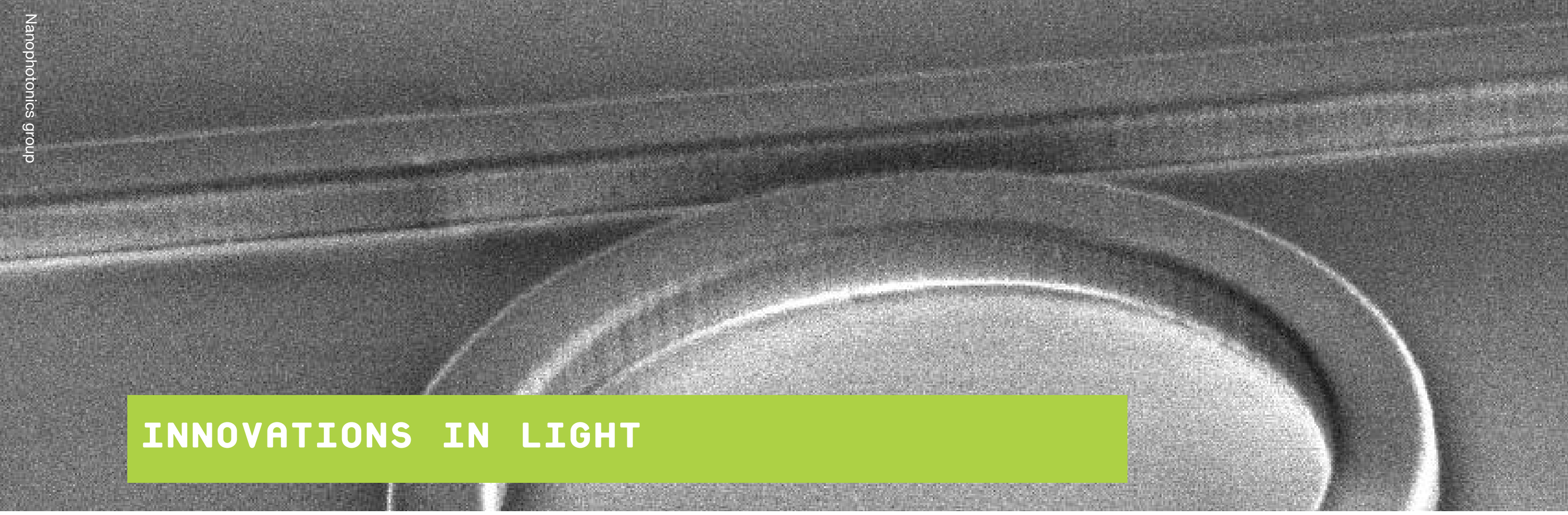


Nanophotonics group

INNOVATIONS IN LIGHT

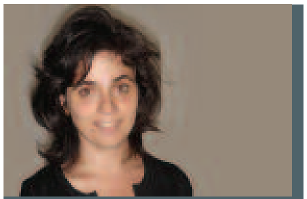
Technologies from the Lab of Michal Lipson

BY THE END OF HER FOURTH YEAR AT CORNELL, DEVICES CREATED IN LIPSON'S LAB FORMED THE BASIS FOR NINE PATENT APPLICATIONS AND TWO ARTICLES IN *NATURE*. IN FEBRUARY 2004, LIPSON RECEIVED AN NSF CAREER AWARD, AND LESS THAN A YEAR LATER, SHE WAS PROFILED IN A FRONT-PAGE STORY IN *EE TIMES*.

It took more than 30 years for Michal Lipson, Electrical and Computer Engineering, to get from her birthplace in Israel to Ithaca, New York, by way of Brazil. It would take only a fraction of a second for the light that she studies to make the same journey—even if it was traveling through the nanometer-sized photonic structures out of which she and her research group are fashioning the datacom and telecommunications future.

