time, these nano-transistors are a very powerful research tool that we use to study the properties of biological and chemical molecules."

His second field of research utilizes natural materials from renewable sources for technological use. "Our sources are diverse—animals, plants, jellyfish," he says. "I emphasize jellyfish because they are a rich source of proteins, including collagen, which are important for the human body. In the Far East half a billion tons of jellyfish are processed every year, mainly for the food industry."

A CALL FROM THE UN

Another reason for utilizing jellyfish is that they are a global ecological problem. "The United Nations has put out a call to scientists for solutions," says Prof. Richter. "Jellyfish swarms are increasing. They attack coastlines worldwide—mainly in Asia, but also in the US and here in the Middle East—and cause major damage to fishing, tourism, and energy industries, for example, by blocking nuclear power station filters."

Prof. Richter and his colleagues produce absorbent materials, degradable plastic, and hydrogel from jellyfish. "The jellyfish is mainly made up of water. By straining the water and injecting nanoparticles with electrical conductivity or antibacterial properties into the remaining mucous material, we can transform jellyfish byproducts into smart plastic." ●

Prof. Shachar Richter heads the Molecular Bioelectronics Group, Department of Materials Science and Engineering. He holds a BA in Chemistry from TAU, and an MA in Physical Chemistry and a PhD in Physical Chemistry and Materials from the Weizmann Institute. He pursued post-doctoral studies at the solid-state physics department of Bell Laboratories, US, where he was a faculty member. Upon returning to Israel, he was among the founders of TAU's Center for Nanoscience and Nanotechnology.

Skin Deep

Prof. Meital Zilberman and her research team develop medical adhesives and advanced wound dressings, including skin substitutes for treating severe burns—based on biological and synthetic components.

In Prof. Meital Zilberman's Biomaterials Laboratory at the Department of Biomedical Engineering, researchers are developing advanced biomaterials, such as medical adhesives, advanced wound dressings, and skin substitutes to accelerate healing of damaged skin. "The skin is the largest organ in our body," explains Prof. Zilberman. "It is a barrier between the body and the environment, protecting organs against contamination and injury. A person cannot live long without healthy, intact, functioning skin. Throughout history, doctors and healers have healed our wounds. Here in our laboratory, we are developing new solutions based on synthetic and natural polymers for this purpose."

TISSUE-FRIENDLY

"A few years ago I attended a lecture by a medical surgeon that fired up my imagination," recounts Prof. Zilberman. "He described a fairly simple surgical procedure, saying: 'I complete the operation within five minutes, but I then need half an hour to sew up the patient. I'm waiting for someone to invent a tissue glue.' Hearing that, I decided to take up the challenge. Within a short time I discovered that this was an especially complex endeavor."

A bioadhesive, or glue, that can substitute for surgical thread must meet a number of conditions: (1) It must be extremely adhesive; (2) it must be biocompatible, i.e., not stimulate undesired bodily reactions; (3) it must possess a precise level of viscosity to spread thinly and still be adhesive; (4) its drying process must be rapid, but still grant the surgeon enough time to perform a quality adhesion; (5) it should be degradable, disappearing during the healing process without further intervention; and (6) the most demanding challenge—it must work in a watery and bloody environment."

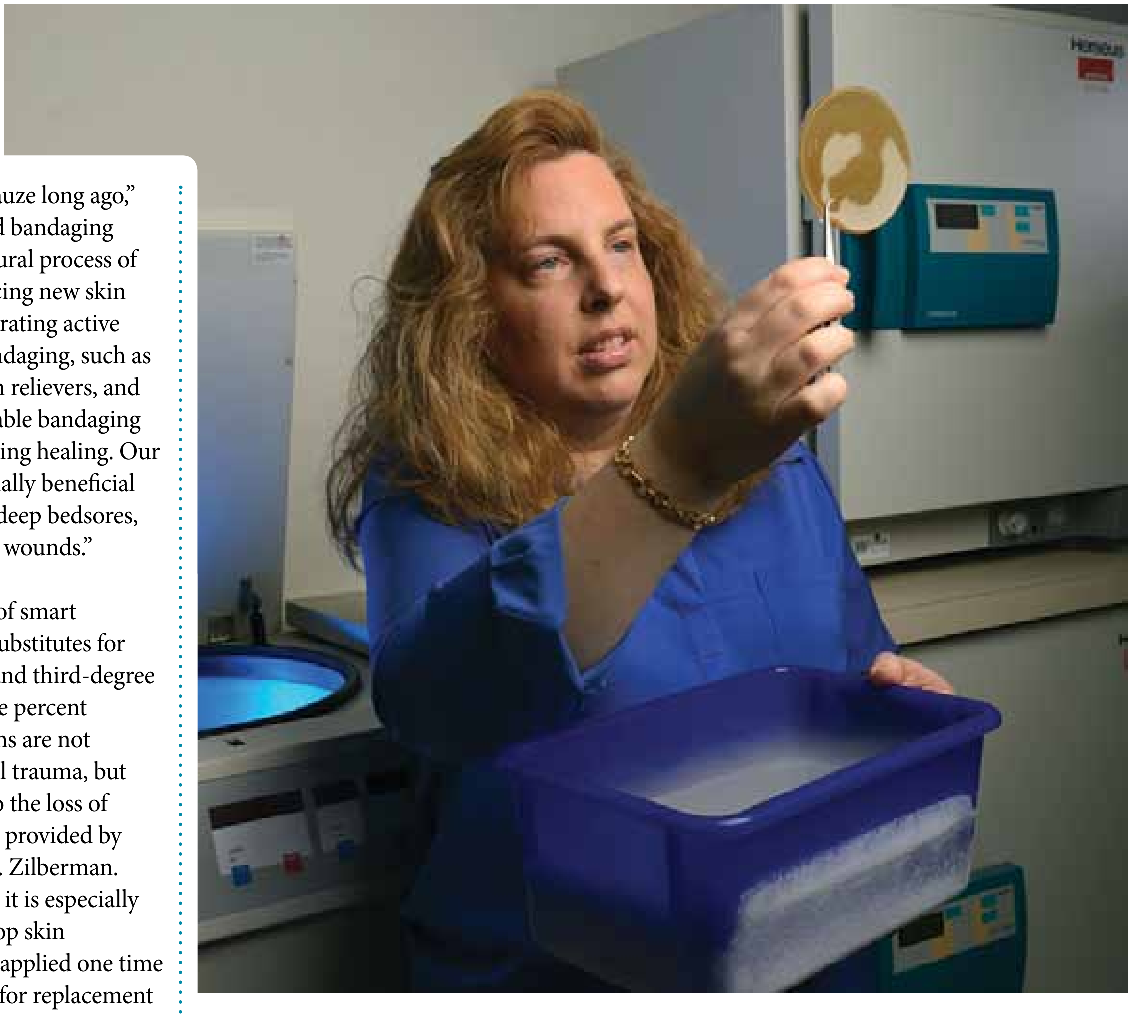
"This combination of requirements presents a huge challenge in materials development. Solutions available up to now do not completely respond to medical need," explains Prof. Zilberman. "A glue called Histoacryl, based on acrylic polymers, is currently in use. It is highly adhesive, but toxic, stiff, and unfriendly to tissue, so it is only used on small cuts. Other glues based on natural substances have relatively low adhesive strength and are used to seal up tissue, such as a punctured lung or intestines, when stitching alone could leave gaps for dangerous leakages."

Prof. Zilberman and her group are developing an innovative solution involving two biological components that are similar to bodily tissue: a protein component—gelatin—derived from collagen; and a polysaccharide component—alginate. Glues based on this compound are naturally biocompatible, and laboratory experiments reveal additional important properties. "We examined our glue on animal skin as well as on live pigs in the lab," explains Prof. Zilberman. "Performance was clearly superior to current surgical glues, exhibiting higher bonding strength, desired viscosity, adhesion time of about 20 seconds, and adhesive ability in a moist environment. This is a very promising project that can be commercialized in the near future. We believe our glue will be a breakthrough for modern surgery." Animal experiments were performed with the assistance of Prof. Yehuda Ullmann, Head of Plastic Surgery, Rambam Medical Center, Haifa.

