Terahertz Pioneer: Michael Bass

"The THz Light at the End of the Tunnel"

Peter H. Siegel, *Fellow, IEEE*

AS A YOUNG MAN growing up in the Bronx, NY, in the 1950s, Michael Bass[1] was able to take full advantage of the museums and other unique multi-cultural offerings of a major metropolis. The extensive New York City subway system cost a nickel a ride, and the trip from the Bronx to the American Museum of Natural History on 83rd street in Manhattan, took less than an hour. Michael found himself visiting the museum frequently and developing an early interest in science. While attending the prestigious Stuyvesant High School,[2] a public secondary school then on 15th street in Manhattan—which boasts four Nobel laureates as alumni—Michael remembers being very impressed by an exhibit at the United Nations building in NYC in the spring of 1955. The exhibit was part of the U.S. "Atoms for Peace" initiative.[3] There he saw a functional cloud chamber,[4] which focused his science interests on physics. In 1956 he enrolled in Carnegie Institute of Technology (now Carnegie Mellon University) in Pittsburgh, PA, to formalize a career in science.

MICHAEL BASS

At Carnegie, Bass happened to hear a seminar on interference (or crossover) spectroscopy [1] by renowned University of Michigan physicist, Peter A. Franken [2].[5] Bass had the courage to approach Franken after the lecture, and they immediately hit it off. After graduating from Carnegie, Bass was offered a graduate student stipend at University of Michigan, and he proceeded to Ann Arbor, MI, in the fall of 1960 where Franken was advisor to first year graduate students.

After acing some tough classes in his first semester at Michigan, Bass was told by Franken to start looking around for something that might serve as his thesis project. Bass bumped into one of Franken's students, Alan Hill,[6] then only a junior in college, who was working with the newly available optical masers. Alan was using a commercial red ruby laser ($\approx$ 6943 Å) focused onto a quartz crystal to try and generate

---

Manuscript received May 19, 2014; accepted May 20, 2014. Date of publication June 10, 2014; date of current version June 26, 2014.

The author is with the Department of Electrical Engineering at the California Institute of Technology, Pasadena, California and a consultant with THz Global, a company dedicated to the worldwide development of the THz field (e-mail: phs@caltech.edu).

Digital Object Identifier 10.1109/TTHZ.2014.2326300

[1] I met with Michael Bass during a short lull in graduation exercises on the campus of University of Central Florida—now the second largest university by enrollment in the United States. Our discussion included many topics of general interest in addition to those contained in this short article. As it turned out, we had much that was common in our backgrounds, despite the gap of one generation. Michael grew up in the "Atoms for Peace" movement, whereas my own experience was in the *heat* of the Cold War. However, we both spent our youth in NYC, were the only ones in our families to have an interest in science, share an enjoyment of science history, and appreciate the twists and turns that often accompany, and in fact dictate, the choices that ultimately sum up a career.

[2] Established in 1904, Stuyvesant High School was open to all NYC (New York City) residents through an examination process. Originally an all-boys school, it became co-ed in 1969, and moved to its current location in Battery Park City (Chambers Street, Manhattan) in 1992 (www.stuy.edu).

[3] U.S. President Dwight D. Eisenhower initiated this international program with a speech at the United Nations Headquarters General Assembly on December 8, 1953, entitled, "Atoms for Peace." This resulted in several widely publicized international United Nations conferences on the peaceful uses of atomic energy and a huge worldwide exhibition in Geneva, Switzerland in 1958. *Reference*: Richard Hewlett and Jack Holl, "Atoms for Peace and War 1953–1961", Eisenhower and the Atomic Energy Commission, University of California Press, Berkeley and Los Angeles, c. 1989, 690 pages.

[4] Invented in 1911 by Scottish physicist Charles Wilson, the cloud chamber was filled with saturated water vapor (later alcohol) which condenses on the ions that travel through it. Wilson received the 1927 Nobel Prize in Physics (along with Arthur Compton) for this invention. (en.wikipedia.org/wiki/Cloud_chamber).

[5] Peter A. Franken is referred to as the father of nonlinear optics by the Optical Society of America. He was best known for his groundbreaking work on optical harmonic generation in crystals, which of course would lead to the work on optical rectification that is the basis of our THz Pioneer article. He left the University of Michigan to head the University of Arizona's Optical Science Center in 1973, and he passed away in 1999.

[6] After a long career at Phillips Laboratories, Kirkland Air Force Base, Albuquerque, NM, USA, Alan founded Plasmatronics, Inc. He maintained a close affiliation with Texas A & M University and has a nice presentation about his work with Peter Franken and Michael Bass at Michigan entitled, *"Memories of the Discovery of Optical Harmonics, Peter Franken, and some thoughts about the future of nonlinear optics,"* presented at the Nonlinear Optics International Conference: East–West reunion in September 2011 (*available from the author*).

the second harmonic at 3472 Å (ultraviolet) through the crystal nonlinear susceptibility χ; the nonlinear dependence of polarization, P, on field strength, E; $\mathrm{P} = \chi\mathrm{E}(1+\alpha_1\mathrm{E}+\alpha_2\mathrm{E}^2+\ldots)$.

When E is a sinusoidal function, the polarization will contain components that are dependent on the fundamental, as well as the higher harmonics generated by the interaction of the field with the atoms in the crystal. Crystal quartz is particularly useful for this experiment because of its birefringent properties, which can be used to provide different harmonic responses depending on the orientation of the impinging electric field. In the Franken and Hill experiment, a simple prism was used to spatially separate out the red and UV signals, which were then focused onto a photographic film. The first observation of second harmonic generation through this groundbreaking experiment in nonlinear electro-optics, which had to be recorded from a single pulse of the ruby laser,[7] was published in 1961 [2]. For reference, the second harmonic conversion efficiency was approximately 10^{-8} [3].

It had been only a year since Ted Maiman had produced the first optical maser [4], and Bass was fascinated by a device that could put out "that much light." He told Franken he would work on anything that utilized the lab's ruby lasers. Franken told him that Hill, still an undergraduate, needed to return to his studies in the fall, and that he, Bass, could take over the harmonic generation project.

Bass started out his experiments by moving on to the logical next step in exploring nonlinear interactions—a mixing experiment.[8] He took two ruby lasers with slightly different output wavelengths [5][9] and superimposed them through a half-silvered mirror-type beam splitter. Bass then focused the beams onto a triglycine sulfate crystal (chosen because of its superior 2nd harmonic output conversion efficiency), and then used a slit prism spectrometer to spatially separate the output wavelengths. The lasers were fired synchronously (within 50 μs), and multiple exposures (500 μs typical) were collected on a photographic plate that followed the spectrometer. The film recorded the 2nd harmonic outputs of both lasers with the sum frequency exactly in the middle, as expected [6]. Similar exposures using only one or the other of the two lasers showed only a 2nd harmonic spot—no mixing signal—confirming the interpretation of the experimental results.

