TEL AVIV UNIVERSITY

NANONEWS

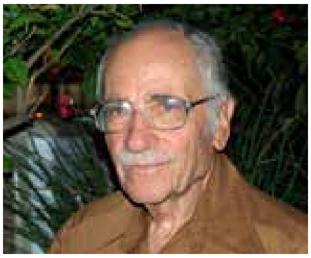
Tel Aviv University Center for Nanoscience and Nanotechnology

Editors: Dr. Nava Ariel Sternberg and Prof. Koby Scheuer

This issue is dedicated to the memory of

Prof. Enrique Grunbaum,

(1926-2013), a great friend and a mentor.



Enrique Grunbaum was a first rate scientist who devoted much of his talent and time towards building the foundations of modern materials science at Tel Aviv University. In this field he was the first to develop at TAU electron microscopy and ultra-high vacuum technology, in the framework of a close cooperation between the Faculties of Exact Sciences and Engineering. These are some of the main components now supporting the work of many scientists at the Nano-Center. Enrique had a sharp eye for talented colleagues, technicians, and students. Some of his former students now hold key positions at TAU, as well as in academia and in industry. Enrique was himself highly regarded in Israel and abroad for his work and originality. I had the privilege of working with him daily for over 40 years. Let his memory be blessed and his contributions remembered.

Guy Deutscher

Featured article

Self-Accelerating Beams of Photons and Electrons

Ady Arie

Dept. of Physical Electronics, School of Electrical Engineering,
Tel Aviv University

1. A new solution to the Schrodinger equation

As some of us remember well from the introductory course in quantum mechanics, the underlying equation in quantum mechanics is the Schrodinger equation, that describes the evolution in time of a physical system. This system is described using its wave function $\psi(\boldsymbol{r}, t)$, and for the simpest case of a free-particle, it is given by:

$$i\hbar\frac{\partial\psi(\boldsymbol{r},t)}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi(\boldsymbol{r},t)$$

Here $\hbar$ is the reduced Planck constant and m is the mass of the particle. The probability density of finding the particle at a given place and time is $|\psi(\boldsymbol{r}, t)|^2$. In 1979, Berry and Balazs [1] found a new and very surprising solution of this Schrodinger equation, in which the probability density function is given by:

$$|\psi(\boldsymbol{r},t)|^2 = \left[A_i\left(x - {}^1\!/_2\, at^2\right)\right]^2$$

Where A_i is the Airy function. This appears to be a counter-intuitive result, owing to the fact that the entire wave function is accelerating, despite the fact that no forces are exerted on the particle. Moreover, the Airy function has many lobes, and each one of them is of finite size at a certain location. We therefore naively expect that owing to diffraction, these lobes should expand as the wave-function propagates in space and time, but as can be seen from the solution, each one of the lobes, and in fact the entire wave function remains unchanged.

It should be emphasized that the solution of Berry and Balazs is an exact solution of the Schrodinger equation, and no approximations were made. Is this "self-acceleration" of the wave function a contradiction to the well-known Newton second law of mechanics? I will come back to this question towards the end of this article.

2. Airy beams in optics

Not much has happened in the 28 years that followed the surprising paper of Berry and Balzas, since no one knew how to create a wave function of a particle in the form of the Airy wave function. However, in 2007, Christodoulides and co-workers suggested to test

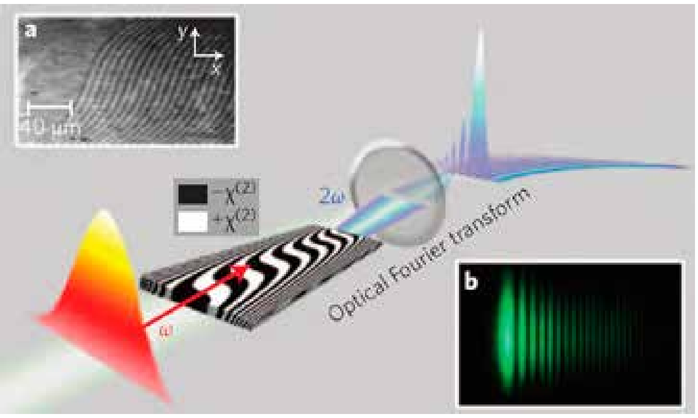


Figure 1: Nonlinear generation of Airy beams [3]. A Gaussian pump is converted to a second-harmonic Airy beam in an asymmetric nonlinear photonic crystal. ω is the angular frequency of the Gaussian pump beam. **a**: Microscope photograph of the upper facet of the quadratic crystal, after selective etching (which reveals the inverted domain pattern). The x- and y-axes were rescaled for viewing purposes and are not comparable. **b**: Profile photograph of the green second-harmonic Airy beam.

this wave function in the optical domain [2]. Their proposal and first experimental realization relied on the similarity between the Schrodinger equation for massive particles, and the paraxial Helmholtz equation for light beams:

$$2ik\frac{\partial A}{\partial z} = -\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)A$$

Here A is the complex envelope of the light beam and k is the wave vector. Note that the time coordinate of the Schrodinger equation was replaced by the propagation coordinate z. This equation is valid under the paraxial approximation, which means that the beam is confined to small angles with respect to the z-axis – the propagation direction. This means that an Airy beam will "bend" along a curved parabolic trajectory in free space. This is another counter-intuitive result, since we know that light beams travel in straight lines in free-space. This will be discussed in the final part of this article.

Airy optical beams became a very active area in light optics in recent years, with applications in nonlinear optics, lasers, micro-particle manipulation, generation of curved plasma channels, Airy plasmons, etc. As an example, at Tel Aviv University we have demonstrated for the first time, methods to generate and manipulate Airy beams using nonlinear optics [3]. Figure 1 shows a setup that converts an infrared laser light into an accelerating Airy beam at the second harmonic. The nonlinear interaction enables the all-optically control of the sign and magnitude of the accelerating beam. Another optical application is the Airy beam laser [4]. In this case the output coupler of a laser cavity was replaced by a specially designed hologram in which the far field first diffraction order was a two-dimensional Airy beam, while the 0^{th} order was reflected back to the laser cavity in order to enable the laser to oscillate.