A physicist by training, Lipson arrived in Ithaca in the fall of 2001 to join the Department of Electrical and Computer Engineering. She quickly assembled a research group of postdocs and graduate students from around the world to help her explore silicon-based photonics, and her lab soon began to make important innovations. The first was a novel design for an optical filter known as a distributed Bragg reflector or DBR. Other innovative devices followed: devices for coupling optical fiber to chips, emitting light from a waveguide, switching optical signals on and off, guiding light on chips, and sensing. By the end of her fourth year at Cornell, devices created in Lipson's lab formed the basis for nine patent applications and two articles in *Nature*. In February 2004, Lipson received an NSF Career Award, and less than a year later, she was profiled in a front-page story in *EE Times*.

Lipson's creativity and ability to get the best from her diverse research group is in part due to her eclectic background and in part to her genes. Born in Haifa, Israel, Lipson moved with her family to Brazil after her father, Reuven Opher, a U.S.-trained physicist, was invited to join the faculty of the University of São Paulo. Physics was not just a job to her father: it was his life's passion. Conversations around the dinner table often revolved around science and the parents' research at the university. Opher encouraged his two daughters to pursue careers in physics, saying, "You can get paid to explore how the universe works. What could be better than that!" To prepare them for such a career, Lipson's mother, Erella Opher, a physicist and artist, tutored Michal and her fraternal twin sister, Merav, at home to supplement the indifferent math and science instruction they were receiving at the local private school.



Michal Lipson

To boost the probability that his daughters would be accepted at a top university, their father convinced administrators at their high school to allow his daughters to skip most of their senior year classes in order to pursue independent science and math studies, arguing that the school's reputation would benefit from having graduates accepted into the University of São Paulo, one of the most prestigious research universities in Brazil. The strategy worked, and the next fall, Lipson and her sister matriculated at the University of São Paulo and began their pursuit of careers in physics. Lipson's sister followed her father into cosmology, studying plasma effects in the early universe. She completed a bachelor's degree in physics and a Ph.D. at the university's Institute of Astronomy and Geophysics. She recently joined the faculty of George Mason University, after several years at the Jet Propulsion Laboratory in California. Lipson's academic career followed a different and unexpected course.

After completing her first year at the university, 19-year-old Lipson visited Israel during the summer. She met Hod Lipson, an Israeli university student, they later got married in Brazil, and Lipson transferred to Technion–Israel Institute of Technology, where her husband was a student. There she began to study physics in earnest. Encouraged by her professors, she stayed at Technion, earning a master's degree and, in 1998, a Ph.D. Her husband completed a Ph.D. in mechanical engineering from Technion in the same year, having served five years in the Israeli navy between his undergraduate and doctoral studies.

The Lipsons moved to Boston, where Michal was a postdoctoral assistant in Lionel Kimerling's research group at the MIT Department of Materials Science and her husband was a postdoctoral assistant at Brandeis University and a lecturer and

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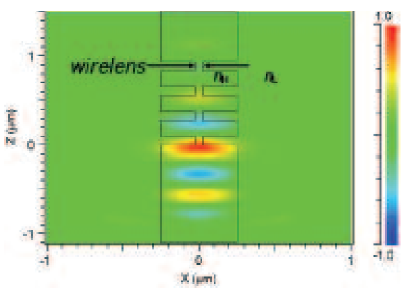
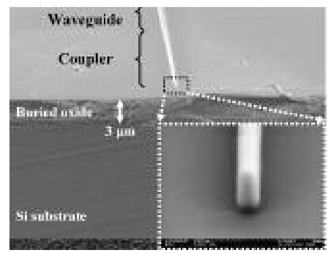
visiting scientist at MIT. Michal Lipson began to work in silicon photonics, which has proven to be a fruitful area of inquiry for her.

Shortly after her arrival in Ithaca, Lipson approached the Cornell Center for Technology, Enterprise, and Commercialization (formerly the Cornell Research Foundation) with her novel design for a DBR developed with one of her Ph.D. students, Vilson Almeida. They had succeeded in designing a near–zero loss DBR far more compact than existing DBRs. Most DBRs are in the form of a waveguide—an optical fiber is one type of waveguide, or way of guiding light through space—with tiny, shallow notches, called gratings, etched into it. DBRs work by allowing only the one wavelength of light that matches the spacing of the gratings to pass through the filter and reflect back the light of all other wavelengths. Lipson and Almeida ignored the well-established experimental results showing that deeper gratings had higher losses and created an innovative design that incorporates gratings so deep that the sections of the waveguide between the gratings are connected only by what they call a "wire-lens," a mere sliver of silicon far smaller than had once been thought necessary to transmit the light passing through it.