But that's not all. To boost beneficial effects, researchers load the glue with medical substances. Prof. Zilberman explains: "Some of our glues release painkillers, antibiotics, and other drugs into the wound in a controlled manner. Other glues, for internal organs during surgery, contain homeostatic agents. We are also developing glues containing a bone component called hydroxyapatite for healing delicate fractures and crushed bones that are difficult to set with screws."

SKIN SUBSTITUTES

Prof. Zilberman also develops advanced wound dressings. "Bandaging material ceased to be a simple scrap of gauze long ago," she says. "Advanced bandaging encourages the natural process of healing and producing new skin tissue. We are integrating active substances into bandaging, such as antibiotics and pain relievers, and developing degradable bandaging that disappears during healing. Our bandaging is especially beneficial for treating burns, deep bedsores, and severe diabetic wounds."

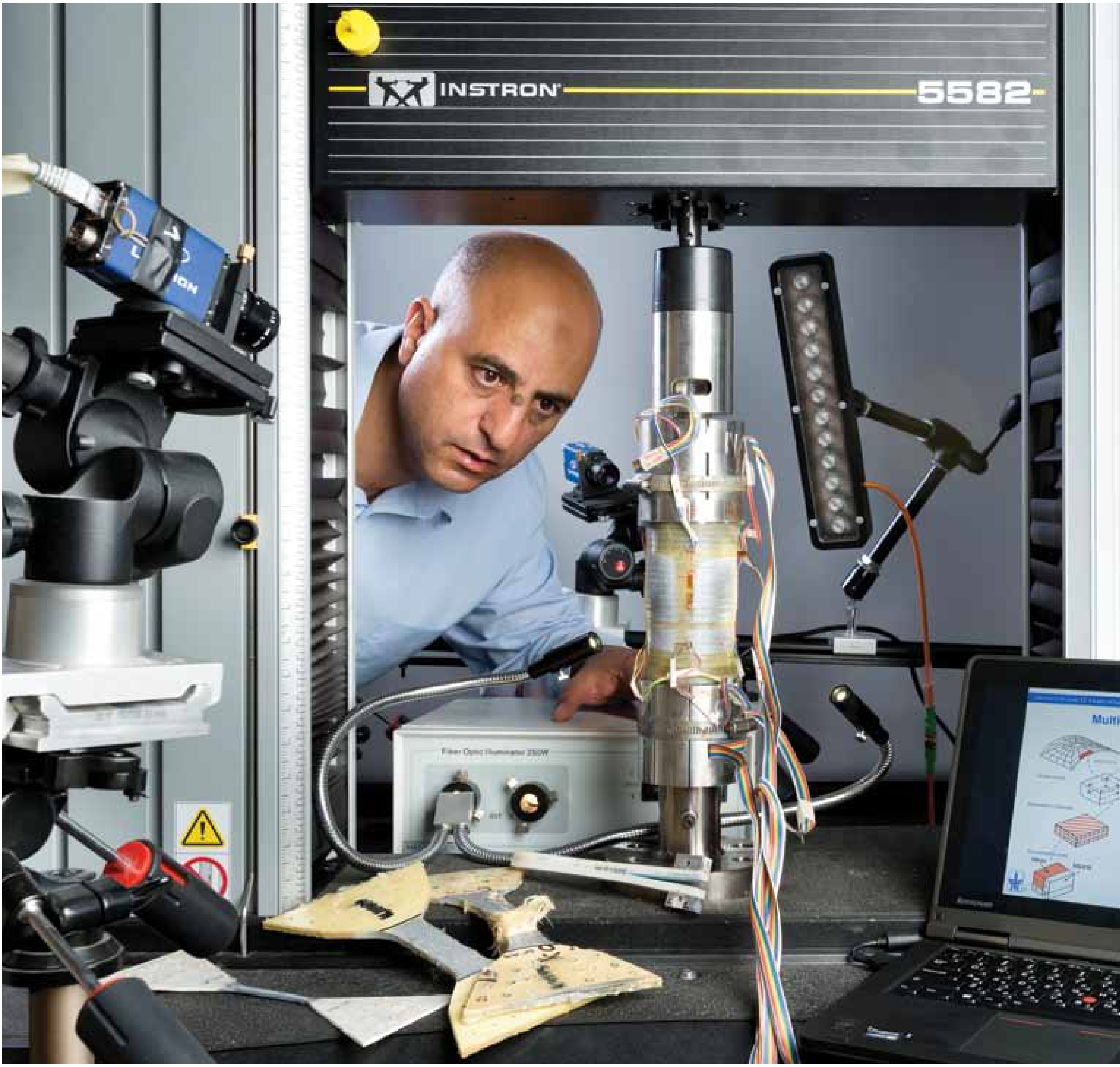


A special category of smart bandaging is skin substitutes for extensive second- and third-degree burns. "Seventy-five percent of deaths from burns are not caused by the initial trauma, but by infections due to the loss of protective covering provided by skin," explains Prof. Zilberman. "For these patients, it is especially important to develop skin substitutes that are applied one time only, without need for replacement during healing. Changing dressings risks infection and is extremely painful. Bandaging should serve as a skin substitute that is not only a physical barrier between the body and environment, but possesses the entire gamut of qualities—strength, pliancy, and porousness, which enable the passage of liquids and air at an optimal rate for healing and producing new tissue."

One of the group's outstanding innovations is a hybrid dual-layer wound dressing. The bottom layer, which is in contact with the skin, is based on collagen, a key component of connective tissues. The top layer, made of a synthetic degradable polymer, possesses suitable mechanical and physical attributes, and regulates drug release to the wound. An additional advanced bandaging solution is based on soy protein, which offers high stability and no danger of disease transfer through animal sources. No less important, its price is significantly lower than that of other proteins used for medical applications.

Two smart wound dressings were tested on animals. Burn-model experiments were conducted with the assistance of Prof. Ullmann, Head of Plastic Surgery Department, Rambam Medical Center, Haifa, and Dr. Dana Egozi, Head of Surgery Department, Kaplan Medical Center, Rehovot. These experiments yielded extremely promising results: The healing process was shortened by tens of percentage points, and was higher quality, leaving less scarring than bandaging methods used today.

Prof. Meital Zilberman is Associate Professor, Department of Biomedical Engineering, Iby and Aladar Fleischman Faculty of Engineering. She received her BSc in Chemical Engineering, cum laude, and MSc and PhD in Materials Engineering from the Technion–Israel Institute of Technology. She conducted post-doctoral research at University of Texas Southwestern School of Medicine, Dallas, and joined TAU in 2002, establishing research and teaching activities in polymeric biomaterials, tissue engineering, and drug delivery. She has published more than 70 peer-reviewed articles, serves on the editorial board of several leading biomaterials journals, and has conducted more than 180 presentations. She holds 5 patents and has received various prizes, including the prestigious Juludan Research Prize, awarded each year by the Technion to an outstanding researcher whose achievements "show promise of having valuable scientific technological applications and are channeled to enhance man's welfare and prolong the human life span."



From Sheba to NASA

Prof. Rami Haj-Ali generates computerized models of composite materials and structures for a range of applications: artificial heart valves, airplane wings, and more.

Composite materials are made up of two or more materials that possess different physical properties, creating a structure with an engineering value greater than the sum of its parts. Prof. Rami Haj-Ali, School of Mechanical Engineering, employs math and physics to study composites—usually made up of polymeric matrix reinforced with long fibers or particles.

"We develop analytical and computational methods to predict the mechanical behavior of composite materials," says Prof. Haj-Ali. "Working in my lab is fun! I also run computational simulations to identify behavior and predict possible failure of composite structures—for example, protective layers being penetrated by a projectile—to ultimately improve materials."

Research institutes and industry, such as the military, Lockheed Martin, and NASA use Prof. Haj-Ali's and his colleagues' mathematical models. "Our models describe mechanical behavior on a microscopic scale, recognizing fibers and matrix phases, and taking into account the material's periodic nature," Prof. Haj-Ali explains. "This is a multi-scale analytical approach for predicting properties and behavior of materials and structures simultaneously. Taking the structure, we zoom in on the wing of a plane, to the rivets, to nearby micron-scale cracks. But today we cannot analyze the molecular or nano levels with the global structure—not even utilizing super-computers. Perhaps in the future we will succeed."