It is interesting to note that the difference frequency of the two Ruby lasers in Bass's experiment would have appeared at about 620 GHz. However, in 1961, there were no off-the-shelf detectors at the Michigan lab for measuring such short wavelength RF energy, and Bass focused only on the optical sum detection. It would take another four years before Fritz Zernike and Paul Berman, working at Perkin Elmer Corporation, Danbury, CT, USA, reported difference frequency generation from closely tuned optical sources when they measured 3 THz signals from two neodymium glass lasers beating together in a quartz crystal [7].

The next series of experiments that Bass undertook was to look for steady induced polarization, the equivalent of the dc term in the nonlinear harmonic generation process.[10] This "*optical rectification*" process, the result of an intense high frequency field interacting with the crystal lattice in a nonlinear manner, is very similar in its mathematical formulation to the linear electro-optic phenomenon known as the Pockel's effect, wherein a dc (or very low frequency) electric field modifies the optical polarizability of the crystal. In fact, a quantitative relationship between the Pockel's effect and the predicted results of high intensity second order field interactions in nonlinear crystals had just been published by J. A. Armstrong and Nicolaas Bloembergen[11] and colleagues at Harvard University [8]. This paper used a rigorous quantum mechanical approach to derive formulae that could directly predict the dc component of the polarization induced change in a sample exposed to intense coherent optical signals, from the inherent properties of the crystal itself, and the magnitude of the Pockel's coefficients.

Bass, Franken, and colleagues John Ward and Gabriel Weinreich, tried the ruby laser on potassium dihydrogen phosphate (KDP) and potassium dideuterium phosphate $(\mathrm{KD_dP})$ crystals, known to have a very strong linear electro-optic effect. Using a very carefully calibrated capacitively coupled mounting arrangement for the crystal, Bass was able to measure the voltage developed across the crystal as the laser beam interacted with the KDP at different polarization directions. Through the Armstrong and Bloembergen formulation, the relationship between the observed voltage and the dc polarization effect coefficients could be derived. The predicted values, based on the crystal parameters and measured dc Pockel's effect in KDP, agreed extremely well with the measurements [9]. The very important discovery and proof of optical rectification was confirmed.

Bass and Franken went on to the investigation of several other crystalline materials, including zinc telluride, and a very rigorous mathematical formalism for quantifying the optical rectification coefficients [10]. More importantly a method was now available for predicting, measuring and understanding not only this observed second order nonlinear effect, but many other higher order phenomena that resulted from intense electro-optic field interactions [11].

From the point of view of the THz community, the optical rectification effect would have enormous positive consequences. When the electric field coupled to the crystal is

---

[7] The early commercial ruby lasers were excited by a strong Xenon flash tube. They were air cooled, or cooled by a flow of gas evaporated from a liquid nitrogen tank, and were powered by a large (kilovolt) discharge capacitor bank. They could only flash a small number of times before the silver coatings became damaged or destroyed. Energy levels reached 3 J with power of more than 3 kW in a 1 ms pulse made up of relaxation oscillation spikes, and more than 30 MW/cm^2 in a focused spot!

[8] As in the traditional electronic circuit analogy, if one substitutes two sinusoidal fields, $\omega_1\mathrm{t}$ and $\omega_2\mathrm{t}$, into the polarization equation, the E^2 term will lead to $\sin^2(\omega_1\mathrm{t})$ and $\sin^2(\omega_2\mathrm{t})$, which by identity give terms containing $\cos(2\omega_1\mathrm{t})$ and $\cos(2\omega_2\mathrm{t})$, harmonics of the two pump frequencies, as well as cross terms: $\cos([\omega_1+\omega_2]\mathrm{t})$, the sum, and $\cos([\omega_1-\omega_2]\mathrm{t})$, the difference or idler.

[9] It is interesting to note how this was accomplished in the days when ruby lasers were not easily tunable or single mode. Bass was able to get the two lasers to output different wavelengths by cooling one of them with liquid nitrogen. This generated a shift of approximately 10 Å from the nominal $\approx$ 6945 Å output to $\approx$ 6935 Å.

[10] Again referring to the P versus E relationship, the second order term in E will give rise to a $\sin^2(\omega t) = (1/2)[1-\cos(2\omega t)]$. The first term here is the dc or permanent induced polarization from the applied field.

[11] N. Bloembergen is a 1981 Nobel laureate in Physics (with Arthur Schawlow and K. Siegbahn) for laser applications in spectroscopy.

derived from an extremely short (picosecond) pulse, rather than the millisecond pulse available from the ruby laser in 1961, the spectral (Fourier) content associated with the pulse falls into the THz regime. Beating of the various components composing the optical pulse produce a difference frequency polarization which is nonlinearly related to the electric field produced by the laser through the susceptibility, χ; $\mathrm{P_{THz}} = \chi \mathrm{E_{laser}} \mathrm{E^*_{laser}}$. Broadband THz energy is created at the laser field concentration point and propagates in all directions, but only the energy which is confined to angles near normal incidence to the crystal boundaries gets out. It is helpful to think about the induced nonlinear polarization as creating a localized oscillating dipole field in the crystal that responds on a picosecond time scale and thus radiates THz energy. The magnitude and frequency content of the accessible THz signal is directly related to the frequency content of the pulse, the nonlinear susceptibility of the crystal, the phase matching conditions for the various difference frequency components, the material index and absorption properties at both the optical and THz frequencies, the geometry of the sample and dispersion effects [12]. The most successful work has focused on $\mathrm{LiNbO_3}$ crystals pumped with Nd:YAG lasers at 1064 nm [13]. Typical conversion efficiencies of 10^{-4} are now obtained with this technique [14]. Very recent results [15] however, report a remarkable 3.7% optical-to-THz conversion efficiency for single cycle pulses in cryogenically cooled lithium niobate samples excited at 1030 nm with a 680 fs pulse!

With the eventual realization of intense femtosecond laser pulses, and the ability to understand and enhance their nonlinear interaction with various crystals, it was possible to generate extremely broad coherent THz signals with intensity sufficient to perform a remarkably wide range of spectroscopic and imaging applications (see, e.g., the many up-to-date references in [16]).

From the perspective of Michael Bass in 1962 however, it would be another 10 years before the phenomenon of optical rectification as applied to ultra-short pulse (picosecond) lasers, would be shown to be a potential generator for broad band THz energy [12], [17], and more than 25 years before this tool began to be gainfully employed for active research [18]. In both of these later innovations, the groundbreaking work of Franken and Bass was largely overlooked, and with the extreme excitement building around the development of the laser, even Bass himself quickly moved on to other topics.

