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Ondrej Krivanek: A pioneering visionary in electron microscopy

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ABSTRACT

This article is a short biographical sketch of the life and times of Ondrej Krivanek. The story starts with his early days in Prague, Czechia, and briefly outlines various events from a PhD in Cambridge to post-docs in Kyoto, Bell Labs, and building his first spectrometer at UC Berkeley. Ondrej's pioneering contributions to electron microscopy as Assistant Professor at Arizona State University and later as Director of R&D at Gatan are covered, as well as his return to academia and focusing on aberration correction. The story wraps up with the founding of Nion, the early success of the Nion aberration correctors, and subsequent progress such as building a complete cutting-edge electron microscope and later a record-breaking monochromator. Ondrej continues to be actively involved in design and in running Nion, and while this article ends at the present, further breakthroughs can be expected from him.

1. Early life

Ondřej Ladislav Křivánek was born on August 1, 1950 in Praha-Bubenec on the plateau behind the Prague Castle. Ondrej's mother, Jitka (Judy) worked as a doctor's assistant during World War II, and then in journalism before focusing on the family after the birth of Katia (Kateřina), Ondrej's older sister. Ondrej's father, Ladislav, studied chemical engineering in Brno, worked at the forward-looking Bata Research Center in Zlin, and later as director of the R&D Center of Prague's Barrandov Film Studios. He specialized in the chemistry of color photography; his book on the subject became the standard reference in Czech, and was translated into several Eastern European languages. Later in his career he taught at the renowned Prague Film School, and in his retirement he edited a Czechoslovak émigré cultural magazine, with a circulation of about 10,000. Ondrej compares his own path through life to a mixture of his dad's and of his maternal grandfather's, Josef Jelínek (pronounced "Yeleenek"), who, after an apprenticeship in Vienna, started a small motorcycle company in Prague. One of the Jelínek motorcycles is on display in the Technical Museum in Prague.

Growing up in the era of the Czechoslovak Socialist Republic (CSSR), Ondrej benefitted from the high priority that the Soviet Union and its satellites put on educating young people. Ondrej was a seven-year-old boy when Sputnik was launched, and a top-notch education system, especially for science, was considered crucial by socialist governments. Ondrej showed a strong talent in math and science, and did well in the Mathematics and Physics Olympiads that started in the Eastern Block and later spread to the rest of the world. During his senior year in high school, he was selected for a team of three representing Czechoslovakia at the 2nd International Physics Olympiad in Budapest in 1968—the team took a joint second place (after the Soviet team) with Hungary and East Germany.

After graduating from high school, Ondrej went on a vacation to France in the summer of 1968, and a subsequent stay in London for a summer job where he planned to improve his English. This was the year of the Prague Spring, in which a group of reformers led by Alexander Dubcek attempted a political liberalization in the country, including reducing restrictions on media, speech, and travel. These reforms were greatly disliked by the Soviet old guard. As Ondrej was boarding the train to France, his father told him: "If the Russians invade, stay in the West." Ondrej had not been following the political situation very closely, and this came as a surprise instruction to him. His parents, on the other hand, had witnessed first-hand the turmoils of Central Europe – they had lived through two world wars, democracy, Nazism and communism, and had been citizens of 4 different countries without moving an inch (Austria-Hungary, democratic Czechoslovakia, German Protectorate, socialist Czecho-Slovakia). They were fully aware of the situation both locally and abroad, and how repression changes the course of lives. Ondrej's father had been persecuted by the Nazis, barely surviving the experience, and later by the Communists. His mother narrowly escaped being labeled by the Communist bureaucracy as of "bourgeois origins", which would have meant that Katia and

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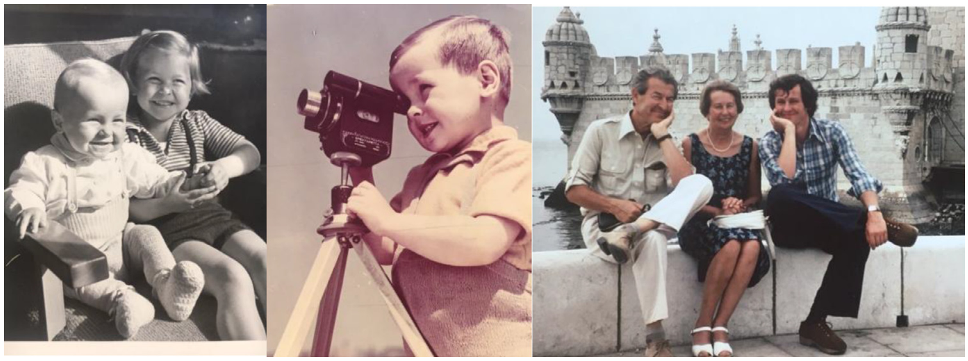

Fig. 1. (left) Ondrej and Katia (middle) Ondrej taking an early interest in imaging techniques (right) Ondrej and parents on vacation in Portugal in 1978.