Prof. Rami Haj-Ali is Head of the Laboratory for Mechanics of Composite Materials, Iby and Aladar Fleischman Faculty of Engineering. He has published over 120 articles, and is the recipient of several prestigious awards, such as the Chester Siess Prize, University of Illinois; American National Science Foundation Career Award; the Maof Foundation Fellowship; and the Marie Curie Fellowship for European Union Scientists.

FIBERS FROM CORALS

Prof. Haj-Ali and his colleagues have developed a biological composite material of long collagen fibers from soft corals, and a computerized simulation of the action of these biological fibers, which are similar to body tissue. "We produce biocompatible materials in the lab, and model them on the computer," explains Prof. Haj-Ali. "My colleagues have found a soft coral that produces collagen-I-like fibers, the most common protein in the body. Our idea is to produce ligaments and tendons from these coral-based fiber composites. To know how many collagen-I fibers are needed, we examine the specific application in action in the body, and plan the tissue using our simulations."

MODELING VALVES

Prof. Haj-Ali is currently working in collaboration with Sheba Medical Center to model the action of heart valves in the human body. "The heart valve is a mechanical structure made up of composite material with collagen fibers," he explains. "The structure's function is to open and close, maintaining blood cycle flow and pressure. The valve calcifies over the years—particularly due to smoking, excess weight, and diabetes—losing function and causing blood pressure to rise. What can be done? Replace it with an artificial valve made of plastic materials with porcine or bovine tissue."

This is where Prof. Haj-Ali and his team come in: "Our engineering role is to model aortic valves of patients, healthy people, and pigs," he explains, "to understand when calcification raises blood pressure. We perform computerized analysis modeling a calcified valve, and verify the models using clinical and in-vitro tests. Our computational models will help design new artificial valves and understand the pathology of aortic valves."

Working in my lab is fun! I also run computational simulations to identify behavior and predict possible failure of composite structures—for example, protective layers being penetrated by a projectile—to ultimately improve materials."

Our computational models will help design new artificial valves and understand the pathology of aortic valves."

Prof. Yossi Rosenwaks is Head of the Physical Electronics Department of the School of Electrical Engineering, and Head of the Research Center for Renewable Energy. To date, he has mentored more than 50 students in pursuing their postgraduate degrees, edited several books, published more than 130 articles, delivered over 55 guest lectures, and organized a large number of conferences. He has served as President of the Israel Vacuum Society (2003-2006), Head of the Wolfson Applied Materials Research Center, and Head of the Gordon Center for Energy Research (2005-2008).

Electrical Tension

Prof. Yossi Rosenwaks proposes a new approach for solving a nanotechnology industry bottleneck: a method that employs electrical fields to mass-produce nanowires.

The future is in nanomaterials—materials engineered from components sized about one-billionth of a meter. But our achievements in miniaturization currently surpass our ability to assemble structures out of nanometric building blocks.

"An acute problem facing the scientific community is how to assess nanometric devices," says Prof. Yossi Rosenwaks, Head of the Physical Electronics Department, School of Electrical Engineering. "We have the nanometric transistor, but now we need an efficient means of checking its electrical properties. Nano components cannot be measured with an electrical tester. Our primary tool is the atomic force microscope. Our group first applied it to measure electrical properties when I arrived at the University 18 years ago."

Today, Prof. Rosenwaks is a leading expert in nanometric characterization of semiconductors, and he develops entirely new devices: "Naturally, in the course of taking measurements, you arrive at insights and apply them. Thus, in recent years we have started developing novel nanometric devices. Today, our group focuses on developing electronic devices based on nanowires."

Nanowires are pipes that measure dozens of nanometers in diameter. "It's all well and good to produce or characterize nanowires," explains Prof. Rosenwaks. "The real problem is large-scale integration: How to use nanowires to produce a billion transistors inside one square centimeter. This is the bottleneck blocking the entire nanotechnology industry over the past 20 years."

TO SCULPT OR TO GROW

Today, there are two primary methods for integrating nanowires, explains Prof. Rosenwaks. The first approach is the top-down method: Take a centimeter-sized material and sculpt it down to an extremely thin wire. That's how major electronics firms like Intel work. But this process costs billions of dollars. The other approach is the bottom-up method: to grow nanowires like mushrooms. But they do not grow in equal lengths or intervals, which makes large-scale integration impossible.

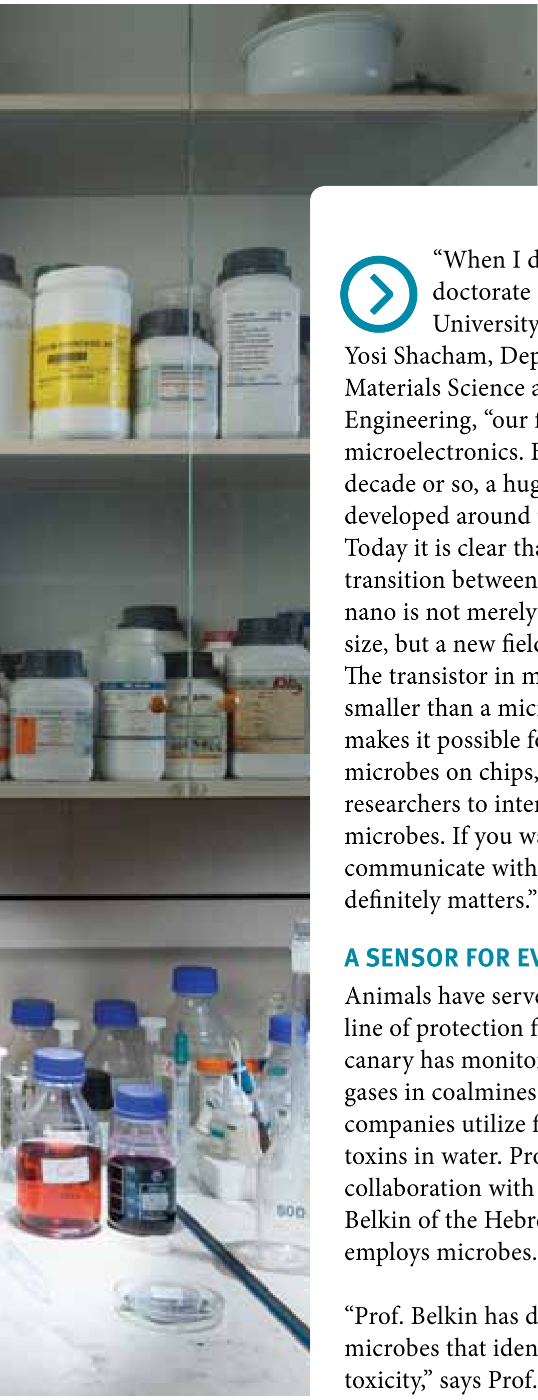
"We have come up with a new paradigm: to engineer nanowires by electrical means," explains Prof. Rosenwaks. "Instead of producing them physically, we engineer the material so that the electrons, i.e. the electrical current, travel through an extremely narrow channel. Using electrostatic potential, we compress the material's electrical charges into nanometer-diameter wire. Now we are trying to prove that the device obtained is at least as good as bottom-up devices. Within half a year we will have preliminary results."

If this succeeds, applications will be far reaching. Prof. Rosenwaks refers to gas sensors for monitoring environmental quality, security uses, and medical uses as examples. "There are researchers who claim to detect cancer by chemically checking gases expelled in the breath. But to do that, extremely sensitive gas sensors are needed. A stone in a river cannot obstruct the river. But a stone in a narrow water channel can stop its flow. This is the logic behind nano-sensors. Why nano? So that the sensor will be sensitive enough to detect a single molecule. With our method, we can engineer a sensor to set off an alarm by altering its electrical conduction if a single target molecule alights on a nanowire." ●

"With our method, we can engineer a sensor to set off an alarm by altering its electrical conduction if a single target molecule alights on a nanowire."

Communicating with Microbes

Prof. Yosi Shacham places microbes on computer chips, translating information from the microbe into data that can be read on a screen.



"When I did my post-doctorate at Berkeley University," says Prof. Yosi Shacham, Department of Materials Science and Engineering, "our field was called microelectronics. But in the last decade or so, a huge buzz has developed around the word *nano*. Today it is clear that the transition between micro and nano is not merely a reduction in size, but a new field of science: The transistor in my computer is smaller than a microbe, which makes it possible for me to place microbes on chips, and for other researchers to interface chips to microbes. If you want to communicate with microbes, size definitely matters."

