Terahertz Pioneer: Jun-ichi Nishizawa

"THz Shogun"

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JUN-ICHI NISHIZAWA[1] looks better at age 88 than most of us do at 60. His latest paper (as of January 2015) came out in November 2014 in *Materials Science in Semiconductor Processing* [1], and he just received yet another patent (with Kimura Mitsuteru) on his 2009 submission of a "Terahertz-wave integrated circuit, and terahertz absorption characteristics measuring apparatus using the same" [2]. With more than 500 publications, 19 books, 1237 patents, over 6000 citations, 1200 talks, 30 major awards—including The Order of Cultural Merits, the IEEE Edison Medal, and an IEEE medal named in his honor, there is no doubt that Nishizawa's technical career is an enviable one. This is not the whole story however, nor is it the whole man.

Jun-ichi was born into an academic family. His father, Kyosuke Nishizawa, was a Professor of inorganic chemistry, and later, a Dean at Tohoku Imperial University, Sendai, Japan. Kyosuke, an opinionated man, had an extremely strong influence on this second of his five children. Jun-ichi states [3][2] that he inherited his stubbornness from his father and his short temper from his mother—a combination that must have made for an animated childhood! He remembers being a sickly boy, not doing particularly well in school, and getting into lots of mischief. He did not get down to serious studies until middle school, where he took up science in preparation for high school.

JUN-ICHI NISHIZAWA

It was 1943 when Jun-ichi enrolled at a highly rated high school (Sendaidainikotogakko, or literally Sendai second high school) specializing in science. The war made normal everyday life impossible. His classes were sparse and irregular and he worked at an arms factory and on a farm between semesters. Although good at math and physics, he was less proficient in his father's field of expertise, so he decided to challenge himself by majoring in chemistry! Thomas Edison was an early hero, and the writings of Friedrich Nietzsche instilled his life view—that of the power of individuals to overcome the world's obstacles. He was influenced by Nobel Prize winning physicist, Percy Williams Bridgman's *The Logic of Modern Physics* [4] and by astrophysicist, George Gamow's *The Birth and Death of the Sun* [5] and *Mr. Tomkins in Wonderland* [6].

After two years of high school it was time for university, and Jun-ichi's grades were not good enough for his father to recommend physics or math. Kyosuke "suggested" that Jun-ichi study engineering. He further recommended electrical engineering, which was a specialty at Tohoku. Jun-ichi entered the university in April 1945, just before the end of World War II in the Pacific. His parents were forced to move out of their home, which was then occupied by US forces, and to relocate to a very small cottage in Sendai, where the family would come together on Saturday evenings for dinner. Jun-ichi related [3] that his parents came to his sparse university apartment to bathe, and he came to their cottage to eat!

At Tohoku, Jun-ichi took classes with Hidetsugu Yagi (of Yagi-Uda antenna fame) and like Hiromasa Ito [7], he benefited from the advice and support of noted electrical engineer and

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[1]I met with Sensei Jun-ichi Nishizawa on December 15th, 2014, in the front parlor of his 1932-constructed western style family home, along the Hirosegawa River, and adjacent to the campus of Tohoku University in Sendai, Japan. Along with me was former Nishizawa protégé and colleague, Professor Koji Mizuno. Together we listened to stories and asked questions about the very unusual and very full technical career of this eminent scholar, prolific inventor and strong science advocate. We were fortunate too, to be introduced to Nishizawa's wife of 59 years, Takeko Hayakawa, and his lovely daughter Keiko, who was not shy about pointing out that a shift of a single letter in her name to Keiso, changes the meaning to "silicon". The results of that meeting, and an autobiographic monograph written in 1985 (translated for me by JPL's Hanii Takahashi), fill in the background and personal content of this article.

[2]Nihon Keizai Shimbun is a Japanese news media and released this biography as a series of newspaper articles in 1985 as well as a book chapter combined with four other notable Japanese scientist biographies in 2007.

semiconductor pioneer, Yasushi Watanabe[3]. Watanabe encouraged Nishizawa to study electronics, and specifically to work in the emerging field of semiconductors.

Jun-ichi graduated in 1948, and then spent the next several years working under a research fellowship at Tohoku. Times were difficult however, and funding for experimental work was extremely limited. Nishizawa recalled making trips to the Akihabara (electronics) district in Tokyo to bring back cheap or discarded electronic parts for use in his experiments. He spent a lot of time just trying to make his equipment function. At one point he became quite discouraged and was only revitalized in what might be described as a “Zen moment”, when a respected professor told him that his technical problems could not be blamed on his lack of equipment, but only on limitations within himself.