Although lasers were still much of a scientific curiosity in 1962, there was one aspect of these early ruby-based devices that attracted very obvious commercial application. Albeit, the lasers only lasted for 30 or 40 pulses before the silver output coatings began to slough off, however they produced an extraordinary amount of energy, several joules, which directly translated into heat when they were focused onto absorptive samples. They could already be used to punch small holes in metals, crystals and many other materials. Maiman coined the power term "Gillette" to describe how many stacked razor blades the focused beam would burn through.[12] While at Michigan, Bass recalls a visit from a local manufacturer in Ann Arbor who was interested in whether the ruby laser might make a good tool for producing the series of clean holes needed for quality baby bottle nipples. After a quick demo, the manufacturer was convinced of the efficacy, and went out to purchase, and then design a multi-beam optical divider for drilling simultaneous holes from a single laser pulse to replace the hot-wire piercing technique currently in use, [19] for example. The coatings became better and this application continued though using longer lasting lasers!

After graduating from Michigan in 1964, Bass took a post-doc appointment at University of California, Berkeley, USA, to work with Erwin Hahn[13] on spin echoes (also known as Hahn Echo signals [20]). Hahn wanted to do the optical equivalent of his RF spin echo experiments, and he needed a clean coherent source. The ruby laser was just not sufficiently narrow band at the time. Bass tried unsuccessfully for two years to get the ruby laser up to the task required to perform Hahn's experiments. He eventually did find the problem (thanks to a suggestion by Art Schawlow[14]) in the stimulated emission of isotopic chromium ions in the ruby [21]. It was also a time of great political unrest at UC Berkeley, and labs were being constantly closed off while student protests raged. Bass became disenchanted with the academic lifestyle, and decided to try his hand in a more commercial environment. Before leaving Berkeley however, he got involved in a national education project to help develop lab experiments that could be used for the dissemination and teaching of laser theory and techniques [22]. He found this activity an extremely enjoyable and positive experience, and as such, it would help pull him back to academia a bit later in his career.

Bass and his wife Judith, moved to Watertown, Massachusetts in 1966, where he took up a position at the Raytheon Research Division in Waltham. Raytheon already had a strong framework in laser research. Its staff had demonstrated the elliptical pump cavity that made solid state lasers commercially successful, developed the first high power continuous wave $\mathrm{CO_2}$ laser under David Whitehouse[15] and demonstrated a 100 W argon ion laser through Roy Paanenan.[16]

Bass took up work on solid-state lasers at Raytheon, and he is credited as one of the co-inventors of the YAP laser (yttrium aluminum perovskite–YAlO3 active medium) in 1970 [23]–[26]. The Nd:YAP laser has an advantage over the Nd:YAG laser in that the neodymium absorption and emission lines are polarization dependent, allowing additional applications.

Along with colleagues Marvin Weber and T. F. Deutch, Bass also developed an operational modality and pumping technique for the dye laser [27]–[29] that ended up being crucial to the demonstration of the first continuous wave dye laser by Pe-

---

[12] John Johnson Jr., "Theodore Maiman, 79; harnessed light to build the world's first working laser," *NY Times*, Obituary, May 11, 2007.

[13] Erwin Hahn discovered spin echo in nuclear magnetic resonance experiments in 1950. They play a critical role in modern MRI through the $\mathrm{t_2}$ spin–spin relaxation time constant.

[14] 1981 Nobel Laureate in Physics, and at this time a professor at nearby Stanford University.

[15] Whitehouse started out his life as a radio broadcast actor, but changed careers to become a well-regarded physicist at MIT and then at Raytheon, where he pioneered high power $\mathrm{CO_2}$ laser development including a 1 kW, 40 ft long device for the Aberdeen proving grounds in the late 1960s.

[16] See, for example, R. A. Paananen, "Progress in ionized-argon lasers," *IEEE Spectrum*, vol. 3, no. 6, pp. 88–99, Jun. 1966.

terson, Tuccio, and Snavely [30] at Kodak Research Lab in 1970. Perhaps in a prescient moment, Bass was also one of the first to observe picosecond pulses in Nd:YAG lasers [31]. Towards the end of his time at Raytheon, Bass worked extensively on laser damage mechanisms [32]–[34] which would later lead to a strong interest in laser materials processing.

Towards the middle of the 1970s, many U.S. companies began reining in the scope of their research facilities to focus more on internal product development. Raytheon was one of these, and so when Larry DeShazer from the University of Southern California (USC), came to ask if Bass would like to relocate to Los Angeles in order to help head up a new Center for Laser Studies that Larry was forming, Bass did not hesitate to accept the invitation. Perhaps the hard winters in Massachusetts and the *warm* memories of his time at UC Berkeley in California, working on the laser education panel, played a small role in the decision to return to academia. As he had correctly anticipated, and adeptly avoided, his research group at Raytheon was dissolved three years later.

Bass arrived at USC in 1973, and immediately began to build up the laser center as Associate Director. He started bringing together personnel as well as grants and contract money. The concept was to draw in faculty from various departments with overlapping interest in laser studies and applications. Funding would come from soft money grants, but the center had a small level of startup money and some equipment inherited from an existing laser damage studies lab.

One of the first new projects to come into the center had its origins at the USC Medical Center. A resident gastroenterologist, Richard Dwyer[17] (still practicing as a laser endoscopist in Los Angeles with affiliations both at USC and at UCLA Medical Centers), came over to talk to Bass about the possibility of using lasers for wound cauterization to treat bleeding ulcers. At that time (1973), fiber-optic endoscopes were available to look at the gut, but there was no way to perform an on-the-spot clinical procedure once a problem was found. Bass off-handedly suggested the possibility of perhaps using an optical fiber to transmit the laser energy down the endoscope [35]–[37] and use it to cauterize.

Shortly after their initial discussion, Dwyer showed up in Bass's office with six caged rats! Bass negotiated some time on one of his USC colleagues' argon ion lasers that same day, and they tried some cauterization experiments. This soon led to canine experiments [38], [39], and eventually to work on human subjects [40]–[42]. For the first of these experiments, Bass had to gerrymander a fiber onto the outside of the endoscope casing [35]. The technique worked however, and Dwyer at least, went on to a long, and pioneering career in laser endoscopy [43]. Eventually, better fibers became available and the Nd:YAG laser proved a better source for this type of cautery.