A SENSOR FOR EVERY CARROT

Animals have served as our first line of protection from toxins: the canary has monitored poisonous gases in coalmines; water companies utilize fish to monitor toxins in water. Prof. Shacham, in collaboration with Prof. Shimon Belkin of the Hebrew University, employs microbes.

"Prof. Belkin has developed microbes that identify water toxicity," says Prof. Shacham, "while I have devised a way to place them on a miniaturized chip. This is a more economical and humane idea than utilizing fish. In evolutionary terms, microbes developed sensitive systems for responding to toxic substances. We have found a way of translating information from the microbes into data that can be read on a screen."

"A plaster combined with a biological sensor can monitor the cut on your little finger. The smart plaster's wireless transmitter will upload data to the network to inform you about the healing process, and if you want, report the condition of your finger on the social network."

Prof. Shacham's microbial nano-laboratory has many applications. "We are working on cancer detection, in collaboration with Prof. Judith Rishpon of TAU; as well as a gas sensor to monitor crowding in chicken coops," explains Prof. Shacham. "But the most significant channel for our research is sensors for the food industry. Billions of dollars are lost every year to spoilage. Although in developed countries there is governmental control of food transport, it is difficult to supervise every truck. It is enough for the driver to make an unscheduled stop, or for there to be a problem with climate control, and somebody could die from an intestinal infection."

PRINTABLE SENSORS

Prof. Shacham will make his biological sensors more flexible by using flexible polymers. "Many groups are working on sensors," he says, "but we focus on flexible sensors, so you can print a sensor at home according to a prescription. Going out on a hike? Print a sensor and check if you can drink the water on the trail. Our dream is for private individuals to use these sensors, not only government agencies or industry."

"This new approach to production and development of sensors," adds Prof. Shacham, "can transform the situation in developing countries where there is no high-tech access. And flexible sensors can be combined with things that exist today: A plaster combined with a biological sensor can monitor the cut on your little finger. The smart plaster's wireless transmitter will upload data to the network to inform you about the healing process, and if you want, report the condition of your finger on the social network." ●

Prof. Yosi Shacham is an electrical engineer at the Department of Materials Science and Engineering. His research group works on electrochemical technologies for making metallic layers for intermediate connections to integrated circuits, barrier layers, electrodes for biological chips, sensors for detecting toxins in water, and more. In addition to his research activities, Prof. Shacham has served as coordinating manager of university research in nanoscience and nanotechnology, Head of the Department of Physical Electronics, Deputy Dean of the Iby and Aladar Fleischman Faculty of Engineering, and a member of the Board of Directors of Ramot, the technology transfer company of Tel Aviv University.

Dynamic Duo

Prof. David Andelman builds models of block copolymers—whose molecular structure combines two different materials. These polymers may contribute to developing electronic chips, screens, batteries, and solar cells of the future.

"I work in theoretical physics, in the field of *soft condensed matter*—polymers, liquids, foams, gels, emulsions, suspensions," says Prof. David Andelman, Head of the Raymond and Beverly Sackler School of Physics and Astronomy. "I build theoretical models of material properties and behavior, and collaborate with experimental groups that examine these materials in the laboratory."

TWO BLOCKS

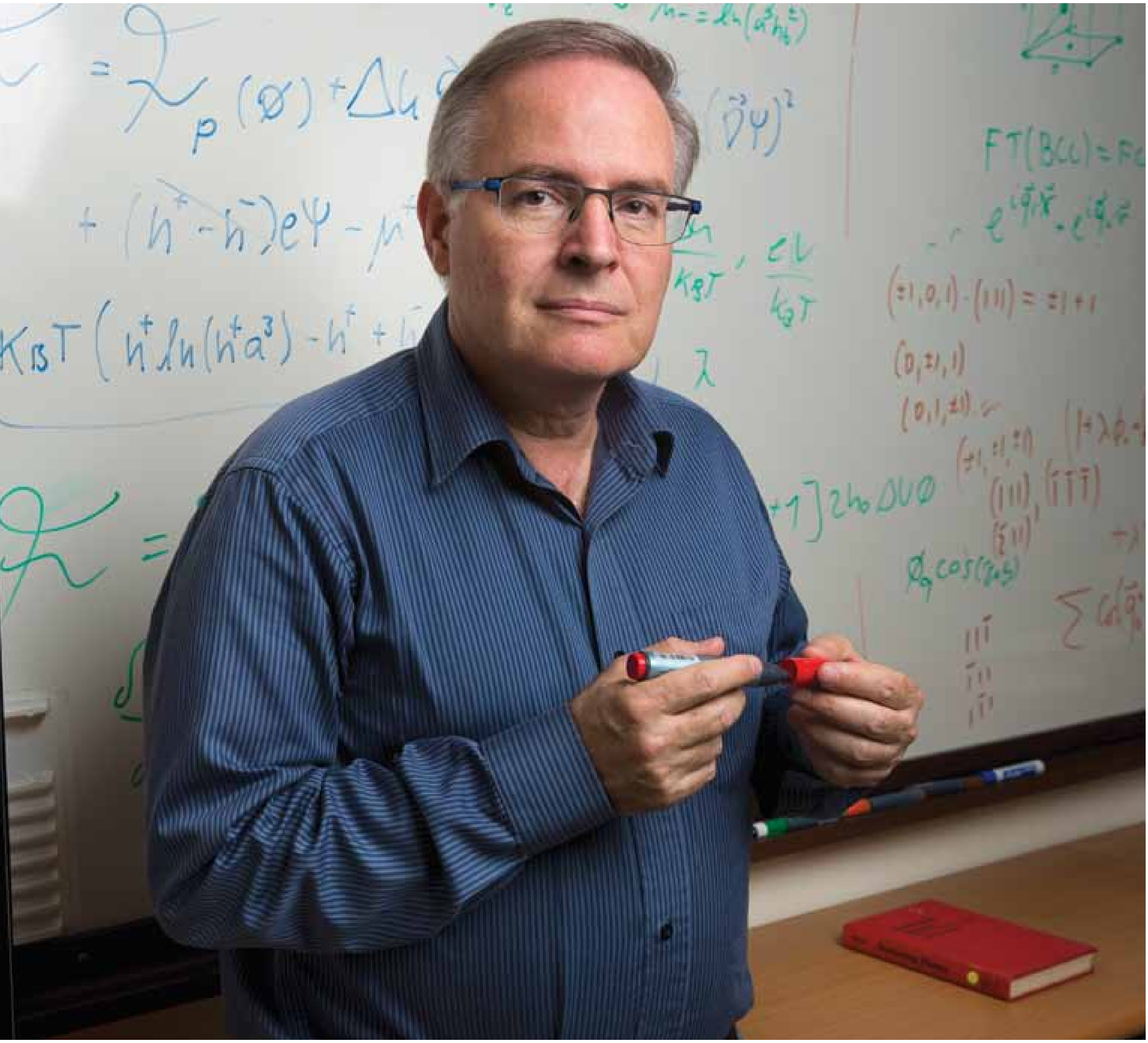
Prof. Andelman focuses on thin layers of block copolymers. "A polymer is a long molecular chain made up of repetitive building blocks called monomers," he explains. "A block copolymer molecule consists of at least two materials, comprised of different chemical building blocks, connected by a strong chemical bond. Block copolymers possess special properties that differ substantively from those of regular polymers. When regular polymers are heated to a high temperature, a viscous, amorphous liquid with no structure is created, whereas the molecules of a block copolymer organize spontaneously into stable nanometric structures. In these structures, the two materials are arranged in orderly structures: e.g. alternating layers of material A and material B; narrow tubes with material A lining the tubes and material B outside; and more complex structures.

Thanks to their special properties, block copolymers have many uses—mainly in complex materials that require opposing or complementary properties not found together in a single polymer. A good example is foam for mattresses, which must be both flexible and fire retardant. Block copolymers possess wide potential for the future: next generation LED screens, super-efficient solar cells, advanced batteries and fuel cells, among others.