3. Electron Airy beams

Recently we have applied methods that were developed in the optical regime to the electron regime, thereby generating for the first time an Airy beam for a massive particle – an electron [5]. This was achieved by diffracting the electrons through a nanoscale hologram that imprints on the electron wavefunction a cubic phase modulation in its transverse plane, see Figure 2. We observed the spatial evolution dynamics of an arc-shaped, self-accelerating and shape preserving electron Airy beams, thereby confirming the theoretical predictions of Berry and Balazs [1]. The key element that enabled the realization of this electron beam is a special nanoscale hologram for electrons. It was constructed from a thin (50 nm) membrane of SiN which was coated with 10 nm of gold and then the required pattern was milled in it using a Focused Ion Beam miller. The entire experiment was performed inside the TAU Transmission Electron Microscope. A field emission gun was used as the source for the electron beam, and the magnetic lenses inside the microscope enabled to transform the electron wavefront that passed through the SiN membrane to the desired Airy beam. It is shown experimentally that the electron wave-function can self-heal, restoring its original shape after passing an obstacle. This method opens up new avenues for shaping and manipulating electron beams, with potential applications in electron microscopy, electron interferometry and electron-matter interactions.

4. Accelerating beams with convex arbitrary curvature

The Airy function is an exact solution of the paraxial Helmholtz equation, or equivalently, of the Schrodinger equation for a free particle, however, these wave-functions carry infinite energy. An actual Airy beam, however, carries finite energy and is obtained by truncating the infinitely long tail of the Airy function by using an exponential or Gaussian window. The truncated Airy beam preserves its shape and self-accelerates, but only over a finite distance. It was shown [6] that free-space non-spreading beams, propagating along arbitrary convex trajectories over *finite* distances, can be realized. This is an extension with respect to the parabolic trajectory that exists in the case of an Airy beam. Quite recently we have extended this concept of arbitrary "bending" to the field of surface plasmon-polariton (SPP) waves [7]. These are surface electromagnetic waves that are coupled to electron waves and propagate at the interface between

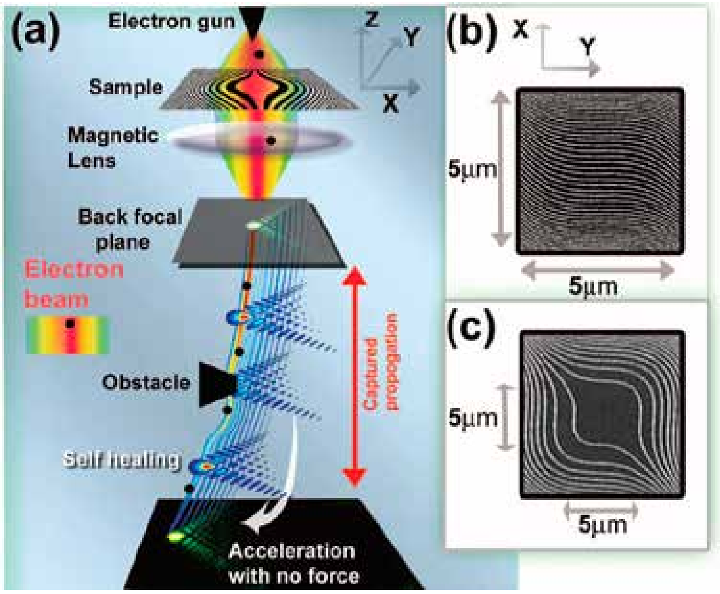


Figure 2: Setup for generating electron Airy beams [5]. The electrons are emitted from the field emission gun, pass through the nanoscale hologram and Fourier transformed using a magnetic lens. The desired electron beam is obtained at the back focal length, and it can then propagate to the slow-scan camera. (b) and (c) are two examples of masks that were produced for generating the electron Airy beams.

a dielectric and a metallic medium. In order to excite these beams we have designed a special two-dimensional coupling element that compensates for the wave-vector mismatch between an input free space beam and the plasmonic beam and simultaneously sets the required transverse phase for the plasmonic beam, so that the required caustic shape will be obtained. These coupling elements were then fabricated by electron beam lithography and the light distribution of the plasmonic beam was measured using near-field scanning optical microscope (NSOM), as shown in Figure 3. In this figure, the caustic curve is not a parabolic curve, and is described by $Y=az^{1.5}$, where *y* and *z* are the transverse and propagation coordinates, respectively.