Bass became director of the Center for Laser Studies in 1976 and expanded into a large number of varied projects. In particular, he picked up the laser damage studies he had begun at Raytheon and broadened these out to surfaces and films, metal mirrors, and other optical elements, semiconductors and dielectrics, and infrared wavelengths [44]–[51]. Other work included new lasing media, Q-switching techniques, dye lasers, detectors and calorimetric studies, and high power interactions with metals and crystals [52]–[64]. He also became very interested in commercial laser applications (a philosophy which he maintained throughout his career with more than two dozen long term industry consulting arrangements), and worked with industrial partners on problems in laser drilling and cutting, welding, material coatings, and generalized heating effects. Overall, more than 70 papers and 12 Ph.D. dissertations came out of his work at USC.

The staff at the USC Laser Center grew to around 8 with 20–25 students in tow. They included Elsa Garmire (who followed Bass as the center director, and is noted for her work in laser art as well as her research in laser science), Eric van Stryland (OSA president in 2005), Milton Birnbaum (YAG laser expert), Susan Allen (chemical vapor deposition), Jean-Claude Diels (pulsed lasers), and Stephen Copely (materials science and laser manufacturing). During this period Bass held additional positions as chair of the USC Research Council in 1980 and 1981 (a role he would later capitalize on at University of Central Florida), and department chair in Electrical Engineering and Electrophysics from 1984 to 1987.

Of particular interest to THz researchers might be Bass's work on flexible infrared waveguides [65]–[70] for applications including endoscopy. He, Elsa Garmire, and their students, developed a low loss, overmoded ribbon-like guide that could be made from sandwiched metal or metal and dielectric sheet (an early and clever form of flexible parallel plate waveguide).

In 1987, Bass's former USC Center for Laser Studies student, M. J. Soileau, then the newly hired Director of the Center for Research in Electro-Optics and Lasers (CREOL) at the University of Central Florida (UCF), came looking for recruits. (CREOL was to become CREOL, the College of Optics and Photonics.) He sought out Bass for an open position as Dean of Engineering. Bass was intrigued by the possibility of being associated with an institute (CREOL) that had significant long-term base funding (the USC Center for Laser Studies survived only on faculty grant funding—there was no independent endowment for the center). However, he had his eye on another open administrative position at UCF, Vice President of Research—a role he had experienced and enjoyed for a short period at USC.

Bass decided to move across the country for the fourth time, and in December 1987 he relocated to central Florida. He was aided financially by his good fortune in having been one of the few to recognize the potential of a home in the Pacific Palisades region of Los Angeles on his arrival in the early 1970s, an area he chose because of the coastal climate (commuting the 35 odd kilometers to USC by car back then did not take up a significant portion of the work day!). By 1987 the commute time had more than doubled, but so had the real estate values in Pacific Palisades. Bass was able to trade his house in Los Angeles for two in central Florida!

The affiliation with CREOL turned out to be a great fit for Bass, but the position of Vice-President of Research at UCF was not quite as snug. The university changed Presidents four

---

[17] Dwyer, age 71, still practices laser endoscopy in southern California. After his association with Michael Bass, he went on to pioneering research work in many areas of laser therapy, as well as maintaining a private medical practice.

times in the 5 years Bass held the post, and in 1992, he finally gave it up in frustration, and went back to full time research and teaching. During his time as an administrator at UCF, Bass undertook lots of outside commitments (perhaps as a respite from the internal politics). He served as President-Elect and President of the Laser Institute of America, General Chair of the 1989 OSA Annual meeting, Editor-in-Chief of the *Handbook of Optics*, and a board member for the Society Objectives and Policies committee of the Optical Society of America (OSA), during the critical period when OSA was considering a merger with SPIE.

On the technical side, Bass continued to work on solid-state lasers and laser crystals, Q-switching, nonlinear absorption mechanisms and upconversion [71]–[82]. Around 2001, he started to get interested in combinations of semiconductor lasers and upconverters for visible display technologies [83]–[87]. This later led, along with colleague Dennis Deppe, to the formation of a company, bdDisplays, LLC, to develop applications.

At age 62, Bass got very involved as an expert witness in a big patent case, and decided to take advantage of an early retirement package at UCF in order to focus more time on this and other outside activities. He became an Emeritus professor working half-time on his many grant and industry-funded research projects at CREOL, and he continued to teach at a reduced course load, but maintained a favorite: "History of Physics: Cultural Connections and Other Issues," a widely popular class which he continues to offer today.

Bass also took on several major professional tasks, including Associate Editor for *Optics Express*, Editor-in-Chief for the third edition of the *Handbook of Optics* (which was to be a massive 5 volume series), and Associate Editor for OSA's 100th Anniversary Commemorative Book—the *OSA Centennial History Book*, due to be released in 2016. He continues to publish extensively (more than 80 papers between 2001 and 2014) on a wide range of topics in lasers and optics. His most recent interests have brought him back to medical technology, where he has been exploiting his upconverter techniques to locate nanocrystals as they interact with both normal and cancerous cells by detecting the up-converted optical luminescence for bioimaging applications [88]–[90]. Ever mindful of the importance of tieing academic research to commercial application, his list of patents has been growing rapidly since his semi-retirement!

In 2006, Bass attended a conference in Pisa at which he happened to hear a talk by UCF colleague to be, Konstantin Vodopyanov, on pulsed optical difference frequency generation of THz power in GaAs [91]. In this, and a later talk [92], Vodopyanov credited Bass with one of the key developments in the THz field—his pioneering work on optical rectification way back in 1962! Up to this time, Bass had not appreciated how widespread this almost forgotten concept (forgotten by him at least) had spread.

Although it has been over 50 years since his first attempt at using nonlinear crystals to generate difference frequency energy, the THz light at the end of the tunnel is now clearly visible. In 2014, Bass was finally recognized for his pioneering role in THz generation through optical rectification, as the recipient of the OSA's R. W. Wood prize.

Michael Bass continues to teach, to do research, to consult and to work with students, staff and faculty at the University of Central Florida, while he lights the way forward for all of us who care about optical science and technology.

ACKNOWLEDGMENT

The author is grateful to Prof. X.-C. Zhang at the University of Rochester for the suggestion of the candidate for this article, and to UCF Professor Constantin Vodopyanov for some early references and some interesting historical notes.

REFERENCES

[1] F. D. Colegrove, P. A. Franken, R. R. Lewis, and R. H. Sands, "Novel method of spectroscopy with applications to precision fine structure measurements," *Physical Rev. Lett.*, vol. 3, no. 9, pp. 420–22, Nov. 1959.

[2] P. A. Franken, A. E. Hill, C. W. Peters, and G. Weinreich, "Generation of optical harmonics," *Physical Rev. Lett.*, vol. 7, no. 4, pp. 118–120, Aug. 1961.