ACCURACY & CONTROL

One future application is nanometric lithography for printing circuits on miniature electronic chips. "Lithographic technique creates a mold or mask that enables a particular picture to be printed many times over," explains Prof. Andelman. "Chip manufacturers such as Intel use optic lithography technology to print electronic circuits on chips. But electronics components are undergoing a rapid process of miniaturization. Today they are measured in tens of nanometers, and it looks like in a few years' time, the optic lithography method will no

Prof. David Andelman is Head of the Raymond and Beverly Sackler School of Physics and Astronomy, and is the incumbent of the Herch Moyses Nussenzveig Chair in Statistical Physics. His scientific work focuses on the physics of soft materials and biological systems. Prof. Andelman holds a combined BA in Physics and Mathematics (computer sciences) from TAU, and a PhD in Physics from MIT. He was a researcher at the College de France, Paris, and Exxon Laboratories, NJ. He joined the TAU faculty in 1987 and has been a full professor since 1995. Prof. Andelman has published over 150 scientific articles to date, which have been cited more than 7,000 times in professional literature. He is a fellow of the American Physical Society, and has won a number of prestigious awards and titles, including the Alexander von Humboldt Research Award, Germany; Bourke Award, British Royal Society of Chemistry; Henri de Rothschild Fellow, Curie Institute, Paris; Yamada Fellow, Japan; Paris-Sciences Lectureship, Paris-Tech Institute; and the Alon Fellowship and Bat Sheva de Rothschild Fellowship, Israel.



longer be effective." Researchers around the globe are searching for alternatives, and Prof. Andelman and his colleagues are investigating nanometric-structured plates based on orderly structures of block copolymers. To this end, they study methods to control the process of forming miniature structures.

"Our main challenge is to understand the physical dynamic of the materials' natural process of self-organization," says Prof. Andelman. "With this knowledge, we aim to develop sophisticated methods of artificial manipulation—physical and chemical—to obtain particular structures for nanolithographic masks, magnetic arrays, diodes, and other miniature devices. Bottom line, this technology possesses a very wide potential for application." ●

"Our main challenge is to understand the physical dynamic of the materials' natural process of self-organization...to obtain particular structures for nanolithographic masks, magnetic arrays, diodes, and other miniature devices."

Crystal Manipulation

Prof. Yoram Dagan develops smaller, more complex, and smarter alternatives to silicon. He manipulates crystals, and explains how the quantum wire will contribute to electronics of the future.

It is the age of silicon: Many of today's technological advances are driven by miniaturizing silicon semi-conductors. But miniaturization is not infinite. To create stronger and faster computers, we must find—or invent—another material that will enable information transmission, not only via electrical current.

This is what Prof. Yoram Dagan, of the Raymond and Beverly Sackler School of Physics and Astronomy and the Department of Materials Science and Engineering, is working towards. "We are developing special nanometric structures with extraordinary electrical properties," explains Prof. Dagan, "When we connect two insulating crystals, a one-atom-thick conductive surface forms between them, creating a tiny platform for chips of the future. How do we do this? We essentially fool the crystals! We grow crystal no. 1 on crystal no. 2, as if it possessed the structure of crystal no. 1. With the crystalline structure of no. 1 and the properties of no. 2, the result is material no. 3. Separately, they are two insulating materials, unremarkable in terms of magnetic and electrical properties—but the interface between them creates something new and surprising!"

ONE-DIMENSIONAL ADVANTAGE

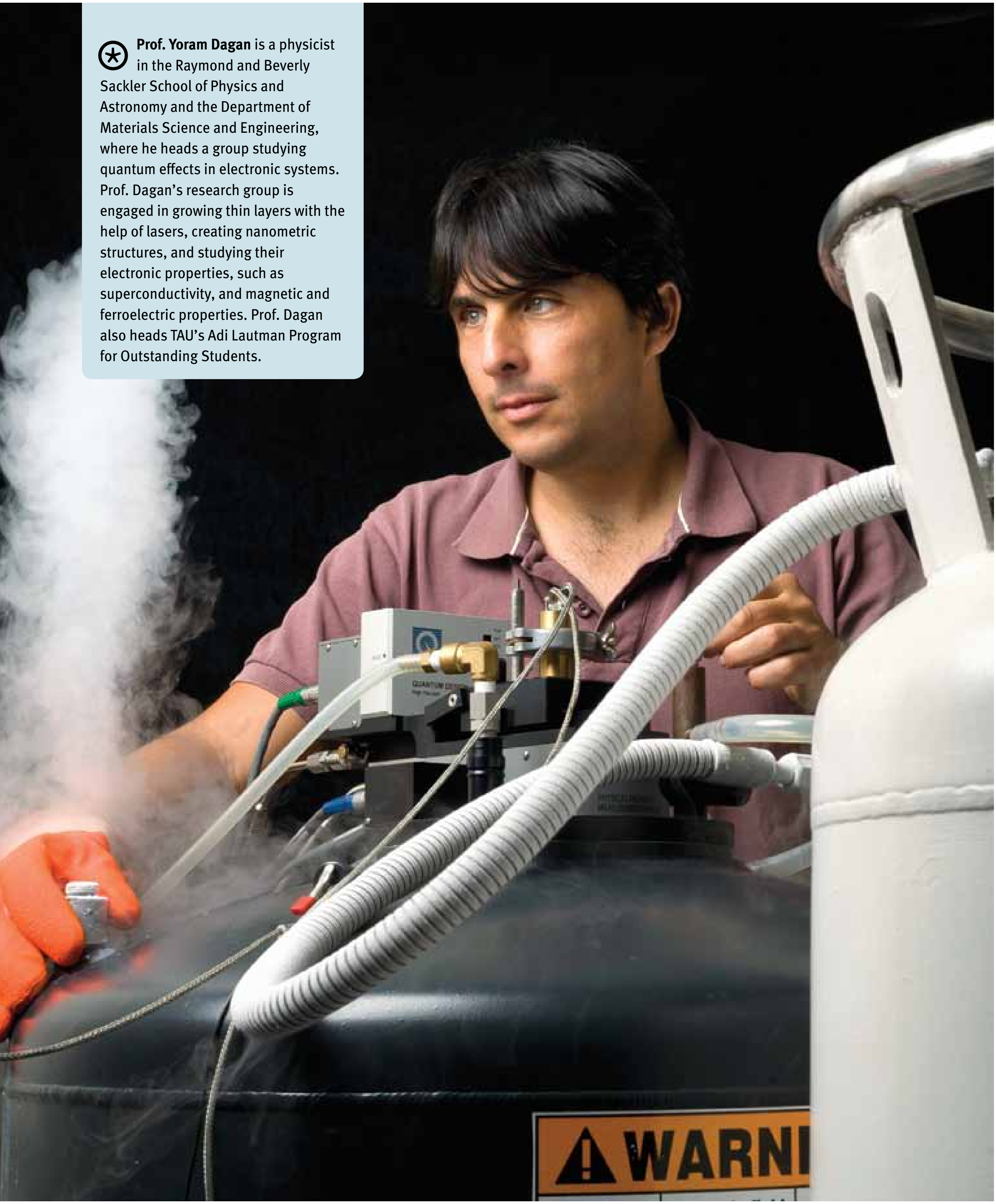
To obtain the new material, Prof. Dagan heats the base crystal to a temperature of 800°C, while the second material remains at room temperature. Ultraviolet laser signals are transmitted to the second, unheated crystal, releasing atoms that adhere to the heated material and adopt its engineering structure. The result is a surface with the thickness of a single atom, which is, in fact, a third material arranged in the crystalline pattern of the heated base material, but made up of atoms of the second material, and differing from both in its properties.

"Our innovation," says Prof. Dagan, "was to make the two-dimensional surface one-dimensional—in other words, to create a quantum wire. The advantage of a quantum wire over a two-dimensional structure is quantized conductivity: electrons can essentially enter one by one into the wire. In addition to charge, these electrons have another property: *spin*. Prof. Dagan continues, "The electronics of the future will make use of electron spin properties to store twice as much information in a single electronic base unit or memory cell, thus squaring the calculating power. In the future, our wire can make a significant contribution to spin electronics and to computing based on quantum mechanics principles."