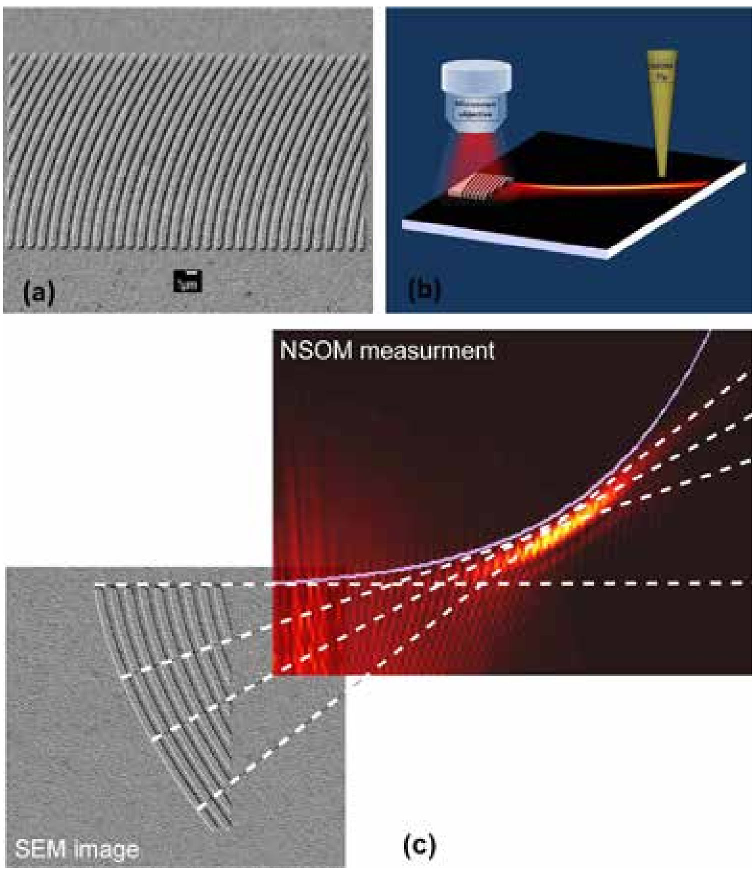


Figure 3: (a) SEM image of the fabricated binary plasmonic phase mask for the case $Y=az^{1.5}$.
(b) Experimental setup. (c) Geometrical representation of the construction of a caustic SPP. Geometrical rays (white dashed lines) emanating from the two-dimensional plasmonic binary phase mask (a SEM image) which generated the caustic SPP (NSOM measurement). The mask and the measured SPP are for the case of an exponential trajectory (a solid purple line shows the analytical curve) [7].

5. Sharply bending beams – Mathieu and Weber beams

So far we have discussed mainly the Airy beam, which is a solution for the paraxial Helmholtz equation. However, there are also exact solutions to the non-paraxial Helmholtz equation that exhibit self-acceleration. These beams can therefore "bend" to much larger angles with respect to the Airy beam. The Mathieu beam is a solution of the Helmholtz equation in an elliptical coordinate system, and propagates along an elliptical trajectory, whereas the Weber beam is a solution of the Helmholtz equation in parabolic coordinate system, and propagates along a parabolic trajectory. Much like the Airy beam, these beams also preserve their shape as they propagate and can "self-heal" from a blocking obstacle. They were demonstrated last year for the first time in free space [8]. Quite recently, we have demonstrated that these Mathieu and Weber beams can also be realized with surface plasmon polaritons. This was done by designing and fabricating a special coupler, that transforms an incoming free space Gaussian light beam into the desired surface-wave beam. The NSOM measurements, which also include measurements of plasmonic Airy beam for comparison, are shown in Figure 4. It can be clearly seen that the caustic curve of these beams follow quite well the analytic shape.

6. Is there any contradiction to known laws in mechanics or in optics?

So far we have described a series of results that may appear to contradict the basic laws of classical mechanics and optics. It is therefore important to emphasize that none of these results stand in any contradiction to these laws. All the beams that were described here - Airy, Mathieu, and Weber - are exact analytic solutions to the underlying equations of quantum mechanics and optics, the Schrodinger equation and the Helmholtz equation. However, these beams carry infinite energy and their wave function is not square-integrable, which means that we cannot define a center of mass for them. Furthermore, when one considers a finite energy beam, which is obtained by truncating the long tails of these beams with some finite exponential or Gaussian window, a center of mass can be defined, but in that case it propagates in a straight trajectory. Still, although all the physical laws are preserved, these beams provide a clear illustration of the difference between a wave-function that can accelerate without any forces and a classical particle that is constrained to move in a fixed velocity [1].

Acknowledgement

There are many current and former students that contributed to the results I reported here, including: Dr. Tal Ellenbogen, Dr. Ayelet Ganany-Padowicz, Dr. Noa Voloch-Bloch, Ido Dolev, Gil Porat, Itai Epstein and Ana Libster. I would also like to thank my collaborators in the electron Airy experiment, Prof. Avi Gover, Dr. Yossi Lereah, and Dr. Yigal Lilach.

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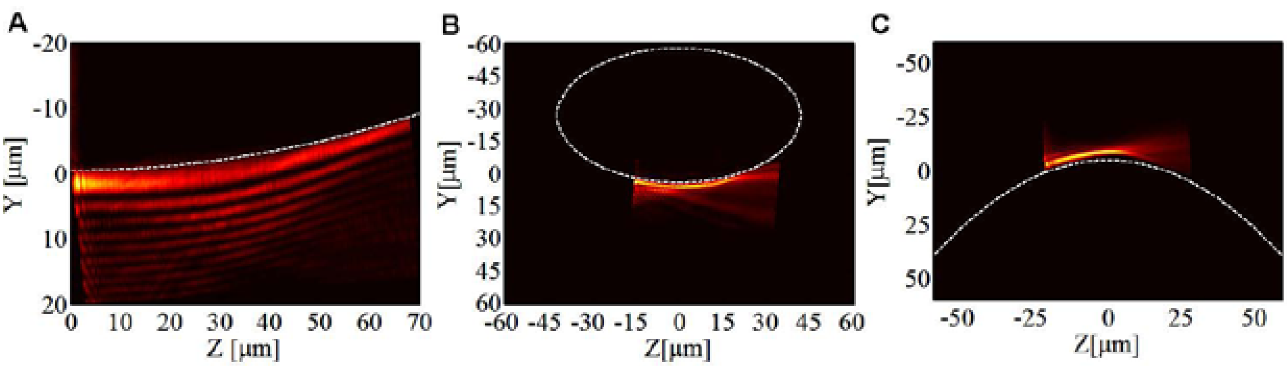


Figure 4: Measurements of plasmonic Airy, Mathieu and Weber beams. (A) Plasmonic Airy beam, (B) Plasmonic Mathieu beam, and (C) Plasmonic Weber beam. The white dashed line in all figures represents the designed analytical trajectory of acceleration.

