Science & Technology Series

Photonics and Optics Research

Science at the Speed of Light

Tradition of Excellence

Bar-Ilan University

From faster computers, to "smart" eyeglasses, to improved protocols for national security, Bar-Ilan scientists are leading the charge, by focusing great minds on photonics' potential to light up our world.

Pictured from left to right:
Dr. Avi Pe'er
Dr. Yuval Garini
Dr. Mira Barda-Saad

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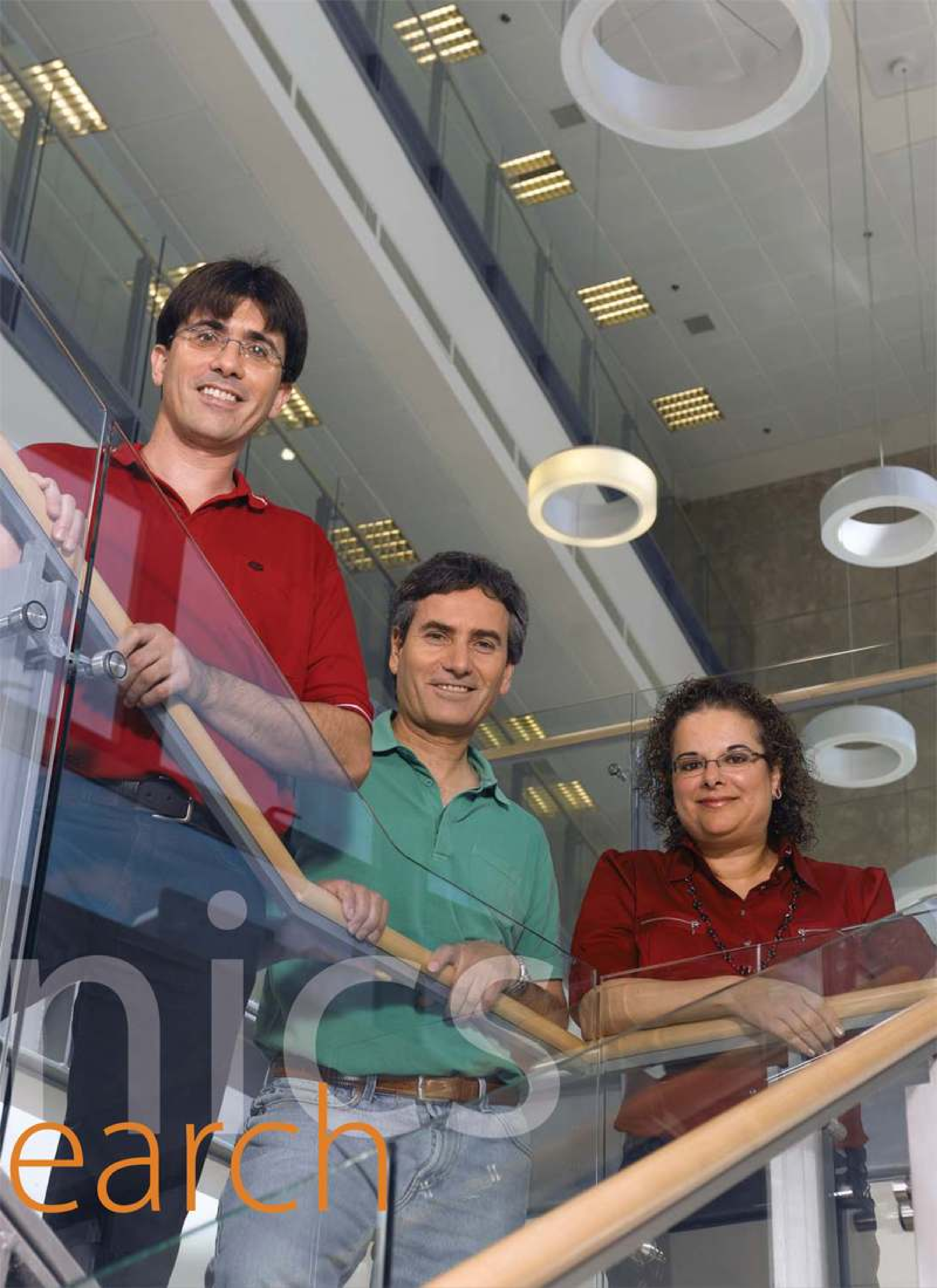
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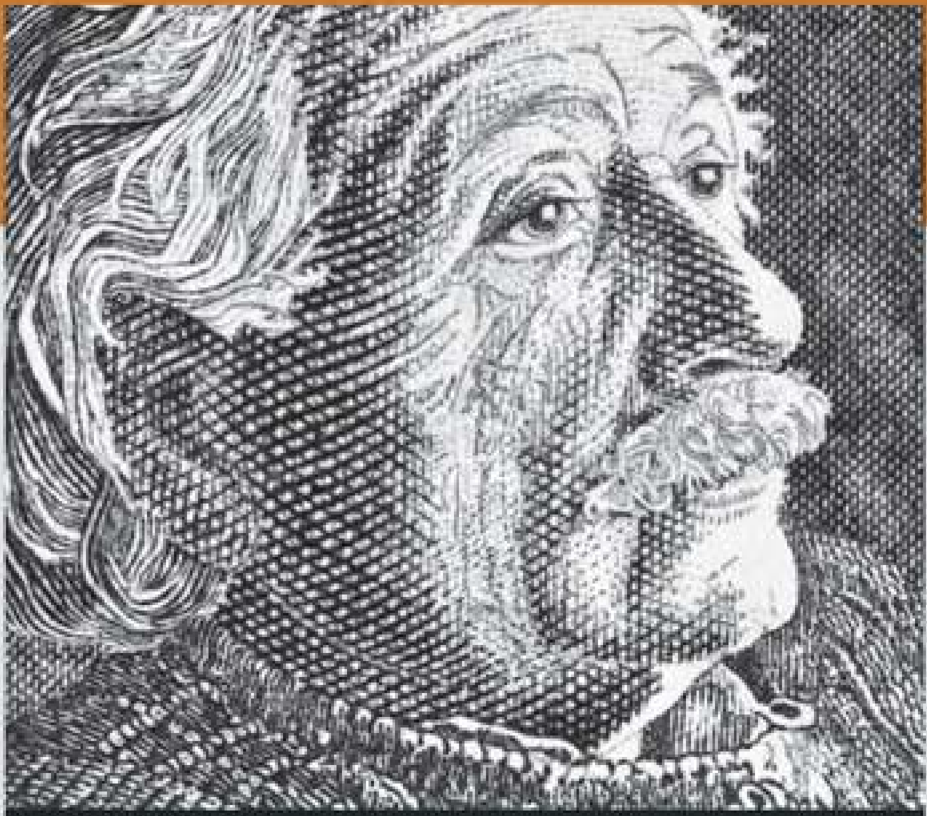