DOUBLE MEMORY

Prof. Dagan and his colleagues are working on new interfaces between materials with unique properties. "Some materials are ferroelectric, while others are ferromagnetic," explains Prof. Dagan. "The hard disk in my computer, for example, is ferromagnetic, meaning that it 'remembers' the magnetic field. Its magnetic polarity remains fixed even after the external magnetic field has been removed. This is how hard disks are encoded today. What we are looking for is a material that is both ferromagnetic and ferroelectric. Then it will be possible to encode both magnetic and electrical encoding on any disk—and thus obtain twice as much memory for each element on the disk." ●

"Take crystal no. 1 and crystal no. 2. Separately, they are two isolated materials, unremarkable in terms of magnetic and electrical properties—but the contact between them creates something new and surprising!"



Prof. Yoram Dagan is a physicist in the Raymond and Beverly Sackler School of Physics and Astronomy and the Department of Materials Science and Engineering, where he heads a group studying quantum effects in electronic systems. Prof. Dagan's research group is engaged in growing thin layers with the help of lasers, creating nanometric structures, and studying their electronic properties, such as superconductivity, and magnetic and ferroelectric properties. Prof. Dagan also heads TAU's Adi Lautman Program for Outstanding Students.

Silver, Gold & Optical Illusions

The challenge facing Prof. Gil Markovich and his team is to grow nano-crystals from atoms of various materials with interesting physical properties. Among the applications—camouflaging objects to confuse the enemy.

Prof. Gil Markovich's Raymond and Beverly Sackler School of Chemistry research team grows nano-crystals with surprising physical properties for innovative applications in optics, electronics, alternative energy, and other industries. "Our research group uses wet chemical methods to create nano-crystals in solutions, and study the magnetism, electrical conductivity, and special optical properties revealed in nanometric dimensions. Our findings look towards applications of the future, which today may sound like science fiction," says Prof. Markovich, a physical chemist.

THE METAMATERIALS FAMILY

Two decades ago, when chemists first grew nanostructures in their laboratories, they focused on crystals with relatively simply geometries, such as balls, rods, and cylinders. These structures are made up of a limited number of atoms—from a few hundred to tens of thousands—that naturally arrange themselves in symmetrical forms. In contrast, biological molecules—such as proteins and DNA—create asymmetrical structures. "Comparing our right and left hands, we see that they reflect each other in a mirror image and cannot coincide," says Prof. Markovich. "This happens in microscopic dimensions: the right-hand spiral of DNA does not coincide with the left-hand spiral, even if the components are chemically identical. The same is true for nucleic acids that make up DNA, and amino acid building blocks for proteins." The scientific field of nanostructures with no reflectional symmetry is called *nano-chirality.*

Prof. Markovich and his group do not deal with biological materials, but with metals and semi-conductors. Their challenge is to grow nano-crystals with non-symmetric geometries—chirality—from atoms of metallic materials. They utilize biological molecules to imprint asymmetry on inorganic materials. "These nanomaterials possess unique physical properties that can inspire a wide range of innovative applications," explains Prof. Markovich. "For example, chiral materials rotate the polarization of light passing through them. This effect is relatively weak in natural biological materials. In the laboratory we aspire to create a chiral nano-spiral of metal atoms that will have a much more dramatic effect on light polarization. A material of this kind belongs to the metamaterials family—materials with unique optical properties that do not exist in nature. If we place many metallic chiral nano-spirals in transparent glass, we may obtain new optical characteristics in certain visible light ranges.

Advanced lenses may be produced with the treated glass. Another fascinating use is creating optical illusions to camouflage objects for military and security applications. "This technology is not exactly Harry Potter's invisibility cloak," he says, "but the optical illusion that we may create using nanometric metamaterials will certainly confuse the enemy."

FULL TRANSPARENCY

Another innovation from Prof. Markovich's laboratory is a transparent and flexible electrical conductor for creating flat, flexible screens for flexible electronic devices of tomorrow.

"Our transparent conductor—nicknamed nano-spaghetti—is

Prof. Gil Markovich, a physical chemist, heads the nanomaterials research group, and currently serves as Head of the Raymond and Beverly Sackler School of Chemistry. His research group is pioneering the field of nano-chirality. Prof. Markovich is also involved in various science education activities, including the Scientists of the Future program of TAU's Dov Lautman Unit for Science Oriented Youth.

a weave of gold and silver nanometric threads," explains Prof. Markovich. "Its advantage is its easy, single-stage, and relatively cheap production process, based on wet chemical methods." To cover a particular surface with the innovative conductor, all that is needed is to spread or spray the surface with, or dip the surface into, a solution containing gold or silver nanoparticles as well as other components, such as special soap molecules. The particles, which adhere to the molecules, do the rest of the work themselves: By a process of self-organization, they arrange themselves, and by additional metal deposition, form ultra-thin nano wires that densely cover the area.

"Manufacturers can easily coat large surfaces, such as wide screens or solar panels," says Prof. Markovich. "And since we are talking about the nanometric scale, the minute quantities of gold and silver will have no significant effect on the price." ●

"Our transparent conductor—nicknamed nano-spaghetti—is a weave of gold and silver nanometric threads. Its advantage is its easy, single-stage, and relatively cheap production process, based on wet chemical methods."

Sensing the Unseen

Prof. Fernando Patolsky and his research group are developing tiny sensors that detect explosives, diagnose cancer, indicate internal injury, and more.

"We seek to create new nanometric structures with beneficial applications," says Prof. Fernando Patolsky, Raymond and Beverly Sackler School of Chemistry. "We specialize in sensors—devices that identify individual molecules of a particular material within a sea of other molecules. Using nanotechnology, we are developing a range of chemical and biological sensors adapted to specific materials—explosives in an airport, a DNA molecule characteristic of an illness, viruses in the bloodstream, and even a rape drug slipped into a drink."

IN THE AIR & THE BLOOD

Prof. Patolsky's sensors are long nanostructures, or nano threads, made of silicone semi-conductors. How does a nanometric silicone thread transform into a highly sensitive sensor capable of detecting individual molecules of matter in air, blood, or a drink? Prof. Patolsky explains: "We use chemical methods to attach molecules of materials called receptors to the surface of the silicone thread. The receptors essentially grab molecules of the material that the sensor is designed to identify."

But the process does not end there. When the receptors locate and grab molecules, information must reach the semiconductor thread, and then reach the person using the detector. According to Prof. Patolsky, communication between receptors and the thread is based on a basic physical principle:

The presence of the trapped molecules creates a change in the electrical environment of the thread. "Each molecule possesses an electrical charge, and the charges of the trapped molecules create an electrostatic envelope around the thread," he says. "On a nanometric scale, such an envelope wields a considerable effect on the thread itself, and on the electrical current that passes through it. In such a tiny thread, with a diameter of a few nanometers, most of the atoms are on the surface of the thread, thus sensitizing it. The charged envelope, which would have hardly affected a thicker thread, significantly changes the flow of electrons in the nanometric thread, creating an electrical fingerprint—indicating both the material identified, and its level of concentration."

A detector based on this technology contains a silicone chip, on which hundreds of nanometric threads operate as sensors. In the presence of the target material, the tiny sensors activate, detect, and then transmit the information. A number of different sensors may be installed on one chip to detect dozens or even hundreds of materials simultaneously. A blood test of this type could take just seconds to identify levels of insulin, glucose, cholesterol, hemoglobin, enzymes, proteins, and more—at an unprecedented level of sensitivity.

ARTIFICIAL NOSE

The enormous potential for miniature sensors has not been lost on entrepreneurs. One company is developing an artificial nose—1000x more sensitive than a dog's nose—to detect explosives, which is already being tested at international airports; another is working on a sensor to detect chemical activity in cancer cells and make it possible to adapt and personalize chemotherapy treatment for each patient; a third start-up is developing a technique to detect cancer with a simple blood test based on characteristic changes in white blood cell activity; and another, currently being established, will develop a miniature optic detector to be installed on the end of a straw to detect the rape drug in drinks. Beyond nanometric sensors, Prof. Patolsky's technologies have innovative applications in alternative energy—in photovoltaic cells that convert solar energy into electricity.