[3] A. E. Hill, "Memories of the discovery of optical harmonics, Peter Franken, some thoughts about the future of nonlinear optics," presented at the Nonlinear Optics Int. Conf.: East-West Reunion in Sep. 2011, 2011, unpublished.

[4] T. H. Maiman, "Stimulated optical radiation in Ruby," *Nature*, vol. 187, pp. 493–494, Aug. 1960.

[5] I. D. Abella and H. Z. Cummins, "Thermal tuning of Ruby optical maser," *J. Appl. Physics*, vol. 32, pp. 1177–1178, 1961.

[6] M. Bass, A. E. Hill, P. A. Franken, C. W. Peters, and G. Weinreich, "Optical mixing," *Physical Rev. Lett.*, vol. 8, no. 1, p. 18, 1962.

[7] F. Zernike, Jr. and P. Berman, "Generation of far infrared as a difference frequency," *Physical Rev. Lett.*, vol. 15, no. 26, pp. 999–1002, Dec. 1965.

[8] J. A. Armstrong, N. Bloembergen, J. Ducuing, and P. S. Pershan, "Interactions between light waves in a nonlinear dielectric," *Physical Rev.*, vol. 27, no. 6, pp. 1918–1939, Sep. 1962.

[9] M. Bass, J. F. Ward, G. Weinreich, and P. A. Franken, "Optical rectification," *Physical Rev. Lett.*, vol. 9, no. 11, pp. 446–448, 1962.

[10] M. Bass, P. A. Franken, and J. F. Ward, "Optical rectification," *Physical Rev.*, vol. 138, no. 2A, pp. A534–A542, Apr. 1965.

[11] P. A. Franken and J. F. Ward, "Optical harmonics and nonlinear phenomena," *Rev. Modern Phys.*, vol. 35, no. 1, pp. 23–39, 1963.

[12] J. R. Morris and Y. R. Shen, "Far-Infrared generation by picosecond pulses in electro-optical materials," *Opt. Commun.*, vol. 3, no. 2, pp. 81–84, 1971.

[13] K. Kawase, M. Sato, T. Taniuchi, and H. Ito, "Coherent tunable THz-wave generation from LiNbO3 with monolithic grating coupler," *Appl. Phys. Lett.*, vol. 68, no. 18, pp. 2483–2485, Apr. 1996.

[14] M. C. Hoffman, K. Y. Yeh, J. Hebling, and K. A. Nelson, "Efficient terahertz generation by optical rectification at 1035 nm," *Opt. Express*, vol. 15, no. 18, pp. 11706–11713, Sep. 2007.

[15] W. Ronny Huang, S.-W. Huang, E. Granados, K. Ravi, K.-H. Hong, L. E. Zapata, and F. X. Kärtner, "Highly efficient terahertz pulse generation by optical rectification in stoichiometric and cryo-cooled congruent lithium niobate," *J. Modern Opt.* Jan. 2014 [Online]. Available: http://dx.doi.org/10.1080/09500340.2013.868547

[16] *"The Terahertz Wave ebook,"* ZOmega Terahertz Corporation, 2014 [Online]. Available: http://dl.z-thz.com/eBook/zomega_ebook_pdf_1206_sr.pdf, Accessed: May 19, 2014

[17] K. H. Yang, P. L. Richards, and Y. R. Shen, "Generation of far-infrared radiation by picosecond light pulses in $LiNbO_3$," *Appl. Phys. Lett.*, vol. 19, pp. 320–322, Nov. 1971.

[18] D. H. Auston, K. P. Cheung, and P. R. Smith, "Picosecond photoconducting Hertzian dipoles," *Appl. Phys. Lett.*, vol. 45, pp. 284–286, 1984.

[19] R. Barber, L. Cross, and W. G. Price, Lear Sigler Inc., Ann Arbor, MI, USA, "Laser optical apparatus for cutting holes," U.S. Patent US3419321A, Dec. 31, 1968.

[20] E. L. Hahn, "Spin echoes," *Physical Rev.*, vol. 80, pp. 580–594, 1950.

[21] L. W. Riley, M. Bass, and E. L. Hahn, "Stimulated emission from 4.3% abundant CR50 in Ruby," *Appl. Phys. Lett.*, vol. 7, pp. 88–90, 1965.

[22] I. D. Abella, M. Bass, D. Dutton, W. L. Faust, E. Mintz, and H. W. Moos, “Laser experiments and apparatus for teaching purposes,” *Amer. J. Phys.*, vol. 34, p. 98, 1966.

[23] M. Bass and D. Woodward, “Observation of picosecond pulses from a ND–YAG laser,” *Appl. Phys. Lett.*, vol. 12, no. 8, pp. 275–277, 1968.

[24] M. Bass and M. J. Weber, “Nd, Cr–YAlO$_3$ laser tailored for high-energy Q-switched operation,” *Appl. Phys. Lett.*, vol. 17, no. 9, pp. 395–397, 1970.

[25] M. J. Weber, M. Bass, and G. A. Demars, “Laser action and spectroscopic properties of Er$_3^+$ in YAlO$_3$,” *J. Appl. Phys.*, vol. 42, no. 1, pp. 301–305, 1971.

[26] M. Bass, R. R. Monchamp, and M. J. Weber, “Laser with a monocrystalline YA1O$_3$:Nd active medium,” U.S. Patents 3 719 901, Mar. 6, 1973.

[27] M. Bass, T. F. Deutsch, and M. J. Weber, “Frequency- and time-dependent gain characteristics of laser- and flashlamp-pumped dye solution lasers,” *Appl. Phys. Lett.*, vol. 13, no. 4, pp. 120–122, 1968.

[28] M. J. Weber and M. Bass, “Frequency- and time-dependent gain characteristics of dye lasers,” *IEEE J. Quantum Electron.*, vol. QE-5, no. 4, pp. 175–188, Apr. 1969.

[29] T. F. Deutsch and M. Bass, “Laser pumped dye lasers near 4000 Å,” *IEEE J. Quantum Electron.*, vol. QE-5, no. 5, pp. 260–261, May 1969.

[30] O. G. Peterson, S. A. Tuccio, and B. B. Snavely, “CW operation of an organic dye solution laser,” *Appl. Phys. Lett.*, vol. 17, no. 6, pp. 245–247, 1970.

[31] M. Bass and D. Woodward, “Observation of picosecond pulses from a Nd-YAG laser,” *Appl. Phys. Lett.*, vol. 12, no. 8, pp. 275–277, 1968.

[32] M. Bass and H. H. Barrett, “Avalanche breakdown and probabilistic nature of laser-induced damage,” *IEEE J. Quantum Electron.*, vol. QE-8, no. 3, pp. 338–342, Mar. 1972.