Research news

Nonlinear Optical Bio-inspired Peptide Nanostructures

Amir Handelman[1], Sergey Lavrov[2], Andrei Kudryavtsev[2], Artium Khatchatouriants[3], Yuri Rosenberg[3], Elena Mishina[2], and Gil Rosenman[1]

[1]School of Electrical Engineering-Physical Electronics, Faculty of Engineering, Tel Aviv University; [2]Moscow Technical University of Radioengineering, Electronics and Automation, Moscow, Russia; [3]Tel Aviv University Center for Nanoscience and Nanotechnology

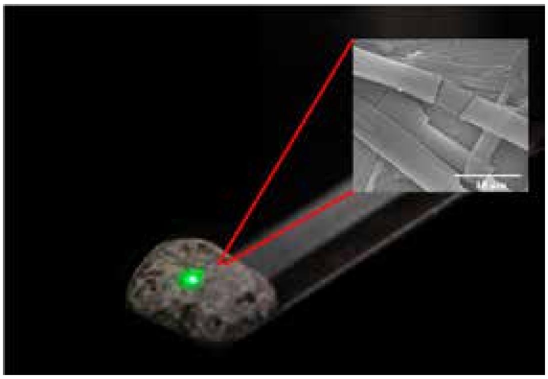


Figure 1 Frequency conversion (IR-to-green light) from a bundle of **FFF** peptide nanobelts

A nonlinear optical effect of a second harmonic generation (SHG) was first observed in quartz and then found in many inorganic materials that have an asymmetric crystalline structure. Second-order nonlinear response was also found in organic and biomaterials and has been exploited in biomedical science for fundamental studies of helical and chiral biological molecules, such as proteins and amyloid fibrils. Another class of bio-organic materials is man-made bioinspired nanostructures materials, which are composed of chemically synthesized biomolecules, and self-assemble into supramolecular nanofibrils. Most of these materials have an asymmetric crystalline structure, and possess ferroelectric and related phenomena such as piezoelectricity and SHG as intrinsic physical properties.

In this work, we have studied SHG effect in bioorganic peptide nanostructures having different morphologies and symmetries, such as nanotubes, nanofibers, nanobelts and nanospheres. These peptide nanostructures were self-assembled in solvents of different origins from precursors with variable number of phenylalanine amino acid (F) units. Pronounced SHG response was detected in FFF-nanobelts, FF-nanotubes and FFF-nanospheres. SHG and Raman spectroscopy studies during phase transformation in FF-nanotubes allowed defining intermolecular bonds responsible for SHG. Using two-photon optical microscopy, we found orientational molecular ordering in aligned peptide supramolecular structures by adapting a generic model that was earlier developed for diverse biological protein fibrils. We demonstrate efficient optical frequency conversion from near infrared to visible green (**Figure 1**) and blue light as well as an effect of nonlinear optical waveguiding (**Figure 2**). These results allow us to propose these bio-inspired nanostructures as a new generation of nonlinear optical nanomaterias, which can be integrated into nano-photonic devices and optical frequency converters.

Reference

Handelman, A., Lavrov, S., Kudryavtsev, A., Khatchatouriants, A., Rosenberg, Y., Mishina, E. and Rosenman, G., Nonlinear Optical Bioinspired Peptide Nanostructures, *Adv. Opt. Mat.*, **2013**, 1: 875–884, doi: 10.1002/adom.201300282

* This work has been awarded for best poster in the 1st SPIE student chapter conference and in the Physical Electronics Department Conference, Tzuba, 2013

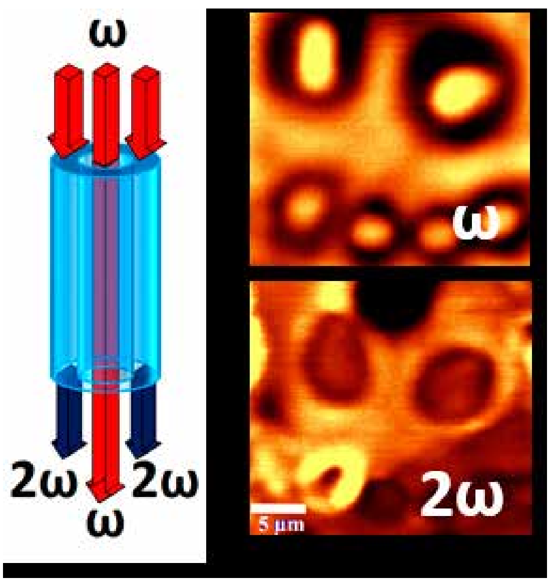


Figure 2: Illustration of the fundamental and second-harmonic generated wave (red arrows – fundamental wave, blue arrows – SHG wave), top: Linear waveguiding of **FF** peptide nanotubes, bottom: Non-linear waveguiding of **FF** nanotubes

On the Uniqueness of the steady-state in molecular junctions

Eli Wilner[1] & Eran Rabani[2]

[1]School of Physics and Astronomy, Faculty of Exact Sciences, Tel Aviv University
[2]School of Chemistry, Faculty of Exact Sciences, Tel Aviv University

In recent years, a growing interest in the properties of molecular transport junction devices has raised fundamental and conceptual issues regarding the nonequilibrium physics of nanometer scale systems. For example, applying voltage to a molecular junction may lead to a deformation of the molecular geometry induced by the coupling between electronic and vibrational degrees of freedom. It has been argued that the mechanism that gives rise to this deformation also leads to multiple steady-state solutions for the average electronic populations of the molecule and thereby to multiple steady-state solutions of the corresponding currents. In fact, the "uniqueness" of the steady state has been an open problem touching upon other fields of nanoscience as well. Understanding this phenomenon and the coupling of individual molecules to macroscopic electrodes under nonequilibrium conditions, calls for the development of robust modeling methods.

To address this problem, we have developed an exact approach within the reduced density matrix formalism where a memory term describing the "history" of the dynamics of electrons was introduced systematically. Apparently, the term describing the memory, also known to give rise to non-Markovian effects, holds a significant amount of information regarding transient properties as well as the relaxation to steady state. Simplifications of the approach relies on the fact that out of equilibrium systems "forget" their "history" rapidly, and therefore the short-lived memory can be calculated within a proper many-body impurity solver. Thus, exact description at short times combined with a short-lived memory provides access to the dynamics at all times as the system approaches steady-state, without introducing uncontrolled approximations.