Ondrej would have been denied admission to any Czechoslovak university.

By luck, Ondrej's parents and sister were also in the West when the Soviets invaded Prague to crush the reforms, four weeks after Ondrej boarded the train to France (his sister was an au-pair in France for the summer and his parents were in Austria on a 5-day vacation). It was an easy and logical decision for them not to return to Prague to face the expected repression. Ondrej's parents and sister moved to Switzerland and became Swiss citizens, while Ondrej stayed in the UK and became a British citizen in 1974.

Skipping ahead in the story to round out the personal picture before getting into his professional life, in 1989, Ondrej met Angela Hildre, an interior designer originally from Seattle, while skiing at Lake Tahoe in California. They were married in 1994, and have two daughters: Michelle (1995) and Astrid (1997). In 2006 Ondrej also effectively adopted his nephew David, then 16, after the untimely death of his sister, who was raising David as a single mom. See Figure 1.

2. PhD from Cambridge

About 6 weeks after the Soviet invasion, Ondrej managed to obtain a scholarship to attend Leeds University in the UK. He excelled in math straight away, but struggled in other subjects at first while his English skills caught up. In 1971 he graduated with a first-class B.Sc. in Physics, at the top of his class, and got accepted to both Leeds and Cambridge Universities for a PhD. Ondrej recalls seriously deliberating about the decision between the two until a friend recommended bluntly that he should choose Cambridge without a quiver of hesitation.

At Cambridge, Ondrej chose to work with Archie Howie, FRS, as his PhD supervisor, who quickly introduced Ondrej to the field of electron microscopy, and also schooled him in high standards and scientific rigor. In Howie's group, Ondrej learned a lot about the theory of electron microscopy, especially image formation and interpretation. This theoretical and practical work came together into a 1976 paper in Nature magazine, "Seeing order in 'amorphous' materials", which shed light on the nature of amorphous materials, and on what electron microscopy could (and could not, at least not at the time) tell us about their structure [1]. In parallel, Ondrej was developing an interest in improving the instrumentation for electron microscopy, and there is an appendix in Ondrej's thesis about experimenting with improved electron sources.

During his years in Leeds and Cambridge, Ondrej was a dedicated student of science and microscopy, and also a keen sportsman, especially in volleyball, skiing, and rowing. He took 2nd place at the 1971 British Universities Volleyball championships as a team member for Leeds University, and 1st places in special and parallel slaloms at the 1975 Oxford–Cambridge Varsity ski race. Rowing for the First and Third (Trinity) rowing club in Cambridge in the 1975 May Bumps, he earned his "oar" for making 3 bumps and an over-bump. To this day, that prize, a decorated full-size oar, hangs in his house by a small lake, where he often takes an early morning row in a scull (or does a kayak paddle), before driving to work.

3. Post-docs: Kyoto, Bells Labs, UC Berkeley

After his PhD at Cambridge, Ondrej got a Royal Society Fellowship that allowed him to visit Kyoto University in Japan and work on a 500 kV electron microscope there. With its high operating voltage, low spherical aberration coefficient of the objective lens, and stable sample stage and power supplies, it had the best spatial resolution of any electron microscope available at the time. Soon after his arrival in Kyoto, Ondrej learned about the practical difficulties of the machine – with a dim viewing screen located behind a very thick piece of leaded glass to protect the user from X-rays, and with the electron source also on the dim side, one could not see well enough to make the fine adjustments needed for taking nice images. Ondrej therefore came up with an innovative method to take a test image of an amorphous material, develop the negative rapidly, make a quick stop at an optical bench for some hardware Fourier transforms, crunch a few numbers, and in 10 min total time return to the microscope (equipped with digital displays of the control setting) knowing just how to set the controls to take the best image. This amounted to an early tuning algorithm. It delivered some of the best images from the Kyoto 500 kV microscope, as well as direct experimental evidence about how elemental semiconductors avoid dangling bonds at grain boundaries [2].

4. Early spectrometers and other developments

Subsequent post docs at Bell Laboratories and UC Berkeley until 1980 established Ondrej as a leading high resolution electron microscopist, who obtained some of the first atomic resolution images of defects in semiconductors and of interfaces in semiconductor devices [3]. During this period, Ondrej also developed an interest in a promising new technique called electron energy loss spectroscopy, or EELS. At this time, there were essentially no commercially available EEL spectrometers on the market, and successful entry into the field required designing and building your own. With this idea in mind, Ondrej attended a 1978 workshop on analytical electron microscopy at Cornell. Encouraged by the promise of the EELS technique outlined in many excellent talks at the landmark meeting, he floated, over a drink, the idea of getting into the EELS field to one prominent expert, and was advised against it because "…everything had already been done." Suffice to say, it turned out there were quite a few problems left to solve in the EELS field…

Shortly after the Cornell workshop, Ondrej approached his supervisor at UC Berkeley, Prof. Gareth Thomas, and made the case that building an EEL spectrometer would be a good way to measure the oxygen content in grain boundaries in nitrogen ceramics. Professor Thomas asked just one question, how much would it cost, to which Ondrej replied "about $10k", and the project was underway. Ondrej secured a Phillips 400 for the project, the only microscope of that time with a contamination-free, ion-pumped sample chamber, and within 10 months, following some late nights and early mornings at Berkeley, he was showing results from his first serial EELS at conferences [4]. He was then invited to give a talk on EELS applications the following year [5], and his career as an instrument designer and technique developer took off.