Jun-ichi's persistence, or perhaps his self-proclaimed stubborn streak, proved to be a valuable asset. He continued to work feverishly, and mostly on his own, expanding his technical skillset and trying out all sorts of experiments on the earliest semiconductor devices. He also worked on tubes and electron devices—which were the subject of his thesis. Nishizawa would read about new breakthroughs or study existing textbooks by buying publications and then reselling them to finance additional purchases. As he came up with new ideas, he presented them to his colleagues and tried to publish them in the open literature. Most often, his ideas were criticized or not accepted, and his attempts at publishing were rejected (almost all of his early work is contained only in local university technical reports).

Despite (or maybe because of) his young age, Nishizawa's ideas were well ahead of their time, and he was labeled as a very radical thinker—a negative assignation that was the antithesis of what it implied in the western world of science at the time. Even though his attempts at publishing were scorned (Nishizawa was actually told by his department to stop this activity [3]), Watanabe was extremely keen on patents, as they not only brought recognition, but any proceeds from royalties or sales could be used to fund their university research. As a result, Jun-ichi had many dozens of patents and pending patent applications before he even finished his Ph.D. work.

The period between 1948 and 1954, while Nishizawa was a research assistant at Tohoku, he considers to be his “golden” years. Despite the early skepticism from many of his colleagues in Japan, he had a staunch supporter in Watanabe, who read and kept his rejected papers, and encouraged more. Watanabe's faith in Nishizawa was spectacularly rewarded when in 1949 they developed and experimentally realized the first p-i-n-junction diode, which was submitted for patent on September 11, 1950 [8], 18 days before General Electric in the USA patented a similar device concept [9]. They also developed a key theory for hot carrier injection over the semiconductor barrier that was published in *Busseiron-Kenkyu* [10] (Japanese Research in Physics and Chemistry) [11], [12].

[3]Watanabe was the director of the Research Institute of Electrical Communications at Tohoku University, and head of the Faculty of Technology. He was later appointed president of Shizuoka University. His early work focused on the development of electron tubes, but he quickly recognized the value of the transistor and was the first to push its development, and that of semiconductors in general, in Japan. As with Hiromasa Ito [7], Watanabe was an honored figure at Nishizawa's wedding ceremony which took place in 1956.

In a second series of major breakthroughs during the same time period, Nishizawa conceived and produced the first pnip and npin transistors (control of injected carriers by the addition of a base electrode embedded within a bipolar junction transistor), and more importantly, the static induction transistor or SIT (inserting an electrode array as a local control gate to act like a vacuum tube grid to regulate the current flow) [13]. The SIT device represented true planar transistor action in using a negatively biased paired gate electrode composed of fine coplanar wires to control the flow of carriers between the source and drain of a bipolar device. It was the first demonstration of an all-planar semiconductor transistor, prior representations by Shockley and other transistor pioneers being point contact devices [14]. SIT devices (especially a later variant—the static induction thyristor [15], [16]) have gone on to enormous success in the power transmission industry, being one of the most ubiquitous and efficient components (in converting ac to dc and vice versa) in use to this day.

Both the p-i-n diode and the SIT devices were realized through semiconductor fabrication advances that were pioneered in Japan by Nishizawa, including ion implantation [17] and electrochemical epitaxy [18], [19]. The p-i-n diode theory was soon expanded upon to include the avalanche effect in reverse bias [20] and the space charge conduction mechanism [21]. By 1953, Nishizawa and Watanabe added photons to the mix, creating the first p-i-n and avalanche photodiodes [22], [23]. As if this wasn't enough, Nishizawa also came up with concepts that would lead to the IMPATT oscillator [24], the TUNNETT diode [25], [26], the static induction thyristor (SIThy) [27], a highly sensitive SIT phototransistor [28], the ideal static induction transistor (ISIT) or permeable base transistor, with a demonstrated oscillation frequency of 780 GHz in 1979 [29], and the ideal static induction tunneling transistor (ISITT) [29], which was calculated to have a cutoff frequency well into the THz range [14, page 324]. None of these early concepts and breakthroughs would make it into the western science literature for almost two decades.