[33] M. Bass and H. H. Barrett, “Laser-induced damage probability at 1.06 microns and 0.69 microns,” *Appl. Opt.*, vol. 12, no. 4, pp. 690–699, 1973.

[34] D. W. Fradin, E. Yablonovitch, and M. Bass, “Confirmation of an electron avalanche causing laser-induced bulk damage at 1.06 microns,” *Appl. Opt.*, vol. 12, no. 4, pp. 700–709, 1973.

[35] M. Bass, R. M. Dwyer, and B. J. Haverback, “Fiber optic laser light delivery,” U.S. Patent 3 858 577, Apr. 5, 1974.

[36] M. Bass and R. M. Dwyer, “Multichannel Endoscope,” U.S. Patent 4146019A, Mar. 27, 1979.

[37] M. Bass, “Optical design for lasers in surgery,” *Opt. Eng.*, vol. 15, no. 2, pp. 143–145, 1976.

[38] R. M. Dwyer, B. J. Haverback, M. Bass, and J. Cherlow, “Laser-induced hemostasis in canine stomach—Use of a flexible fiberoptic delivery system,” *JAMA—J. Amer. Med. Assoc.*, vol. 231, no. 5, pp. 486–489, 1975.

[39] R. M. Dwyer, A. E. Yellin, J. Cherlow, M. Bass, and B. J. Haverback, “Laser-induced hemostasis in upper gastrointestinal-tract using a flexible fiberoptic,” *Gastroenterol.*, vol. 68, no. 4, pp. 888–888, 1975.

[40] R. M. Dwyer, A. E. Yellin, J. Craig, J. Cherlow, and M. Bass, “Gastric hemostasis by laser phototherapy in man—Preliminary-report,” *Jama—J. Amer. Med. Assoc.*, vol. 236, no. 12, pp. 1383–1384, 1976.

[41] E. Yellin, R. M. Dwyer, J. R. Craig, M. Bass, and J. Cherlow, “Endoscopic argon-ion laser phototherapy of bleeding gastric lesions,” *Arch. Surgery*, vol. 111, no. 7, pp. 750–755, 1976.

[42] R. M. Dwyer and M. Bass, “Laser phototherapy in man using argon and Nd–YAG lasers,” *Gastrointestinal Endoscopy*, vol. 24, no. 4, pp. 195–196, 1978.

[43] R. M. Dwyer, “Safe and effective laser phototherapy in man using the Nd-YAG laser,” *Gastroenterol.*, vol. 76, no. 5, p. 1126, 1979.

[44] M. Bass and K. M. Leung, “Dependence of pulsed 10.6 micron laser damage threshold on manner in which a sample is irradiated,” *IEEE J. Quantum Electron.*, vol. QE-12, no. 2, pp. 82–83, Feb. 1976.

[45] K. M. Leung, C. C. Tang, M. Bass, and M. J. Soileau, “Damage-resistant optical components for 2–5 micron laser systems,” *J. Opt. Soc. Amer.*, vol. 66, no. 4, p. 383, 1976.

[46] J. O. Porteus, D. L. Decker, J. L. Jernigan, W. N. Faith, and M. Bass, “Evaluation of metal mirrors for high-power applications by multithreshold damage analysis,” *IEEE J. Quantum Electron.*, vol. QE-14, no. 10, pp. 776–780, Oct. 1978.

[47] F. Stewart and M. Bass, “Intensity-dependent absorption in semiconductors,” *Appl. Phys. Lett.*, vol. 37, no. 11, pp. 1040–1043, 1980.

[48] L. D. Merkle, N. Koumvakalis, and M. Bass, “Laser-induced bulk damage in SiO$_2$ at 1.064 μm, 0.532 μm, 0.355 μm,” *J. Appl. Phys.*, vol. 55, no. 3, pp. 772–775, 1984.

[49] N. Koumvakalis, C. S. Lee, and M. Bass, “Intensity-dependent absorption in Cu and Ag metal mirrors—The role of temperature and surface-roughness,” *IEEE J. Quantum Electron.*, vol. QE-19, no. 10, pp. 1482–1485, Oct. 1983.

[50] C. S. Lee, N. Koumvakalis, and M. Bass, “A theoretical-model for multiple-pulse laser-induced damage to metal mirrors,” *J. Appl. Phys.*, vol. 54, no. 10, pp. 5727–5731, 1983.

[51] M. Bass, “Pulse laser damage in infrared materials,” *J. Opt. Soc. Amer.*, vol. 67, no. 2, p. 254, 1977.

[52] L. G. Deshazer, M. Bass, U. Ranon, J. K. Guha, and E. D. Reed, “Laser performance of Nd$_3^+$ and HO$_3^+$ in YVO$_4$, Nd$_3^+$ in gadolinium gallium garnet (GGG),” *IEEE J. Quantum Electron.*, vol. QE-10, no. 9, pp. 683–684, Sep. 1974.

[53] W. Q. Shi, R. Kurtz, J. Machan, M. Bass, M. Birnbaum, and M. Kokta, “Simultaneous, multiple wavelength lasing of (Er, Nd)–Y$_3$Al$_5$O$_{12}$,” *Appl. Phys. Lett.*, vol. 51, no. 16, pp. 1218–1220, Oct 1987.

[54] M. Bass, “Electrooptic Q-switching of Nd:YVO$_4$ laser without an intracavity polarizer,” *IEEE J. Quantum Electron.*, vol. QE-11, no. 12, pp. 938–939, Dec. 1975.

[55] F. P. Roullard and M. Bass, “Waveguide dye laser with Gaussian mode output,” *Opt. Commun.*, vol. 15, no. 2, pp. 161–165, 1975.

[56] M. Bass, E. W. Vanstryland, and A. F. Stewart, “Laser calorimetric measurement of 2-photon absorption,” *Appl. Phys. Lett.*, vol. 34, no. 2, pp. 142–144, 1979.

[57] M. Simhony, M. Bass, E. W. Vanstryland, E. M. Tenescu, and B. Levy, “Fast response of PLZT pyroelectric detectors to megawatt CO$_2$-laser pulses,” *IEEE J. Quantum Electron.*, vol. QE-15, no. 4, pp. 206–208, Apr. 1979.

[58] S. D. Allen, M. Bass, E. Garmire, and E. Packer, “Calorimetric measurement of LiNbO$_3$ waveguide losses,” *Appl. Phys. Lett.*, vol. 34, pp. 435–437, 1979.

[59] M. Bass and L. Liou, “Calorimetric studies of light-absorption by diamond turned Ag and Cu surfaces and analyses including surface-roughness contributions,” *J. Appl. Phys.*, vol. 56, no. 1, pp. 184–189, 1984.