Albert Einstein

Sometimes it takes decades before the practical significance of a scientific breakthrough comes to light. This is certainly the case for the laser – a device whose theoretical foundations were laid out by Albert Einstein in 1917, some 40 years before the first working model was built. In fact, it took another ten years – and the discovery of laser-carrying optical fiber – for this technology to emerge from the lab and have a significant impact on our everyday lives.

Today, the unique properties of laser light are transforming the way we live. We have entered an era in which many of the devices we use every day – from DVD players, to bar-code readers, to our Internet connections – are activated not by electrons, the fundamental units of electricity, but by photons, the fundamental units of light.

Photonics – a scientific discipline that uses light to manipulate, transfer and store information – is poised to provide ultra-fast components for everything from communications to computers to life-saving medical technologies. At the same time, it is giving researchers the precision tools they need to solve some of the most basic and intractable mysteries of science.

At Bar-Ilan University, experts trained in physics, physical chemistry and electrical engineering are creating pioneering techniques that use light to tease more and more information out of molecules and atoms. They are characterizing the fundamental interaction between light and nano-optic circuits. And they are fine-tuning the theories that will be built into the "blueprints" for tomorrow's super-fast photonic devices and optical technologies.

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Spotlight on New Devices

In order to "grab" light and guide it toward a specific target – say, a logic gate within a computer memory device – components must be measured on the scale of hundreds of nanometers, or even less. Prof. Michael Rosenbluh, who heads the Quantum Optics Research laboratory in the Department of Physics, employs ultra-short laser pulses that manipulate materials on an atomic scale, and has successfully fabricated "nano-wires" for use in photonic applications. In other areas of his research, Rosenbluh has developed a laser-based atomic clock that is ten times smaller than those currently used in GPS systems, and requires a hundred times less power to operate. He has also shown how data derived from scattered light can be amplified – something that may lead to the creation of more powerful tools for the identification of molecules.