In 1954, Nishizawa became a research professor at the Research Institute of Electrical Communications (RIEC) at Tohoku and he received his doctorate in engineering there in 1960. Between 1954 and 1960, Nishizawa continued to work on expanding his semiconductor device concepts and honing new semiconductor processing techniques. He made notable contributions to transistor theory when he worked out the accurate operating mechanisms of the FET and bipolar junction transistors, later detailed in [30], as well as inventing the TUNNETT device in 1958 [26]. He published his first substantial paper in an English-language journal on the development and theory of the hyper-abrupt junction varactor in 1961 [31]. Even more amazing, in 1957, Nishizawa came up with an idea for a semiconductor optical maser and wrote it up in great detail in a Japanese patent application [32], seven months before Gordon Gould, and more than a full year ahead of the Schawlow-Townes paper [33] and their patent application in July 1958. Unfortunately, Nishizawa was unable to realize the structure at Tohoku, and he could not convince Japanese industrial partners to open up research in this area. He would have to come back to the semiconductor laser at a much later date [34].

Watanabe sent Nishizawa on his first trip abroad in October 1958 for 3 months. He attended the International Electron Devices meeting (IEDM) in Washington DC, USA, and visited many laboratories in both the US and Europe (specifically in England, France, and Germany). He recalls having a per diem of $10/day and sometimes paying $6–$7/day for hotel accommodations. When he exceeded his budget, he just didn't eat! [3]. This first trip outside Japan was incredibly exciting and uplifting for Nishizawa. He returned to Tohoku invigorated and certain that his ideas were valuable. In 1960, Watanabe retired from RIEC and took up the post of President of Shizuoka University in Shizuoka City, Japan. Nishizawa was now on his own at Tohoku, but he was starting to get the recognition he had rightfully earned. He was promoted to full Professor at RIEC in 1962, only two years after receiving his doctorate.

Research work at RIEC continued on semiconductor processing methods—liquid [35] and light assisted vapor phase epitaxy (photo-epitaxy) [36] of germanium and silicon, and crystal growth with precise lattice matching [37]. These would set the stage for later developments using GaAs and other compound semiconductors to realize both high quality optical and THz devices.

By 1963, Nishizawa came to grips with the fact that many of his earlier ideas, because they had not been publicized in the west, had been "scooped" by other research groups working in parallel outside of Japan. Undeterred, he decided to focus his future efforts on bridging the gap between the two electromagnetic domains for which he had already made significant device contributions: microwaves and light. In an introductory article in which he was asked to set out the future directions for semiconductor devices [38], Nishizawa proposed four areas of development: 1) improved crystal growth and epitaxy, especially of GaAs, so as to enhance optical generation and electronic device performance; 2) optical fiber communications through the use of beam waveguides and RF modulation; 3) the generation of ultra-high frequency radio waves through the excitation of lattice and molecular vibrations to span the regimes of electronics and optics, i.e., *THz*, and (4) the enhancement of tunneling and transit time devices (IMPATT, TUNNETT, ISIT, ISITT etc.), that had already proven to be extremely effective at long wavelengths, but which could be developed for new applications at high frequencies.

In 1968, Nishizawa was finally able to convince the university to establish a research center exclusively devoted to the semiconductor field. Partially employing funds he himself had accumulated through his patents and industrial partnerships, the Semiconductor Research Institute (SRI) was established in Sendai, and Nishizawa became its founding director. He would now have the facilities to perform the experimental work that had been so hard under the limited self-funded university programs, which he started. Note that even the concept for SRI was unusual, as Nishizawa set it up as a separate research facility managed under a non-profit foundation that would allow it to be associated with the university, but to work directly with, and transfer technology out to industry—a sort of early university technology incubator concept. It was a unique arrangement in Japan at the time.

The first of Nishizawa's self-imposed technical challenges—improving on his early semiconductor processing methods [35]–[39], could now be undertaken. An enormous number of new and improved epitaxial and crystal growth techniques were the result. These included photo-assisted epitaxy [40]; vapor phase epitaxy [41]–[44]; liquid phase epitaxy [45]; MOCVD (metal-organic chemical vapor deposition) [46], [47]; newly devised molecular layer epitaxy [48]–[51]; better characterization of epitaxial grown compound semiconductors [52]–[55]; and near perfect crystal growth techniques [56]–[59]. The latter led directly to a spectacular increase in the light output and efficiency of light emitting diodes. Nishizawa realized yellow [60], green [61], red [62], [63], and even blue LED's [64], [65], for which Shuji Nakamura received the 2014 Nobel Prize in physics. In fact, Nishizawa wrote a popular science book with Nakamura as co-author that came out in 2001 transliterated as "*Discovery of Red and Discovery of Blue*" which is mainly a conversation between the two pioneers [66]. Nishizawa is also purported to have decorated trees around his laboratory with his newest LED devices to celebrate the holidays every December [67]!