[60] S. L. Narasimhan, S. M. Copley, E. W. Vanstryland, and M. Bass, “Epitaxial re-solidification in laser melted superalloys,” *IEEE J. Quantum Electron.*, vol. QE-13, no. 9, p. 2D, Sep. 1977.

[61] S. D. Allen and M. Bass, “laser chemical vapor deposition of metals and insulators,” *J. Vacuum Sci.*, vol. 16, no. 2, p. 431, 1979.

[62] H. B. Singh, S. M. Copley, and M. Bass, “Fatigue resistance of laser heat-treated 1045 carbon-steel,” *Metallurg. Trans. A—Physical Metallurgy and Mater. Sci.*, vol. 12, no. 1, pp. 138–140, 1981.

[63] S. M. Copley and M. Bass, “Laser melted surfaces for corrosion-resistance,” *J. Metals*, vol. 33, no. 9, pp. A59–A60, 1981.

[64] Y. M. Xiao and M. Bass, “Thermal-stress limitations to laser fire polishing of glasses,” *Appl. Opt.*, vol. 22, no. 18, pp. 2933–2936, 1983.

[65] E. Garmire, T. McMahon, and M. Bass, “Propagation of infrared light in flexible hollow waveguides,” *Appl. Opt.*, vol. 15, no. 1, pp. 145–150, 1976.

[66] E. Garmire, T. McMahon, and M. Bass, “Flexible infrared-transmissive metal waveguides,” *Appl. Phys. Lett.*, vol. 29, no. 4, pp. 254–256, 1976.

[67] T. R. McMahon, E. Garmire, and M. Bass, “Flexible, infrared transmissive waveguides at 10.6 microns,” *J. Opt. Soc. Amer.*, vol. 66, no. 10, p. 1102, 1976.

[68] E. Garmire, T. McMahon, and M. Bass, “Measurements of propagation in flexible IR transmissive (FIT) waveguides,” *IEEE J. Quantum Electron.*, vol. QE-13, no. 9, p. D21, Sep. 1977.

[69] E. Garmire, M. Bass, and T. McMahon, “Low loss optical transmission through bent hollow metal waveguides,” *Appl. Phys. Lett.*, vol. 31, pp. 92–94, 1977.

[70] E. Garmire, T. McMahon, and M. Bass, “Flexible infrared wave-guides for high-power transmission,” *IEEE J. Quantum Electron.*, vol. QE-16, no. 1, pp. 23–32, Jan. 1980.

[71] M. Bass, “Solid-state lasers develop new capabilities,” *Laser Focus World*, vol. 25, no. 6, pp. A4–A5, Jun. 1989.

[72] M. E. Innocenzi, R. T. Swimm, M. Bass, R. H. French, A. B. Villaverde, and M. R. Kokta, “Room-temperature optical-absorption in undoped alpha-Al$_2$O$_3$,” *J. Appl. Phys.*, vol. 67, no. 12, pp. 7542–7546, June 1990.

[73] M. E. Innocenzi, R. T. Swimm, M. Bass, R. H. French, and M. R. Kokta, “Optical-absorption in undoped yttrium-aluminum-garnet,” *J. Appl. Phys.*, vol. 68, no. 3, pp. 1200–1204, Aug. 1990.

[74] M. Stalder, B. H. T. Chai, and M. Bass, “Flashlamp pumped Cr–LiSrAlF$_6$ laser,” *Appl. Phys. Lett.*, vol. 58, no. 3, pp. 216–218, Jan. 1991.

[75] C. Deka, B. H. T. Chai, Y. Shimony, X. X. Zhang, E. Munin, and M. Bass, "Laser performance of $\mathrm{Cr}_4^+-\mathrm{Y}_2\mathrm{SiO}_5$," *Appl. Phys. Lett.*, vol. 61, no. 18, pp. 2141–2143, Nov. 1992.

[76] M. Stalder, M. Bass, and B. H. T. Chai, "Thermal quenching of fluorescence in chromium-doped fluoride laser crystals," *JOSA B*, vol. 9, no. 12, pp. 2271–2273, 1992.

[77] R. Paugstadt and M. Bass, "A new technique for spatially resolved thermal lensing measurements," *Opt. Laser Technol.*, vol. 24, no. 3, pp. 151–154, Jun. 1992.

[78] E. Munin, A. B. Villaverde, X. X. Zhang, and M. Bass, "Broad-band, intensity-dependent absorption in tetravalent chromium-doped crystals," *Appl. Phys. Lett.*, vol. 63, no. 13, pp. 1739–1741, Sep. 1993.

[79] E. Munin, A. B. Villaverde, and M. Bass, "Broad-band, tunable passive q-switching with semiconductor-doped glass filters," *Opt. Commun.*, vol. 108, no. 4–6, pp. 278–282, June 1994.

[80] X. X. Zhang, P. Hong, M. Bass, and B. H. T. Chai, "Blue up-conversion with excitation into TM ions at 780 nm in YB-codoped and TM-codoped fluoride-crystals," *Physical Rev. B*, vol. 51, no. 14, pp. 9298–9301, Apr. 1995.

[81] G. H. Xiao and M. Bass, "A generalized model for passively Q-switched lasers including excited state absorption in the saturable absorber," *IEEE J. Quantum Electron.*, vol. 33, no. 1, pp. 41–44, Jan. 1997.

[82] J. Dong, M. Bass, Y. L. Mao, P. Z. Deng, and F. X. Gan, "Dependence of the Yb3+ emission cross section and lifetime on temperature and concentration in yttrium aluminum garnet," *J. Opt. Soc. Amer. B—Opt. Phys.*, vol. 20, no. 9, pp. 1975–1979, Sep. 2003.

[83] F. Rapaport, J. Szipocs, H. Milliez, M. Jenssen, M. Bass, K. J. Schafer, and K. D. Belfield, "Optically written displays based on up-conversion of near infrared light," in *Proc. Soc. Photo-Opt. Instrum. Engineers (SPIE) Projection Displays VII*, M. H. Wu, Ed., 2001, pp. 47–55.

[84] F. Rapaport, J. Milliez, F. Szipocs, M. Bass, A. Cassanho, and H. Jenssen, "Properties of a new, efficient, blue-emitting material for applications in upconversion displays: Yb, Tm:$\mathrm{KY}_3\mathrm{F1O}$," *Appl. Opt.*, vol. 43, no. 35, pp. 6477–6480, Dec. 2004.

[85] Q. H. Wang and M. Bass, "Photo-luminescent screens for optically written displays based on upconversion of near infrared light," *Electron. Lett.*, vol. 40, no. 16, pp. 987–989, Aug. 2004.