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In the School of Engineering, Prof. Zeev Zalevsky focuses on the generation and manipulation of light for use in ultra-small applications for high-speed information processing, chemical detection and biological sensing. He has developed next-generation optical fibers for communication networks and medicine. Zalevsky's work is being applied to everything from satellite-based remote sensing to microscopy, as well as clinical ophthalmology. In the area of neuroscience, he has created a "nano-pipette" that transmits light and electrical signals to and from activity centers in the brain.

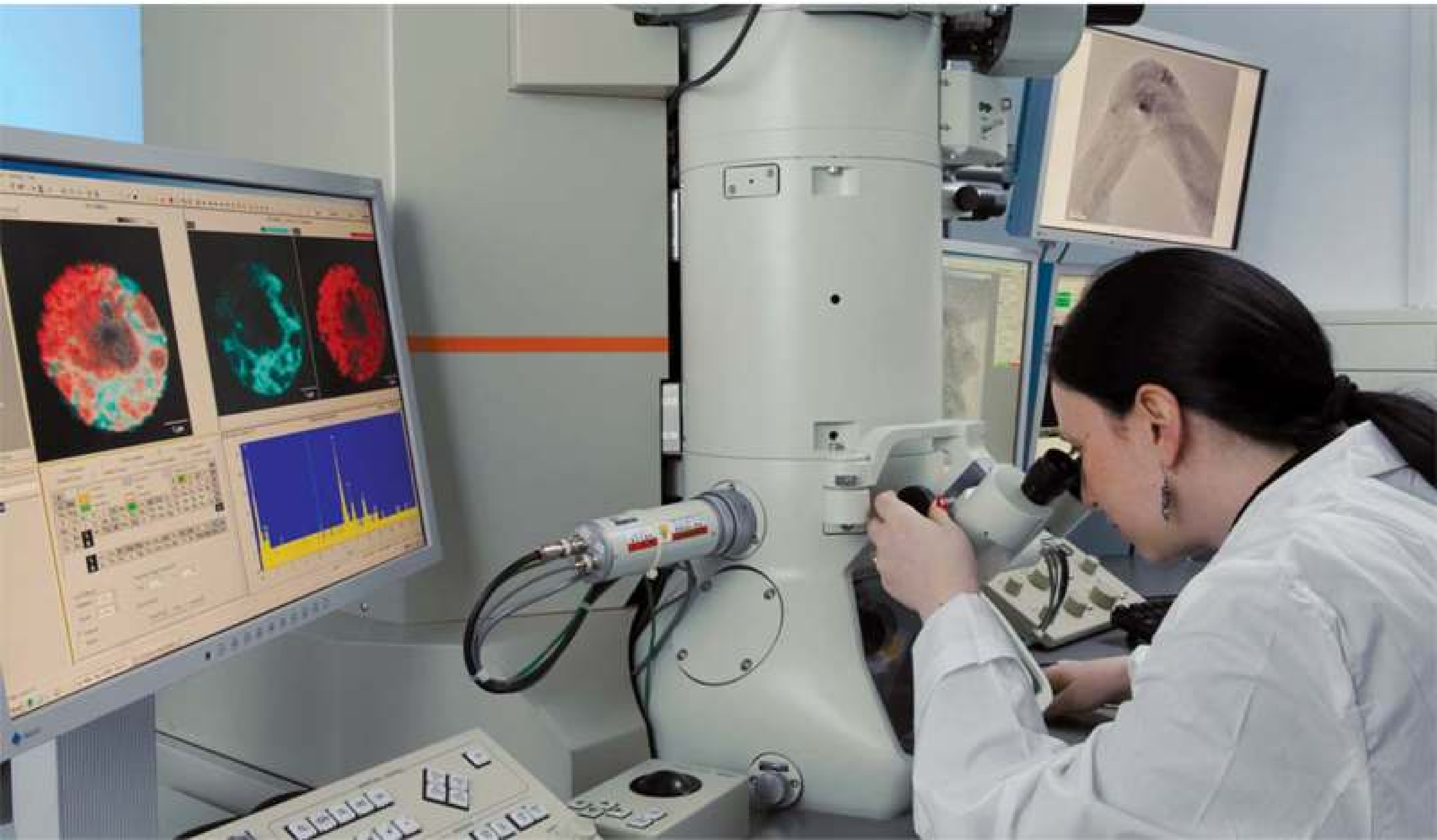
Photonics can also help scientists measure the basic forces at work within biological materials.