Nishizawa's second challenge, using electromagnetic waves for communications, was a dream he carried forward from his first association with Hidetsugu Yagi, who he quotes as stating "the final goal of communications technology should be to open a communications between any pair of people at any time and any place" [34], page 454. This goal required ultra-high frequency operation, that Yagi believed would have to extend to X-Ray wavelengths in order to provide the necessary bandwidth [34]. Fortunately, optical wavelengths have since satisfied the requirements.

Optical communications networks require high efficiency narrow-band optical sources, low-loss guide networks, and high frequency modulators and demodulators. The semiconductor optical maser, patented by Nishizawa in 1957 [32], was realized in 1962 by Robert Hall at General Electric, USA [68] and Marshall Nathan at IBM, USA [69]. Nishizawa added GaAs devices shortly afterwards [70]–[72], and demonstrated millimeter-wave modulation of the optical energy in 1968 [73]. Again, remarkably, Nishizawa also developed the concept of using a focusing optical lens implemented with a graded index sheath for efficient transmission of light way back in 1964 [74]–[76], two years before Charles Kao and George Hockham at Standard Telecommunications Laboratories, Essex, England launched the optical fiber revolution with their classic paper [77]. The Nishizawa graded index fiber concept was realized and published in various configurations between 1965 and 1973 [78]–[83], and was at the heart of what would become very widely utilized GRIN guide [84].

Since his days with Yagi, Nishizawa had been interested in the generation of high frequency electromagnetic waves. In 1990, he held a conference at Sendai in which he highlighted this topic [85]. He even initiated a conference series as recently as 2008 on this theme, in conjunction with Chalmers University in Sweden [86]. In 1968, Nishizawa approached the idea of generating THz waves from both ends of the electromagnetic spectrum. His development of IMPATT and TUNNETT devices was to take him up from the microwave regime to several hundreds of GHz. He also realized very early on [38], that he might be able to draw on optical techniques to generate THz energy through the excitation of molecular vibrations (phonon modes) in crystals. Nishizawa experimented with acousto-optic interactions between a 35 GHz klystron and optical Brillouin scattering in CdS [87], but then realized that optical phonon (rather than acoustic-phonon) interactions were preferred, because more semiconductors had optical phonon frequencies in the far infrared. Following the earlier work of Yarborough *et al.* [88] on far-infrared generation in optically pumped $LiNbO_3$ crystals, Nishizawa and Ken Suto developed and realized the first semiconductor Raman laser using YAG laser pumped GaP and GaAs in 1979 [89]. They refined their experiments and provided an elaborate theoretical formulation in [90], [91].

Nishizawa's goal, even in 1979, was to be able to generate broadly tunable THz energy from these solid-state devices for use in communications applications, both as sources and as local oscillators for heterodyne detection [91]. The first demonstration of useful THz power generation came in 1983, when a combination of GaP and GaAs crystals placed in an external cavity and pumped with a Q-switched YAG laser at 1.06 μm, produced over 3 W of pulsed power at 24.8 μm (12.09 THz) [90]. Further development in this area with GaP [92]–[95] ultimately resulted in a semiconductor laser-based continuous wave, tunable THz generator with microwatt output power levels [96], [97], [98] that was employed for a wide variety of broad line spectral measurements [99]. Typical THz output line bandwidth is 3 GHz for this system.

At the same time as Nishizawa was developing optical-to-THz generators using laser techniques, he was also pushing his semiconductor oscillators and three terminal devices up in frequency—the fourth goal of his future directions speech [38]. The IMPATT (impact ionization and transit time) diode, which he first described in a report to Nippon Telegraph and Telephone in 1953 [24], and the TUNNETT (tunnel injection transit time) diode, presented in 1958 [26], were both demonstrated to oscillate above 100 GHz by the mid 1970's [100], [25]. The GaAs TUNNETT diode reached the submillimeter in 1979 [101] and hit 650 GHz in 2005 [102] and 700 GHz in 2006 [103]. Power levels are well below a μW however.