Next, we considered a generic model for quantum transport through a quantum dot with electron-phonon interaction and proved, based on the reduced dynamics formalism that a unique steady state exists regardless of the initial electronic preparation of the molecular quantum dot. However, more than a single steady state can exist for different initial phonon preparations. In Figure 1 we show the steady state value of the differences between the average electronic occupation of the quantum dot for two different preparations of the phonon distribution ($\Delta\sigma$). For a unique steady-state solution, this quantity should vanish. Finite values indicate more than a single steady-state solution. Indeed, we find a regime of parameters where bi-stability is observed. The bi-stability is expected to disappear at vanishing electron-phonon couplings (λ) and at high phonon frequency (ω) away from the adiabatic regime. Interestingly, it also vanishes at high values of the coupling λ.

Adopting the language of statistical mechanics, can be thought of as an order-parameter in the system and thus, the 2D plot in the figure can be viewed as a "phase diagram". In molecular junctions, particularly those who involve electron-phonon interaction, the observed transition point (unique stability or bi-stability) occurs as the effective energy of the molecular dot passes through the window of conductivity which is determined by the applied voltage known as the resonance situation.

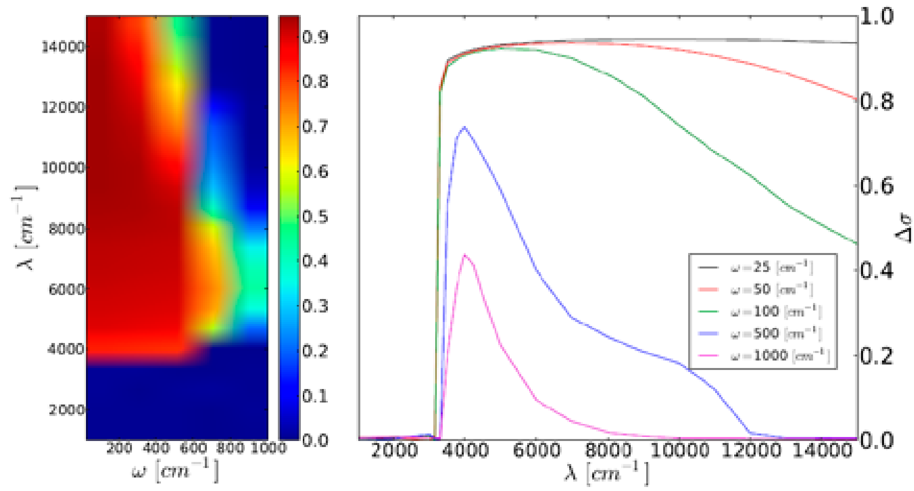


Figure 1: Zero temperature average electronic population of molecular quantum dot with energy ε_d=1/2 eV and applied bias of 0.1 eV.

XIN – A New Nano-Collboration

The Tel Aviv University Center for Nanoscience and Nanotechnology is pleased to announce the foundation of a unique collaborative initiative, the Xin Center, for promoting scientific innovation. The Xin Center establishment is part of a new collaboration between Tel Aviv University and Tsinghua University in China. To lead this project, Dr. Ramon J. Albalak joined the Center in November 2013 as Head of International Collaboration. Dr. Albalak has a broad academic background which includes a doctorate in Chemical Engineering from the Technion in Israel and and post-doctorate in the Dept. of Materials Science and Engineering at MIT, Cambridge, Massachusetts. He has over 15 years of experience managing industrial research and development. Ramon joins the Center after completing 6 fruitful years at one of Israel's industrial success stories, Caesarstone (Nasdaq: CSTE), where he served as Vice President for Research and Development.

Xin, which means "new" in Chinese, will nurture talent and originality, advance interdisciplinary research, expand academia-industry cooperation, and enhance the Chinese-Israeli contribution to scientific and technological progress in both countries as well as in the rest of the world. Focusing on high-impact and ambitious R&D projects, Xin will create an international hub for innovation by building a sophisticated laboratory complex, recruiting top scientists in China and Israel, supporting faculty and student exchange, awarding fellowships to the very best students, and pursuing collaborative activities with industry. Xin students will benefit from a unique mentoring system in which leading scientists and figures from industry and the business world accompany them throughout the different stages of their research.

A Memorandum of understanding (MOU), between Tsinghua and Tel Aviv universities, was signed in September of 2013, and the Xin project will be publicly announced in 2014, with initial activities and collaborations between researchers from both universities already under way.

Prizes and Awards

- **Prof. Ron Lifshitz**, of the Physics department, has received the 2013 Jean Marie Dubios Award in recognition of his theoretical research contributing to the understanding of stabilization mechanisms in soft quasicrystals and for insightful development of group theory and symmetry concepts for quasicrystals.

- **Itai Epstein**, from the research group of Prof. Adi Arie, won the Incubic/Milton Chang Travel Grant and the Emil Wold Outstanding Student Paper, at the Frontiers in Optics 2013 conference in Florida, USA, on his work titled: "Quasi-Phase-matching of Surface Plasmon Waves".