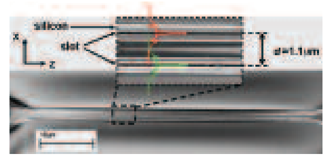
Soon after the new DBR came a new design for a coupler to get light from an optical fiber onto a silicon chip. Instead of following the path of most researchers who were trying to build ever more exotically constructed funnel-shaped couplers, with the large end pointing towards the optical fiber and the much smaller end connecting to a waveguide on the chip, Lipson and Almeida turned the funnel design on its head by tapering the waveguide to a sharp point where it meets the fiber. Despite their 80-fold difference in size, to the light in the optical fiber, the sharp taper just looks like another optical fiber, as the mode of the taper matches the mode of the fiber.



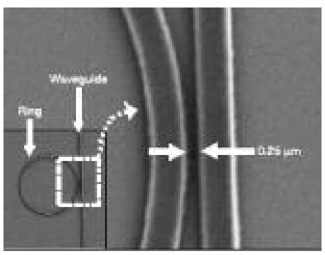
Light therefore passes from one to the other very efficiently, just as water passes efficiently from one pipe to another of equal size. Lipson's and Almeida's new design was not only significantly more efficient than most other couplers, but also much smaller and could be made using standard silicon-processing techniques.

The unusual design of the coupler highlights an important aspect of photonics. Light does not behave in the way most of us expect it to. It behaves both as a ray and as a wave, and its behavior can be counterintuitive to the layperson. For example, looking at fiber-optic cable, it is easy to imagine that light travels through the transparent glass core in the same way water travels down a tube, but this intuitive understanding is misleading. When light travels through a fiber-optic cable, a portion of that light actually travels outside of the glass core. The portion of the light traveling *outside* the glass core is referred to as its evanescent field and accounts for many of the more interesting properties of photonics devices, such as optical fiber and other waveguides.

Over the past four years, Lipson's group has taken advantage of the unusual properties of light to develop a series of breakthrough technologies for the photonic future. Some, like a new kind of waveguide (shown below), are in the areas of datacom and telecommunications. In their so-called slot waveguide, instead of confining the light in the part of the waveguide with the highest index of refraction by the principle of total internal reflection, as in all other waveguides, light is confined in a low-index slot between a pair of rails of high-index material. Researchers around the world have just begun to explore the many potential applications of this unique structure.



Other innovations from Lipson's lab have been in areas such as biological sensing. One is an ultra-sensitive particle sensor capable of detecting a single particle attached to an organism or analyte of interest, which works by exploiting the interaction of the evanescent field with its environment. Particles that enter the evanescent field around the waveguide have a detectable effect on the transmission of light through the waveguide. Lipson's group dramatically enhanced the effect of a particle on transmission by building a "defect" ("D" in the figure at left) into the structure to enhance light-field strength at the sensing point. This technology has potential in areas such as biological agent sensing.