The ballistic transistor concepts (ISIT and SITT) were also potential candidate THz devices, and although Nishizawa's ground breaking molecular layer epitaxy techniques [48], [49], [104], [105] have made the electron injection path and corresponding transit times incredibly short (2×10^{-14} s) [106], no working THz devices have yet to be reported as far as the author is aware. It should be noted that Nishizawa made significant progress on generally useful SIT [15], [107]–[114] and thyristor [27], [115]–[121] devices during this very fruitful period, as well as publishing many dozens of papers on other semiconductor fabrication and diagnostic techniques, and on applications.

Nishizawa directed the SRI in Sendai from 1968 all the way through to 2004. He also took on the role of Director of RIEC at Tohoku from 1983 to 1986. In 1987, Nishizawa became project leader for a new program at SRI that he brought in through the ERATO (Exploratory Research for Advanced Technology) office [122], funded under the Japan Science and Technology agency. The author was informed [123], that this is most likely the first program in Japan to use the term "Terahertz" in the project title. The ERATO program lasted for 5 years and was responsible for improvements in the semiconductor Raman laser, monolayer epitaxial growth in GaAs, an ideal static induction transistor (ISIT) with a cutoff of 800 GHz, 500 GHz TUNNETT devices, Pt:Au Schottky barrier diodes with anode diameters from 0.4–0.8 microns, a quasi-optical Yagi imaging array, spatial power combining, and an optical modulator [122].

In 1989, Nishizawa was awarded one of Japan's highest honors, the *Bunka-Kunsho*—Order of Cultural Merits, which was conferred on him by the Emperor of Japan. After a second term as Director of RIEC from 1989 to 1990, he retired from his professorship and took up the post of President of Tohoku University. Rather than slowing down his research interests and involvement, this promotion had the exact opposite effect!

At this time, RIKEN, the Institute of Physical and Chemical Research—the major government research organization in Japan—was working on a new model to establish world-class research centers under a program called Frontiers of Research. Sendai was selected as one of the locations for a new center because it already had a large research base that included Tohoku University as well as an established materials science institute, Kinken[4] that had been part of RIKEN for a short while in the 1920's. Nishizawa was selected as an advisor to help implement this new branch of RIKEN in Sendai. He proposed that the new center focus its research on the interaction of light and matter and specifically to include the life sciences. He coined a new title for the research and the new institute: *photodynamics*. The Photodynamics Research Center was established in 1990 and Nishizawa was named as its first director. One of the four research teams he set up was specifically directed at THz, and Prof. Koji Mizuno [124] was appointed as its team leader.

Nishizawa then poured his energies, and whatever time he had to himself (he stated once that he did much of his thinking and any work requiring concentration, in the evening before dinner, and that he did not eat dinner until past 11PM because he liked to be hungry while he worked! [125]) into his now extremely widespread research projects. The author cannot hope to site more than a few of the 300 plus papers that he authored between 1990 and present day (more than 120 as first author). These included papers on crystal growth [126], p-i-n [127] and photo diodes [128], molecular layer epitaxy [129], photo-quenching [130], Raman lasers [131], MOCVD [132], new diode structures [133], surface chemistry [134], silicon device physics [135], semiconductor luminescence [136], high power SIT devices [137], growth of IV–VI semiconductors [138], GaAs growth and doping [139], thin film deposition [140], Raman amplifiers [141], and even some politically prescient work on atmospheric CO_2 [142].

On the THz front, Nishizawa actively pursued the continued development of tunable sources using both optical and elec-

[4]Kinken is now the Institute for Materials Research. It was established by noted inventor and scientist Kotaro Honda (KS steel—magnetic resistant) at Tohoku in 1913. In 1987 it became a center of excellence for materials research in Japan and hence was a factor in the decision to locate a Frontiers of Research program in Sendai.

tronic approaches, and began to use the resulting instruments for spectral measurements [143], [144]. He became particularly interested in biological and biomedical applications a [145]–[147] and started looking at individual biomarkers [148] and cancer signatures [149]. He even patented a THz endoscope [150]. Nishizawa also teamed up with RIEC colleagues on some new THz waveguide approaches [151], [152].