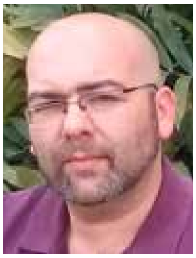
- **Doron Bar-Lev**, from the research group of Prof. Koby Scheuer, received the Robert S. Hilbert Memorial Travel Grant to the Frontiers in Optics 2013 conference in Florida, USA, on his work titled: "Second Harmonic Generation from Nanoantenna Arrays on $LiNbO_3$ – Nonlinear Polarization and Pump Considerations"

- **Eli Wilner**, a PhD student in Prof. Eran Rabani's group, received the Prof. Rahamimoff travel grant for excellent young scientists of the US-Israel bi-national Science Foundation (BSF)

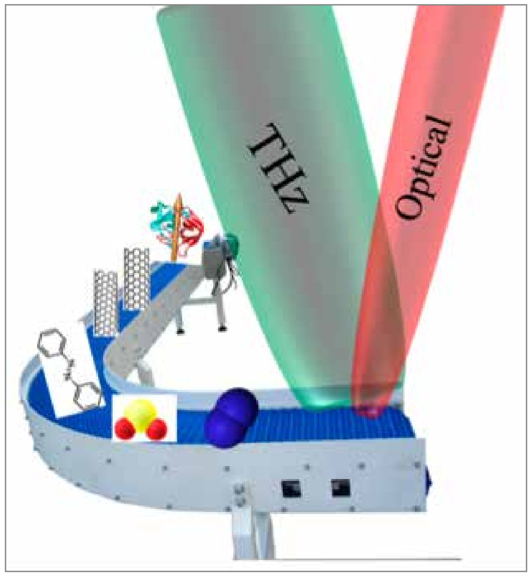
- **Yuval Yifat**, from the research group of Prof. Koby Scheuer, received the Ministry of Science and Technology Travel Grant to the Photonics West 2014 conference in California, USA, on his work titled: "Nano-antenna elements for controlling optical phase"

New researchers in the Center

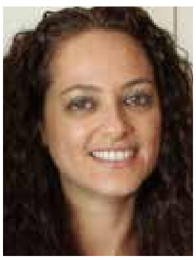
Dr. Sharly Fleischer, School of Chemistry



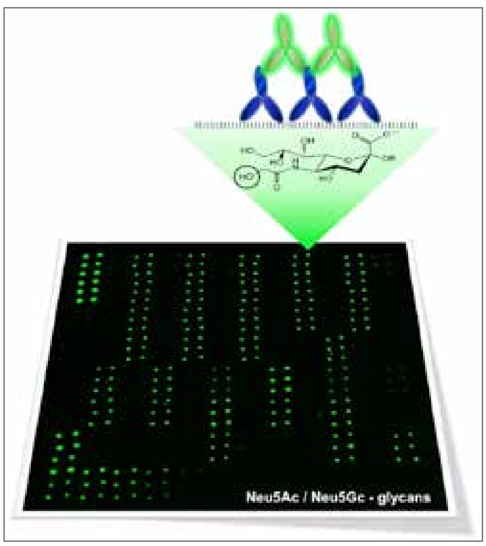
Dr. Fleischer received his PhD in 2009 from the Weizmann institute of Science, for his research on "selective manipulations of molecular rotations", conducted under the supervision of Prof. Yehiam prior and Prof. Ilya Sh. Averbukh. In November 2009 he joined the group of Prof. Keith A. Nelson at MIT as a postdoctoral associate, where he studied aspects of coherent control and spectroscopy provided by intense Terahertz fields. In October 2013 he joined the School of Chemistry, Faculty of Exact Sciences at Tel Aviv University to establish the ultrafast Terahertz research laboratory. Dr. Fleischer's group will focus on ultrafast molecular dynamics upon photochemical reactions, induced by intense femtosecond laser fields in both the terahertz (THz fields, 10^{12} Hz) and the visible/near-IR (optical fields, 10^{15} Hz). The group aims to develop new excitation schemes based on these two frequency regions, inducing unique angular distributions in molecular ensembles and their ultrafast spectroscopic interrogations. The group will study the basic light-matter phenomena in multi-level rotational systems, governed by the quantum-mechanical nature of molecular rotations, collective molecular responses induced by intense electromagnetic fields, towards the goal of providing complete three-dimensional angular control of 'big' and 'complex' molecules of chemical and biological significance.



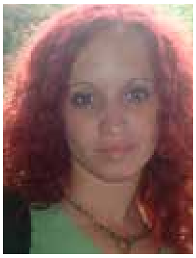
Dr. Vered Padler-Karavani, Department of Cell Research and Immunology, Faculty of Life Sciences



In October 2013, Dr. Padler-Karavani joined the Department of Cell Research and Immunology, the Faculty of Life Sciences at Tel Aviv University as part of the FTA program led by Prof. Dan Peer, to study the immune recognition and responses to sugar antigens. Dr. Padler-Karavani received her PhD in biochemistry from Tel Aviv University. She then moved to California for her postdoctoral studies at The Glycobiology Research and Training Center, led by Prof. Ajit Varki at The University of California San Diego in the USA. During this period she investigated the role of the non-human acidic sugar N-Glycolylneuraminic acid (Neu5Gc) and its related humoral responses in human cancer initiation, prognosis and immunotherapy. She developed technologies involving recognition of sugar molecules, including a novel high-throughput carbohydrate-platform (sialoglycan microarray) as a biomarker discovery tool. In 2013 she joined Tel Aviv University as a senior lecturer and she is currently establishing The Laboratory for Glycoimmunology to study mechanisms that govern glycan immune recognition and responses in animal models and in humans, both *in vitro* and *in vivo*. Currently, her group is focusing on: investigating unique anti-carbohydrate antibodies in mucosal secretions and sera, development of novel diagnostics and therapeutics to chronic inflammation mediated diseases, and development of bio-nanotechnology tools based on glycan recognition. This type of research combines glycobiology, immunology, bio-nanotechnology and cancer research, and involves cutting edge technologies within these disciplines, including glycan microarray and glyco-nanotechnology.



New faces at the Center



Noa Shafir

Noa joined the Nanocenter in November 2013, replacing Tamar Sotnikov as the Center's secretary. Noa is currently in the process of completing her BA in the History of Art, here at TAU. Before joining the Nanocenter Noa worked at the unit of Special projects in the Arts at the Faculty of Arts of TAU. Noa has joined the administrative staff of the center, working hard to keep its multi-disciplinary activities running.