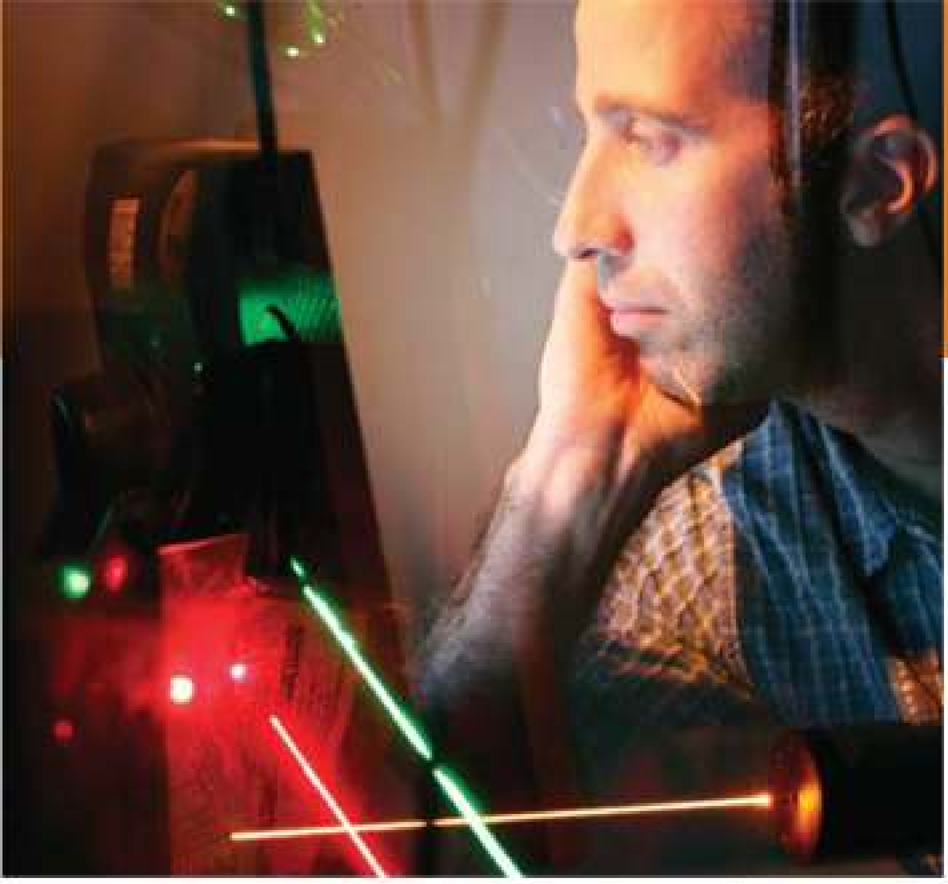
Also in the Engineering School, Dr. Avi Zadok is working on the integration of laser light into high-speed, silicon-based electronic circuits – something that would support the development of large scale, multi-processor computers. Dr. Zadok has advanced this area of research by designing layered chips in which ion-implanted materials are placed on top of a pre-patterned silicon substrate. Using a specialized, hybrid laser, Dr. Zadok has demonstrated that these chips run fast while staying cool – something vital for the endurance and stability of electronic devices. In another project, Dr. Zadok has devised a method for securely receiving encrypted messages sent over fiber optic cables.

Measuring and Manipulating With Light

In the world of music, amplifiers turn a quiet sound into something that's louder. Bar-Ilan Institute of Nanotechnology and Advanced Materials (BINA) member Dr. Avi Pe'er is developing a new "amplification" technology to brighten up the dim optical signals emitted by individual molecules – and in so doing is setting new standards for high-precision measurement of both light and matter. Using an ultra-rapid pulsed laser, Pe'er enhances light signals emitted from individual molecules by arranging for each signal to be boosted by the next incoming pulse. This "turns up the volume" without distorting the signal's message. Pe'er's methodology is a significant improvement on existing technologies currently used by scientists to "visualize" the molecular interactions that fuel chemical processes.

Photonics can also help scientists measure the basic forces at work within biological materials. Dr. Yuval Garini, from BINA's Nano-Bio-Photonics Laboratory, focuses on the development of imaging methods for the study of sub-cellular biology and genetics – studies





that are helping to clarify the structure of the genome within the cell nucleus. A multiple patent holder, Garini has developed an optical method that allows scientists to measure the physical changes that occur in DNA when it comes into contact with individual proteins, something that may be useful for screening molecules for drug design.