[86] J. Milliez, A. Rapaport, M. Bass, A. Cassanho, and H. P. Jenssen, "High-brightness white-light source based on up-conversion phosphors," *J. Display Technol.*, vol. 2, no. 3, pp. 307–311, Sep. 2006.

[87] F. Rapaport, J. Milliez, M. Bass, A. Cassanho, and H. Jenssen, "Review of the properties of up-conversion phosphors for new emissive displays," *J. Display Technol.*, vol. 2, no. 1, pp. 68–78, Mar. 2006.

[88] S. Babu, J.-H. Cho, J. M. Dowding, E. Heckert, C. Komanski, S. Das, J. Colon, C. H. Baker, M. Bass, W. T. Self, and S. Seal, "Multicolored redox active upconverter cerium oxide nanoparticle for bioimaging and therapeutics," *Chem. Commun.*, vol. 46, pp. 6915–6917, 2010.

[89] J. H. Cho, M. Bass, S. Babu, J. M. Dowding, W. T. Self, and S. Seal, "Up conversion luminescence of $\mathrm{Yb}_3^+-\mathrm{Er}_3^+$ codoped CeO_2 nanocrystals with imaging applications," *J. Luminesc.*, vol. 132, no. 3, pp. 743–749, Mar. 2012.

[90] D. C. Harris, L. R. Cambrea, L. F. Johnson, R. T. Seaver, M. Baronowski, R. Gentilman, C. Nordahl, T. Gattuso, S. Silberstein, P. Rogan, T. Hartnett, B. Zelinski, W. Sunne, E. Fest, W. H. Poisl, C. B. Willingham, G. Turri, C. Warren, M. Bass, D. E. Zelmon, and S. M. Goodrich, "Properties of an infrared-transparent MgO: $\mathrm{Y}_2\mathrm{O}_3$ nanocomposite," *J. Amer.Cer. Soc.*, vol. 96, no. 12, pp. 3828–3835, Dec. 2013.

[91] K. Vodopyanov, J. Schaar, X. Yu, M. Fejer, J. Harris, V. Kozlov, Y.-S. Lee, G. Imeshev, M. Fermann, D. Bliss, and C. Lynch, "Tunable THz source based on quasi-phase-matched GaAs," in *2nd EPS–QEOD Europhoton Conf.*, Pisa, Italy, Sep. 10–15, 2006.

[92] K. L. Vodopyanov, J. E. Schaar, P. S. Kuo, M. M. Fejer, A. Lin, J. S. Harris, V. G. Kozlov, W. C. Hurlbut, D. Bliss, and C. Lynch, "THz source based on resonantly-enhanced difference frequency generation in periodically-inverted GaAs," presented at the 33rd Int. Conf. on Infrared, Millim. and THz Waves (IRWWM-THz 2008), Pasadena, CA, USA, Sep. 15–19, 2008, Paper no. PaM4K5.1383.

Michael Bass (M'71–SM'77–F'81–LF'06) received the B.S. degree in physics from Carnegie-Mellon University, Pittsburgh, PA, USA, in 1960, and the M.S. and Ph.D. degrees in physics from the University of Michigan, in 1962 and 1964, respectively.

He is Professor Emeritus of Optics at CREOL, the College of Optics & Photonics, University of Central Florida, Orlando, FL, USA. From December 1987 until December 1992 he served as UCF's Vice President for Research. Until November 1987, he was Professor and Chairman of Electrical Engineering–Electrophysics at the University of Southern California, Los Angeles, CA, USA. From 1977 to 1984, he served as the Director of the Center for Laser Studies at U.S.C. Prior to coming to the university in 1973, he was a Senior Research Scientist at the Research Division of the Raytheon Company. He has been active in quantum electronics research since his thesis work on optical rectification. He was amongst the first to demonstrate homogeneous broadening in dye lasers showing why they could oscillate over so broad a spectral range. Prof. Bass is responsible for the use of the statistical approach to understanding the processes of laser induced damage. This work led to the recognition of avalanche breakdown as the principal cause of intrinsic laser induced damage to transparent media. As part of his research on the optical properties of matter, Prof. Bass developed the technique of pulsed laser calorimetry to measure small intensity dependent absorptions. He is one of the co-inventors of the YAlO_3 laser host, the flexible, hollow, metal walled infrared transmissive waveguide and the use of fiber optics to deliver laser light for the treatment of internal bleeding and tumors. Prof. Bass and colleagues were amongst the first to establish research at a U.S. university on laser materials processing where they demonstrated laser assisted machining, laser shaping of ceramics, and laser driven chemical vapor deposition. His current research interests are in the areas of optically pumped solid state lasers, design of high power solid state lasers, the use of up-conversion for displays and novel fiber lasers. In 2006, he and his colleagues were the first to demonstrate gain guided index anti guided fiber lasers that had been predicted in 2003. Subsequent work on such fiber lasers showed that lowest order mode oscillation can be achieved in fibers with core diameters as large as 400 μm and diode pumped scalable lasers were demonstrated. He has authored over 190 refereed publications, presented many invited lectures in several countries and at international conferences. He is the editor of a book entitled *Laser Materials Processing* (North Holland, 1983), the co-editor of the *Laser Handbook* (North-Holland, 1985), and the co-author with Walter Koecher, of *Solid State Lasers: A Graduate Text* (Springer-Verlag, 2003). In 1991, he was appointed by the Optical Society of America to be the Editor-in-Chief of the *Handbook of Optics, 2nd ed.* (McGraw-Hill, 1995) which sold over 11 000 copies. In 2009, he completed work as Editor-in-Chief of the *Handbook of Optics, 3rd. ed.* (McGraw-Hill, 2010).

Prof. Bass is a Life Fellow of the Optical Society of America (OSA) and the Laser Institute of America (LIA). In 1979, he was honored as the first recipient of the U.S.C. School of Engineering Distinguished Researcher Award. He has been a guest editor of the IEEE JOURNAL OF QUANTUM ELECTRONICS and was one of the founding editors of the *Journal of the Optical Society B*. He has been a member of the IEEE Outside Awards Committee, both member and chairman of the OSA Adolph Lomb Award Committee and served as General Chairman of the 1989 Annual Meeting of the OSA. He served as a member of the governing board, the ADCOM of the IEEE Laser and Electro-Optics Society. During 1988, he was President of the Laser Institute of America. In 1989, he was elected to a full three-year term as a member of the Board of Directors of the OSA. He was elected a Foreign Member of the Russian National Academy of Engineering Science in 1994. He is a member of Sigma Xi, Tau Beta Pi, the American Society of the Advancement of Science, and is listed in Who's Who in Engineering, and Who's Who in America. In 2013, Prof. Bass was elected a Fellow of the National Academy of Inventors. He is the 2014 recipient of the R. W. Wood Prize of the Optical Society of America.