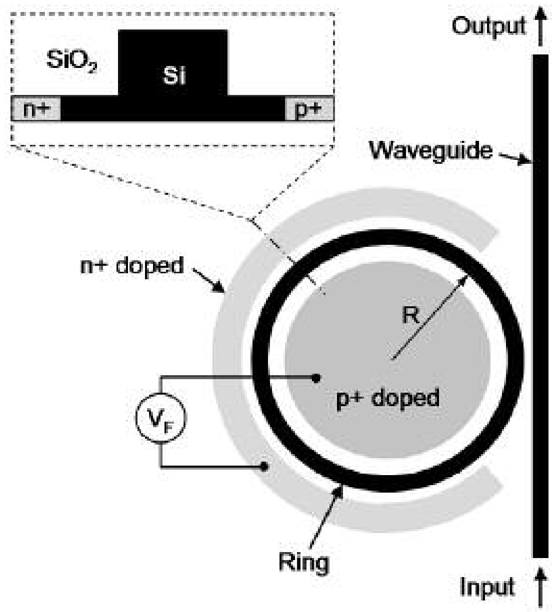


Another innovation enables light to be taken from a waveguide on a chip and projected out perpendicularly from its surface by a ring resonator (shown at left). This innovation has potential applications in computer and entertainment device displays. It is one of several approaches for display construction that Lipson's research group is actively pursuing.

Two optical switching technologies created in Lipson's lab recently appeared in *Nature*. In October 2004, her group reported the first practical all-optical switch in silicon—faster and smaller than previous devices. Less than a year later, the group reported a micrometer-scale, gigahertz-speed electro-optical switch (EOS). Both switches could be crucial enabling components for optical connections on computer chips, optical computers and telecommunication devices, and optical computing.

THEY HAD SUCCEEDED IN DESIGNING A NEAR–ZERO LOSS DBR FAR MORE COMPACT THAN EXISTING DBRS.

The similar mechanism by which these switches operate highlights another counterintuitive behavior of light. Because light is a wave, as well as a particle, light has a frequency or wavelength, which in the visible range we see as colors. A resonator is something that has one or more resonate frequencies at which it vibrates most readily; tuning forks and guitar strings are resonators. If a resonator is coupled to a waveguide by placing it within its evanescent field, all light traveling through the waveguide that matches the resonator's resonate frequency will jump from the waveguide into the resonator, while light of all other frequencies will pass by unaffected. If there is a place for the light to go from the resonator, such as into another waveguide or into light emissions, it will go there. This bizarre behavior of light is analogous to filling a bucket by placing it beside a running garden hose.



Both switches from the Lipson lab consist of a ring resonator coupled to a waveguide. The key to their operation is that they incorporate a mechanism for changing the resonate frequency, which is determined by the resonator's circumference and the refractive index of the material from which it is made. Injecting energy into silicon will alter its refractive index. Taking advantage of this property of silicon, switching is accomplished in the all-optical switch by injecting energy in the form of a second light signal and by applying a voltage in the EOS switch. The injected energy changes the refractive index of the silicon, which alters the resonate frequency of the resonator. This will either stop light in the waveguide or allow it to pass, depending on whether the resonator's resonate frequency matches that of the light.

The key to the success of Lipson's research group is that their devices are practical and innovative. They can be made in silicon with the same manufacturing techniques used to make the electronics chips that are so ubiquitous in modern products.

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Lipson's Lab

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They are small enough to fit on electronics chips, and they are efficient enough to provide the performance required by device designers. Lipson is effective because she keeps one eye on the needs of industry and the other on the needs of the end user, and she brings cutting-edge science and impressive creativity to designing devices that meet those needs. Her innovations have the potential for commercial application within the next few years.

Along with Lipson's innovative technologies (nine patents pending and twenty-three journal publications while at Cornell), she had a second child: one-year-old Ethan, brother to eight-year-old Lahav. Lipson's husband, Hod, is now a professor in Cornell's Department of Mechanical and Aerospace Engineering, and the two have found time to collaborate on research using evolutionary algorithms to design photonic crystals.

How does she do it all? Lipson attributes some of her success to her eclectic upbringing, which melded the distinct cultures of Israel and Brazil. Attracting top-notch students and postdocs also contributes. However, her leadership and dedication to research and her staff are most important. Carlos Barrios, a former postdoc in Lipson's lab who has since joined the faculty at the Centro de Tecnología Nanofotónica at Universidad Politécnica de Valencia in Spain, says, "Michal gave me the opportunity to propose and to discuss exciting and crazy ideas and to meet brilliant and helpful people. She is a very enthusiastic and hard worker and is able to transmit these virtues to her students and coworkers."

Scott S. Macfarlane
Senior Licensing Associate
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