Dr. Mira Barda-Saad, from the Mina and Everard Goodman Faculty of Life Sciences, is another researcher who is using photonics in the form of microscopy-based equipment for applications in the field of immunology. Barda-Saad is advancing our understanding of immune-cell activation – knowledge that could lay the foundation for the development of therapeutic approaches to cancer and infectious disease.

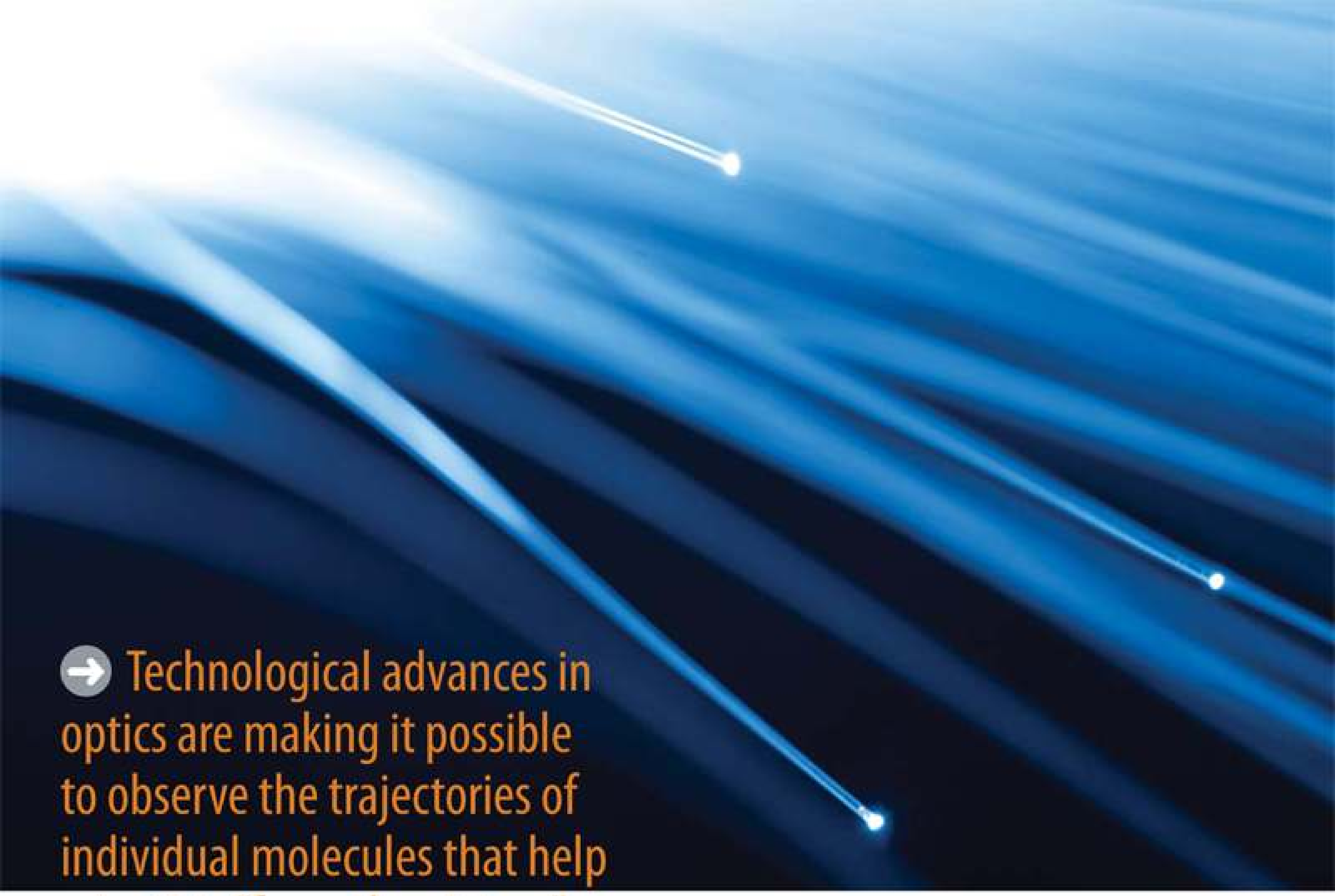
When you want to monitor something that happens very quickly, you need a rapid detection mechanism. That's why the light-based methods employed in the laboratory of BINA member Dr. Yaakov Tischler are so effective for characterizing chemical reactions – in particular, the speedy reactions that take place in the presence of catalysts. Tischler uses ultra-fast laser spectroscopy to characterize the properties of light-activated materials arranged in films only one molecular layer thick, and has shown that such "monolayers" generate an enhanced optical signal. This discovery may lead to improved sensors for a variety of applications. In addition, Tischler is working on the development of next-generation nano-lasers for the promotion and control of chemical catalysis.