Prof. Patolsky's personal favorite is the trauma chip—for medics at a trauma scene to instantly detect internal injury through a rapid, simple blood test. "Every organ in our body possesses unique proteins. When the organ is damaged, these proteins are released into the bloodstream," he explains. "A device measuring protein concentrations in the blood can indicate internal injuries of the brain, pancreas, heart, liver, and so forth within seconds to the person administering treatment. Paramedics can then inform the emergency room, saving valuable time. I hope that these systems will be installed in ambulances, and I have no doubt that they will save lives." Prof. Patolsky adds that a similar device could be used to identify injuries not revealed in CT and MRI imaging. This would prevent situations where following a concussion a patient is examined and sent home from the hospital, but collapses a few days later.

A device measuring protein concentrations in the blood can indicate internal injuries of the brain, pancreas, heart, liver, and so forth within seconds to the person administering treatment."

"I have some 40 researchers hard at work on a wide range of developments," Prof. Patolsky sums up. "We have established contacts with entrepreneurs, and several projects are in the commercialization process. I eagerly await the day when a device that we have developed comes onto the market to benefit many people." ●

Prof. Fernando Patolsky immigrated to Israel from Argentina in 1989, and holds a BA, MA, and PhD in Chemistry from the Hebrew University of Jerusalem. As a researcher at Harvard University, he developed innovative interfaces between nanotechnology and life sciences, and was one of the founders of a new scientific field: nanobiotechnology. Since 2007, Prof. Patolsky has served as Senior Researcher at the Raymond and Beverly Sackler School of Chemistry at TAU. He was the incumbent of the Raymond and Beverly Sackler Career Development Chair in 2007-8, and in 2013 won the Israel Chemistry Society Award for Outstanding Young Scientist and TAU's Applied Research Prize.

Planting a Nano-Forest

Prof. Ehud Gazit and his laboratory team create innovative materials from organic molecules.

Professor Ehud Gazit, Department of Molecular Microbiology and Biotechnology, George S. Wise Faculty of Life Sciences, and his laboratory team play with blocks—building blocks that are organic molecules. With them, they create novel materials with surprising properties. "We are proud to be part of the materials revolution of the 21st century," says Prof. Gazit. "Many periods in human history have been named for discovered materials that characterized the age—stone, bronze, and iron. In the 20th century, the polymer revolution brought us Nylon, Teflon, Dacron, Acrylon, and PVC. Today, we are experiencing the nanotechnological revolution: We can utilize nature's most basic building blocks—atoms and molecules—to build completely new structures with benificial properties. And with organic nanotechnology, we construct completely new matter from simple biological molecules, using molecular engineering methods."

HEIGHTENED SENSE OF SMELL

A decade ago, Prof. Gazit's research group identified a tiny organic molecule with which to build complex structures. "We discovered that peptide diphenylalanine molecules form tiny tubes in a process called self-assembly," he says. "We used these tubes as molds and cast silver into them. Peeling away the molds, we discovered very fine silver threads. Since then we have created a wide repertoire of new nanomaterials and nanostructures—including spheres, plates, and gels—based on simple organic molecules."

As research progressed, the researchers created "nano-forests" of surfaces covered with minute structures. They even developed methods—from evaporation to a simple technique reminiscent of ink printing—for growing nanostructures and arranging them in arrays. In this way, it is possible to scatter thousands of nanotubules over a surface the size of a pinhead, thus considerably increasing its surface area.

"These materials can be used for innovative developments," says Prof. Gazit. "One possibility generating interest is a sensor to identify explosives for sensitive sites such as airports, replacing the dogs used today. Nanometric structures are spread on a surface that is similar to a dog's nose, which contains hundreds of millions of tiny fibers. But it will be far more effective—able to identify even a single molecule of explosive from a great distance." Such nanometric forests could be used to produce super-efficient batteries and capacitors, with a significantly larger surface area for storing energy.

> **"We found that the structures we engineer from organic molecules possess unique physical properties not existing in nature, such as the mechanical strength of steel combined with the light weight of plastic."**

INFINITE APPLICATIONS

Other research directions have led to surprising discoveries. "We found that the structures we engineer from organic molecules possess unique physical properties not existing in nature," he says, "such as the mechanical strength of steel combined with the light weight of plastic." These materials are suitable for protective devices, implants, cars, planes, space shuttles, and so forth. A flak jacket fashioned of this material is twice as strong, but much lighter than existing flak jackets. Other organic nanomaterials have shown unique

Prof. Ehud Gazit is a researcher in organic nanotechnology, and heads a laboratory with over 20 researchers and research students. He holds a senior academic appointment in the Department of Molecular Microbiology and Biotechnology, and a secondary appointment in the Department of Materials Science and Engineering. Prof. Gazit is a former Chief Scientist of the Ministry of Science, and formerly served as Vice President of Tel Aviv University for R&D, and Chair of the Board of Directors of Ramot. He has received many awards, including the Landau Prize and the Herstin Award. In 2012 he was elected a fellow of the British Royal Society of Chemistry.

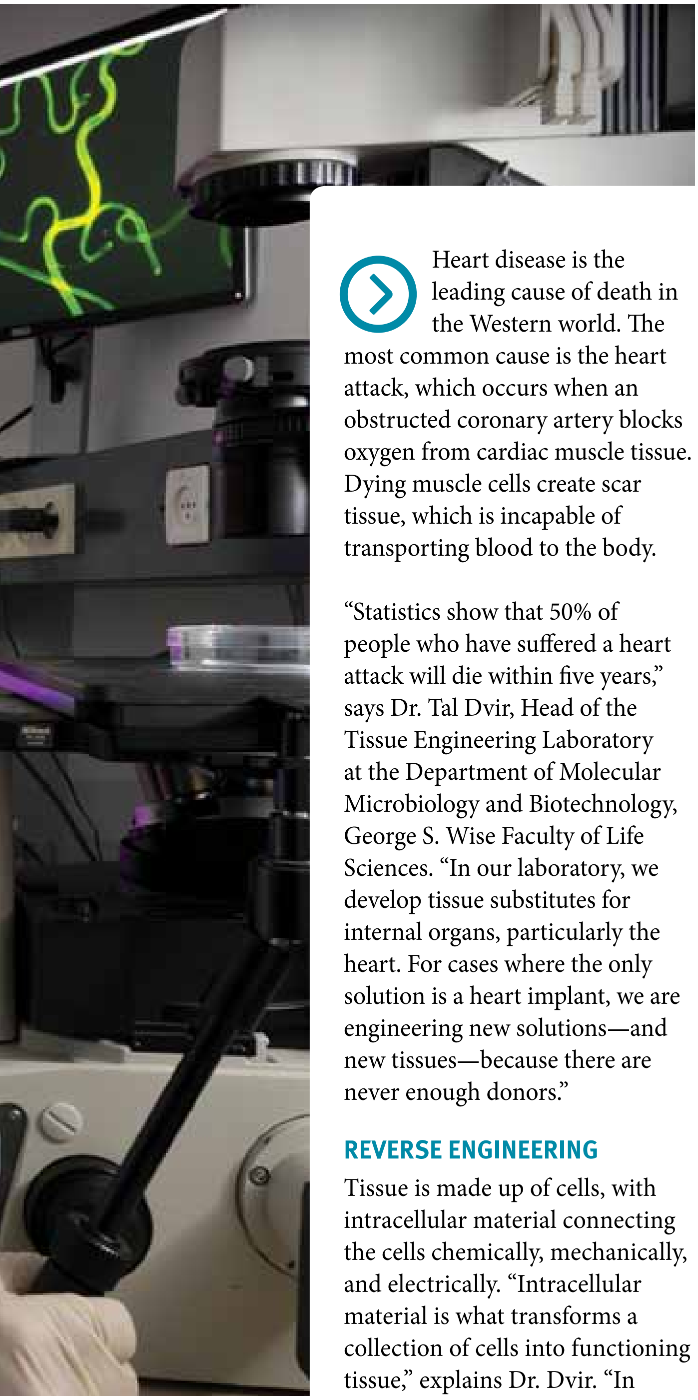
electronic, piezoelectric (producing electrical current in response to mechanical pressure), optical, and semi-conductive properties.

Some materials discovered by the group are already in development at Israeli and international companies. The technology's future potential includes innovative devices for storing energy, semiconductors for electronics, composites for the car and space industry, sensors for imaging and medical uses, and more. The Israeli start-up StoreDot has taken technologies from Prof. Gazit's laboratory one step further. Its team is applying the unique optical and electrochemical properties of organic, peptide-based nanomaterials to develop components for future smartphones and tablets.