Before ending his influence at Tohoku, there was yet one more program decision that Nishizawa played a role in, and that had a major impact on THz research. In 1996, Nishizawa left Tohoku University for Iwate Prefectural University, but he still had a major influence in the RIKEN Photodynamics Research Center and its focused research efforts. He helped Hiromasa Ito [7] become a THz program director at RIKEN in 1998, following in the footsteps of Professor Koji Mizuno [124]. Nishizawa also met, and mentored for a short time, Professor Kodo Kawase (now a professor at Nagoya University). It was of course Kawase and Ito who first demonstrated tunable, high power THz sources derived from optically excited $LiNiO_3$ [153], [154]—realizing a long time dream of Nishizawa's.

Nishizawa was awarded the IEEE Edison Medal in 2000, most appropriate because, as already mentioned, Edison was a childhood hero of Nishizawa's. Two years later the IEEE established the *Jun-ichi Nishizawa Medal* in honor of "Nishizawa's lifetime of outstanding achievements ranging from fundamental semiconductor materials and devices through optical communication and power systems."

In 2005, Nishizawa switched from Iwate to Tokyo Metropolitan University, where from age 78–83 he served as university President. He stepped down in 2009, and became a Professor by Special Appointment at Sophia University, Tokyo, a position he held until March of 2013.

Nishizawa is now more than 88-1/2 years old, and as stated in the introduction to this article, he is still interested in research, in writing, in mentoring, and in science and philosophy. A recent illness has severely curtailed his activities, but if anyone at his age can surprise his peers and his colleagues with something new and creative, it is *Jun-ichi Nishizawa*.

We wish him as many more years of fortune and productivity as life will allow, and cannot thank him sufficiently for all he has already done to make our own lives better.

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Jun-ichi Nishizawa (M'57–SM'62–F'69–LF'93) devoted his entire adult life to invention and technical achievement. He entered Tohoku University, Faculty of Engineering, Electrical Engineering Department, in 1945 as a student, just after the departure of Prof. H. Yagi to Osaka University. After experiencing some difficulties, he was selected as a special student to conduct research. His theme was the application of electron physics to engineering. Since he had very limited equipment, he had to start his semiconductor experiments by first melting semiconductor powders using a vacuum-tube oscillator that he constructed himself. After many experiments he ascertained the now accepted theory of hot electron transport in semiconductor junctions. He introduced the structures of a p-i-n diode and a pnip transistor, developed an innovative inhomogeneous control mesh structure and succeeded in fabricating several very nice devices, like diodes, triodes and thyristors. Subsequently, he jumped into optical communications after inventing the semiconductor optical maser in 1957. However, because of a lack of financial support, he was unable to immediately pursue development of the optical maser, and ended up coming back to the structure many years later. He did eventually return to the semiconductor laser concept, and developed the terahertz Raman laser, which he successfully demonstrated in 1983, with Assistant Professor K. Suto.

He served as a Professor at Tohoku University from 1962 to 1990, Director of RIEC from 1983 to 1987 and from 1989 to 1990, and he was the Founding Director of the Semiconductor Research Institute from 1968–2004. He also successively served as the Presidents of Tohoku University, Iwate Prefectural University and Tokyo Metropolitan University, and still remains Emeritus President of Iwate Prefectural University and Tokyo Metropolitan University. He was Adviser to the Sophia School Corporation and Professor (by Special Appointment) of Sophia University from 2009–2013, after retiring from Tokyo Metropolitan University. He has been Chairman of half a dozen important scientific organizations in Japan. His scientific contributions include more than 500 technical papers, 1237 patents, more than 20 books and book chapters, and 1200 lectures. He has more than 6000 citations and is considered the "Father of Japanese Microelectronics." *IEEE Spectrum* recognized him as one of the geniuses of the 20th Century in an article in 1991.

Professor Nishizawa is an elected member of the Japan Academy, the Russian Academy of Science, the US National Academy of Engineering, the Korean Academy of Science and Technology, the Engineering Academy of the Czech Republic, the Academy of Engineering Science of Serbia, and the Polish Academy of Sciences. He is a Fellow of the Electrochemical Society, the IEE, and a Life Fellow of the IEEE. He received the Academy Prize from the Japan Academy in 1974, the Jack A. Morton Award in 1983 and the Edison Medal from IEEE in 2000. The IEEE also created the Nishizawa Medal in his honor in 2002. Amongst his 30 plus major achievement awards, he is particularly proud of the Order of Cultural Merits, which he received from the Emperor of Japan in 1989. He also received the First Order of Merit from the Emperor in 2002.