In recent years, two separate Nobel prizes were awarded to physicists whose research involved using laser light to cool atoms. As temperatures dropped, atomic movement slowed dramatically – something that allowed these scientists to observe the behavior and structure of individual atoms with more precision than ever before. Today, Dr. Lev Khaykovich, of the Department of Physics, is manipulating the motion of atoms using a wide range of laser-based techniques. First, a laser slows down atomic movement. Then, slow atoms are "trapped" by a second laser that brings their temperature to an unprecedented level – close to absolute zero. This triggers a new state of matter called a Bose-Einstein Condensate (BEC), in which atoms lose their individuality, and seem to act as one. By manipulating these BEC-state atoms using yet another laser, Khaykovich is able to model the atomic-level behavior of complex systems. His studies are also helping to characterize the quantum behavior of atoms – something that may improve scientists' ability to measure and understand fundamental forces such as electromagnetism and gravity.

From Theory – To Practice

Technological advances in optics are making it possible to observe the trajectories of individual molecules. One might think that single-molecule tracking would provide a more accurate picture of molecular dynamics than the more common technique of averaging the data extracted from a larger sample. However, Prof. Eli Barkai who developed the theory of single molecule spectroscopy while doing post-doctoral research at MIT, has shown that the character of data generated by single molecules or nano-objects is qualitatively different from data obtained in conventional experiments. He has developed specific methods that help scientists "focus the picture" and achieve statistically relevant information.

Prof. Arlene Wilson-Gordon, of the Chemistry Department, is another researcher who draws on quantum mechanics – the theory that explains the



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behavior of matter and energy on the atomic and subatomic level – to characterize how light and atomic systems interact. Using laser light, Wilson-Gordon manipulates groups of atoms so that light passes through them without being absorbed. In another area of her work she is characterizing an electromagnetic phenomenon that allows scientists to "store" light by slowing it down while it passes through a particular medium. These and other studies are revealing important data that may be parleyed into photonics applications ranging from optical devices for measuring magnetism to super-accurate atomic clocks.

When sensitive information – like a credit card number – is sent over the Internet, it is scrambled to protect the sender's privacy, then unscrambled at the receiving end. Prof. Ido Kanter, a theoretician from the Department of Physics, has clarified the way in which chaotically-generated laser light can also be used as an encryption tool. Working together with his departmental colleague Prof. Michael Rosenbluh, Prof. Kanter showed how, when two lasers emitting random pulses are trained one upon the other, they begin to synchronize, eventually "firing" in an exactly coordinated pattern. This phenomenon could be used to send uncrackable, coded messages over long distances. In another project, Prof. Kanter is applying his studies of chaotic lasers to the theory of neural networks, specifically, propagation patterns of nerve impulses in the brain.

Photonics in Focus at BIU

At Bar-Ilan University, photonics research is building up the knowledge-based bandwidth that is fulfilling society's need for ever-faster and more powerful technologies. By using light to break the "speed limit" of the electronic age, BIU researchers are cracking fundamental mysteries of basic science, and illuminating a future that is brighter – and more information rich – than ever before.

For more about the research of BIU faculty listed in this brochure go to: www.biu.ac.il and click Research.

BIU's Leslie and Susan Gonda (Goldschmied) Nanotechnology Triplex

Bar-Ilan University
Science and Technology

Bar-Ilan University stands at the forefront of cutting-edge research. Bar-Ilan researchers are making breakthroughs that improve life around the globe in areas such as drug-development, nanotechnology, medical research, bio-engineering, microscopy, optics, communications, energy, security, and more. As part of a national program to combat Israel's brain drain, BIU has taken the lead by committing to absorb dozens of returning experimental scientists within its world-class research infrastructure, and has added state-of-the-art physical facilities in engineering, brain sciences and nanotechnology to house these innovative initiatives. The Science and Technology Series highlights some of the University's most exciting research endeavors.

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