"Organic nanomaterials possess significant advantages," sums up Prof. Gazit. "Our building blocks are common natural molecules, so the raw material is available and inexpensive. The production process is relatively simple and cheap, as molecules organize by self-assembly, usually at room temperature. And the end product is non-toxic and environmentally friendly. This is part of an exciting technological revolution that will no doubt play an increasing role in the 21st century."

Heart of Gold

Dr. Tal Dvir is developing alternatives to heart implants: engineered heart muscle tissue threaded with nanometric gold fibers.



Heart disease is the leading cause of death in the Western world. The most common cause is the heart attack, which occurs when an obstructed coronary artery blocks oxygen from cardiac muscle tissue. Dying muscle cells create scar tissue, which is incapable of transporting blood to the body.

"Statistics show that 50% of people who have suffered a heart attack will die within five years," says Dr. Tal Dvir, Head of the Tissue Engineering Laboratory at the Department of Molecular Microbiology and Biotechnology, George S. Wise Faculty of Life Sciences. "In our laboratory, we develop tissue substitutes for internal organs, particularly the heart. For cases where the only solution is a heart implant, we are engineering new solutions—and new tissues—because there are never enough donors."

REVERSE ENGINEERING

Tissue is made up of cells, with intracellular material connecting the cells chemically, mechanically, and electrically. "Intracellular material is what transforms a collection of cells into functioning tissue," explains Dr. Dvir. "In the laboratory, we reconstruct intracellular material synthetically. We study biological tissue, and then reverse engineer it by scattering cells over biomaterials and examining how the cells reorganize into tissue: How they contract; transmit electrical signals; divide; and for cardiac muscle tissue cells, how they beat."

However, there are a few problems with cardiac muscle tissue from synthetic polymers. One is rejection by the patient's immune system. The solution that Dr. Dvir and his colleagues have found is to use proteins from the patient himself. "There is nothing more suitable for the patient than his own proteins," he says. "Rather than creating them synthetically, we have produced a heart patch—based on biomaterials and cells taken from the patient himself—that possesses an excellent ability to contract. These types of tissues have already been implanted in animals."

Another problem in engineering cardiac muscle tissue is electrical conductivity. Because biomaterial is not conductive, cells scattered over a synthetic surface do not contract in unison. At the French-Israeli Conference on Nanotechnology Applied to Life Sciences, held in 2011 in Tel Aviv, Dr. Dvir presented an original solution to the problem: cardiac muscle tissue threaded with nanometric gold fibers. "Gold is an inert material. It does not react to other materials, and it does not produce an immune reaction," he explains. "Gold is approved for use by the American FDA."

"We envision a patient, at home, with our patch, and a doctor monitoring his or her heart via remote computer. As necessary, the doctor clicks to release a drug or create an electrical stimulus."

ONLINE MONITORING

Dr. Dvir and his team's most ambitious project is incorporating electronic conductors in engineered tissue. "The idea is to monitor heart function, regulate the action of engineered tissue, and even release drugs through special polymers developed for the tissue—*online*," says Dr. Dvir. "We envision a patient, at home, with our patch, and a doctor monitoring his or her heart via remote computer. As necessary, the doctor clicks to release a drug or create an electrical stimulus. We are even working on eliminating the need for the doctor, and using an algorithm to monitor the tissue from the moment it is produced in the laboratory, and for many healthy years to come." ●

Dr. Tal Dvir is a member of the Department of Materials Science and Engineering, and Head of the Tissue Engineering Laboratory at the Department of Molecular Microbiology and Biotechnology. Dr. Dvir completed doctoral studies under Prof. Smadar Cohen, Ben Gurion University of the Negev, and his post-doctorate under Prof. Robert Langer, Department of Chemical Engineering, MIT. Dr. Dvir has been awarded many prizes for his research, among them the American Heart Association Fellowship and the Alon Fellowship for Outstanding Researchers awarded by the Israeli Academy of Science.

To the Intestines!

Prof. Dan Peer develops nano-submarines to ferry drugs and imaging devices directly to diseased target sites.

"Our project represents a focused Israeli research effort to develop nano-drugs," says Prof. Dan Peer, Department of Cell Research and Immunology, George S. Wise Faculty of Life Sciences. "We enjoy substantive support from the Israel National Nanotechnology Initiative (INNI), a government initiative to establish nano research centers in Israel. Twelve research teams are developing nanoparticles to guide drugs and imaging devices directly to targets inside the body. The researchers focus on diseases involving blood vessel deficiency or excess, such as solid tumor cancers, cardiovascular disease, and heart attacks; inflammatory intestinal diseases; and viral immune system diseases, among them AIDS. Our goal is to develop applied technologies and provide scientific and technological infrastructure for establishing start-up companies in the field. The project is already sparking interest among major pharmaceutical companies."

JOURNEY IN A DIVING CELL

Prof. Peer's group focuses on inflammatory intestinal diseases, such as Crohn's and colitis. His multidisciplinary team of 18 researchers—engineers, bio-technologists, physicists, biologists, chemists, and a veterinarian—collaborates with doctors and surgeons at Sheba, Rabin, and Ichilov medical centers, as well as Snyder Institute for Chronic Diseases, Univ. of Calgary, Canada.

"We develop drug delivery strategies and nanometric diagnostic tools," explains Prof. Peer. "Our technology is based on antibody-coated nanoparticles, which recognize immune cells in the bloodstream and home in on diseased sites. These antibodies can be used as a GPS navigational system to guide nanometric particles directly to their target. We have also developed a noninvasive method—in contrast with colonoscopy and gastroscopy—for diagnosing inflammatory bowel diseases: We injected marked nanometric particles into the bloodstream of lab animals suffering from intestinal inflammation. The particles homed in on immune cells, hitchhiked with them to diseased intestinal cells, and marked them for imaging systems. By extension, these particles can transport and deliver drugs."

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

SILENCING GENES

Prof. Peer is not stopping at smart drug delivery systems. "Many research groups worldwide are developing nanometric drug carriers. Our lab is unique in that we integrate technology *and* biology. A dedicated team of biologists is concurrently investigating actual drugs. This model grants our research exceptional strength." 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 Tel Aviv University to examine patient tissue samples through a 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 global pioneer in manipulating immune cells with siRNA molecules. In the future, this method will enable tailoring medication for individual patients.

"Technology and drugs that we develop will treat diseases ranging from inflammatory bowel diseases, psoriasis, and arthritis, to different types of blood cancer—leukemia, lymphomas, and myelomas,"

Prof. Peer anticipates. “For each disease, it will be possible to custom-tailor nanoparticles to the patient’s conditions and specific needs. Two startups have already been established based on our work: Leuko Bioscience, a Boston-based spin-off focusing on blood cancers, has conducted preliminary clinical human trials with impressive success; Quiet Therapeutics, an Israeli company focusing on cancer, is expected to reach clinical trial phases in the next few years.

Prof. Peer partners with TAU colleagues: Prof. Ehud Gazit, faculty member, George S. Wise Faculty of Life Sciences, and former Chief Scientist, Ministry of Science; Prof. Itai Benhar and Prof. Rimona Margalit, George S. Wise Faculty of Life Sciences; Prof. Doron Shabat and Prof. Moshe Portnoy, Raymond and Beverly Sackler School of Chemistry; Prof. Ronit Satchi-Fainaro, Sackler Faculty of Medicine; and Prof. Jonathan Leor, Sackler Faculty of 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.

Prof. Dan Peer is a pioneer in utilizing RNA molecules for manipulating leukocytes in immune system illnesses. He was recruited from Harvard University in 2008 to join TAU and set up the Nanomedicine Laboratory at the Center for Nanoscience and Nanotechnology. He holds an academic appointment at the School of Medicine of Harvard University, Boston, MA, and at the Cancer Research Institute, Houston, TX. Prof. Peer has published over 80 articles and book chapters; is editor of three major periodicals on drug delivery systems; and sits on the scientific panel of eight journals. He is scientific adviser to a number of start-ups and large pharmaceutical companies in Israel and abroad. He has submitted 45 inventions for patent registration, and has founded two start-ups: Leuko Bioscience, Boston, and Quiet Therapeutics, Israel.

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