Valery Garber

Valery Joined MNCF in April 2013 after being the co-founder and CTO of Sirica R&D center in Israel. While at Sirica he was responsible for the development of a unique infrared detector for low cost and high performance, IR imaging. Prior to his job at Sirica Valery, who holds an M.Sc. degree in Physics, worked as a senior research engineer at the Solid State Institute and Microelectronics Research Center, at the Technion, Haifa for 14 years. At TAU, Valery is working as a senior process engineer and project manager at MNCF, managing R&D projects for industrial customers and utilizing his vast experience to improve the center's industrial services.

News & events

- Tel Aviv Center for Nanoscience and Nanotechnology has recently established an advanced computational cluster, named the Nano-cluster. The new cluster is a powerful state-of-the-art computational machine including 384 cores, and is dedicated to intensive computational studies in the field of nano-materials science. The new cluster serves a wide group of researchers affiliated with the center, who are involved in theoretical and computational studies of materials and processes occurring at the nanoscale. The establishment of the new cluster opens the way for advanced computational studies, aiming to understand systems ranging from solid state physics to biomaterials and soft-matter that require intensive computational resources. For more information please contact Dr. Oded Hod.

- The Fred Chaoul 9th Annual workshop was held this year in Nazereth and consisted of three successful days of fascinating talks and fruitful interdisciplinary discussions. The next workshop is planned for February 2015.

- A three year 800K Euro project (EduNano) has been approved for creating a bank of online courses in the field of nanotechnology with TAU team as the coordinator led by Jack Barokas and Dr. Ramon Albalak. This project is part of the Tempus program of the European Union, which supports the modernization of higher education in the Partner Countries of Eastern Europe, Central Asia, the Western Balkans and the Mediterranean region, mainly through university cooperation projects. TAU will host also all the distant learning infrastructure of the project and will be in charge of courses video recordings. Israeli partners to the project include in addition to Tel-Aviv University, the Technion, the Hebrew University, Ben Gurion University, Bar Ilan University, the Weizmann Institute, the Samuel Neaman Institute and Elbit Systems. The European partners are from institutes in Grenoble, Torino and Sophia. The project started in February 2014.

New equipment at the center

ELAS Femtosecond Laser Micromachining System

Figure 1: The machine as was installed at TAU

A new Femtosecond (Fs) Laser system consisting of three wavelength in the UV, Vis, and IR ranges has arrived to Tel Aviv Center for Nanoscience and Nanotechnology. Fs lasers can be used for microprocessing many types of materials: metals, polymers, semiconductors, ultra-hard materials, transparent materials, tissues, etc. Because the machining process is not dependent on linear absorption at the laser wavelength, virtually any dielectric, metal, or mechanically hard material can be machined by the same laser beam. Compared to micromachining with continuous waves (CW) and long-pulse lasers, ultrafast lasers have several advantages: micro-sized structure creation, no collateral damage to the surroundings, clean process look, small heat affected zone creation, no material property change, and capability for transparent material sub-surface engraving.

The machine operates in two modes: 1. The beam (with a wavelength of 350nm) is fixed and the stage moves. In this mode the beam diameter is 2 microns. This mode is suitable for precise and gentle machining 2. The beam (at 1060nm or 530nm) is scanning using a galvo scanner, with a beam diameter of around 30 microns. This mode enables fast dicing of wafers such as silicon or glass. One example for a specific application is cuting microscope slides by scribing a line across them and cleaving them cleanly along the line. The machine is equipped with three cameras, one for the fixed optics, one for the galvo scanner, and a macro camera for a full view of the sample for alignment purposes.

The operating software enables working with several popular CAD formats, such as DXF, STL and PLT, but it is possible to program processes with simple lines and circles directly by a flexible software.

This is the first system of its kind in Israel and one of the first in the world.

The installation was completed this fall and the machine went through a qualification process and is now finally open for new projects and challenges with an introduction price for a limited time. Please contact Dr. Yigal Lilach for more information.

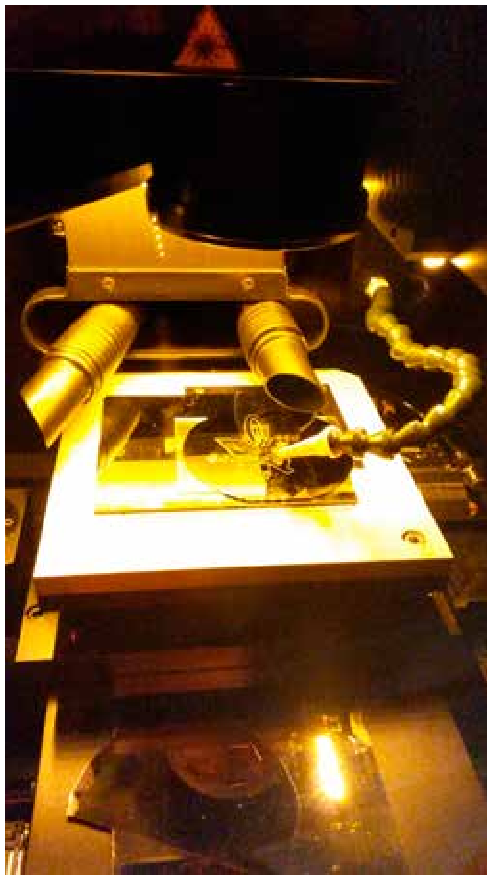


Figure 2: The Laser Micromachining in action: curving TAU symbol in silicon

Technology Advertising: Welcome to the next research revolution

Aviv Eliyahu

Nano Lithography Account Manager – AVBA

"We cannot solve our problems with the same thinking we used when we created them" (Albert Einstein).

It is exciting to find from time to time a new technological solution that suddenly enables new perspective on how to override existing limitations. Such an inspiring technological solution is now available in the form of 3D laser nanolithography. This solution - developed by *Nanoscribe*, a young company established out of the Karlsruhe Institute of Technology (KIT) in Germany - uses the concept of direct laser writing based on two photon polymerization in UV-curable photoresists combined with beam deflection by galvo mirrors and piezo-based stage precise movement. The technology is implemented in standard writing process through transparent glass cover slips or Inverse configuration. Substrates don't have to be conductive, in fact a variety of substrates including Silicon are standard.

Nanoscribe (recently won the Prism Award during the SPIE Photonics West 2014 exhibition in the category of „Advanced Manufacturing") developed this 3D printer, allowing for the fabrication of true three-dimensional micro- and nanostructures that is used today in boundary-challenging researches such as in Photonics, Micro-Mechanics, Bio-mimetics, Microfluidics and more.

The first tool in Israel is used today in the Hebrew University of Jerusalem at the Brojde Center for Innovative Engineering and Computer Science.

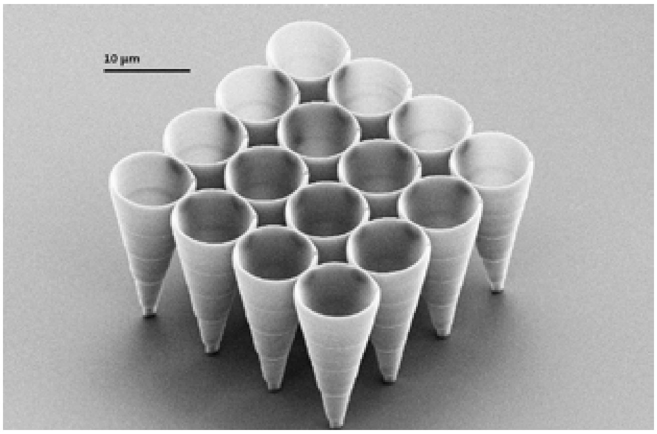


Figure 1: Light director array

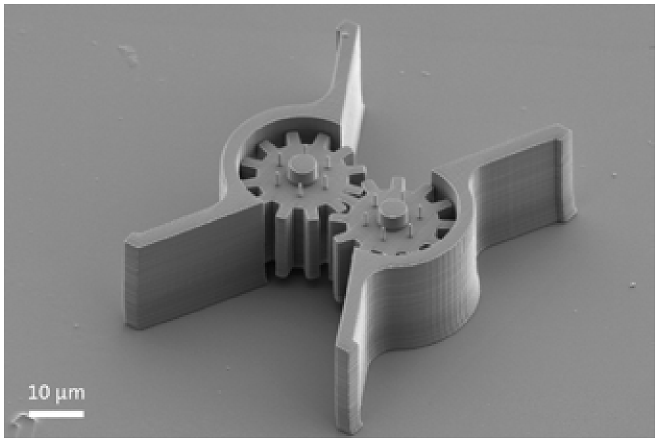


Figure 2: Micro Rapid Prototyping - Micro-gear for applications in micro rapid prototyping

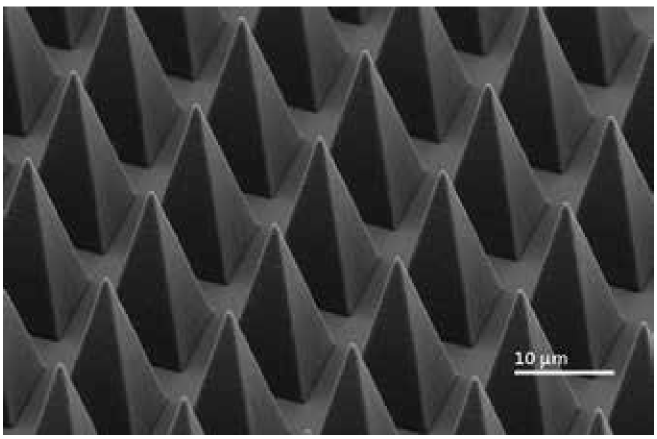
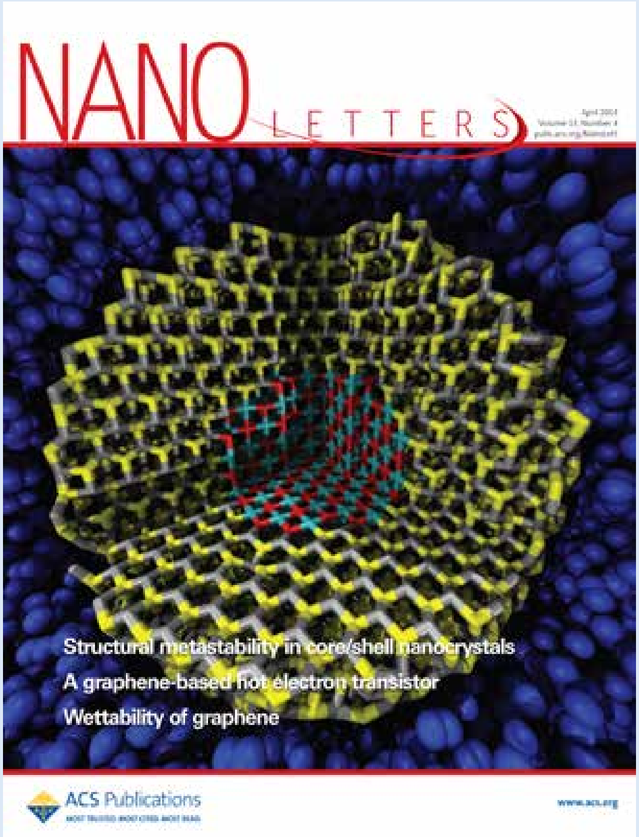


Figure 3: Micro-optics: Pyramid array for applications in micro-optics



"Metastability in Pressure-Induced Structural Transformations of CdSe/ZnS Core/Shell Nanocrystals" by Prof. Eran Rabani, Appeared on the cover of Volume 13, Number 4 issue of the *Nano Letters*

Milimeter in size silicon wafers – curved out by Dr. Yigal Lilach, using our new Laser Micromachining system

TAU logo curved in silicon by the new Laser Micromachining system

The 9th Fred Chaoul Nano-Workshop