The Berkeley spectrometer was very simple by today's standards, but it introduced a number of important features, including: (a) the prism, practically the only optical element, was designed to focus on the exit crossover of the last microscope lens, which meant that no adjustment to the microscope optics were required to make it work (except moving things out of the way like the viewing screen), and (b) the prism was not symmetric, so that the exit side of the device including the detector was short enough to fit at the back of the user's leg-well below the microscope table. The detection system was also innovative with an automated change in detection method (current measurement vs pulse counting), and an accompanying change in the gain, at a certain point in the spectrum after the intense zero-loss peak had passed [4].

Ondrej's Berkeley spectrometer attracted the attention of Dr. Peter Swann, the co-founder and president of Gatan. Peter was also a Cambridge PhD, a former Professor (at Imperial College London), a talented designer and an accomplished businessman. He saw promise in Ondrej's compact design. About this time (in 1980), Ondrej was also transitioning to a new job as an assistant professor at Arizona State University. He became a consultant for Gatan, and together with several collaborators, Ondrej developed a higher performance, user-friendly serial spectrometer, which proved a major commercial success. Ondrej's collaboration with Gatan worked out well for ASU too, as they got one of the first "modern" serial spectrometers. That spectrometer was used, among other things, by Ondrej and Channing Ahn to produce the EELS Atlas [6], now a standard reference for EELS.

Ondrej's 5-year period at ASU coincided with the flowering of the Cowley-led and NSF-sponsored National Facility for High Resolution Electron Microscopy. Ondrej was the Associate Director of the Facility, in charge of organizing yearly schools and workshops on High Resolution EM. A lot of productive research came out of the 5 years, as well as Ondrej's life-long passion for organizing workshops on topics of current research interest. This started with the five workshops he organized at ASU (1981 to 1985) and continued with the Lake Tahoe, Leukerbad and Port Ludlow workshops on EELS (in 1990, 1994 and 1998, respectively), which later became established as the EDGE workshop series of meeting that continues to this day. Ondrej also started several research collaborations during his ASU years, especially with Christian Colliex's lab in Orsay France, where he came several times on visits ranging from one to six months in length, and learned first-hand about the power and versatility of EELS when carried out with the small yet intense electron probe available at that time in VG STEM instruments. Another notable collaboration was with Katsumichi Yagi's group at the Tokyo Institute of Technology, where Ondrej stayed a couple of times, working mainly on surface reflection EELS under UHV conditions.

Around 1984, Ondrej started thinking about a new development in EELS: parallel detection, which promised to increase the detection efficiency by several orders of magnitude. This was roughly at the same time as Peter Swann moved Gatan's R&D from Pittsburgh to Pleasanton, CA. Parallel EELS promised to be a major project, not readily done on the side while Ondrej was holding a full-time research/teaching job. In April 1985 he therefore joined Gatan full-time, as the Director of R&D, and set out to hire an R&D team and develop a parallel detection spectrometer.

The following year, in 1986, Ondrej presented papers at conferences about two important developments in EELS instrumentation. The first was at the annual MSA meeting (called EMSA in 1986), showing the first results from a prototype parallel-detection spectrometer. Ondrej's design introduced, once more, several important innovations compared to what others were doing in the field—notably, the use of three post-prism quadrupoles to magnify and focus the spectrum with variable energy dispersion onto the final detector, and an attenuator that allowed the intense zero loss peak (ZLP) to be recorded on the parallel detector without saturation [7]. This device could take spectra in 0.1 s with about the same quality as the serial spectrometer could do in 100 s. The first commercial delivery of the parallel EELS, aka Gatan PEELS, took place in 1987, to Richard Leapman at NIH [8].

The second was a poster at the 1986 International Congress on Electron Microscopy (ICEM) in Kyoto about a post-column imaging filter that used an energy-selecting slit as well as three post-slit quadrupoles to produce either energy-filtered images or EEL spectra [9]. Energy-filtered imaging at the time was typically done with an in-column Castaing–Henry or Ω-filter. However, a post-column imaging filter had two major advantages: it could be also used for high-quality EELS, and it could be bolted onto any column and hence transform any microscope into a multi-mode spectroscopy platform. The promise of this work was confirmed when the Congress organizers selected Ondrej's poster as one of the two they would show to the Japanese Crown Prince (a former electron microscope user, presently His Majesty Emperor Akihito) when he visited the Congress. Gatan soon received an order for an imaging filter from JEOL, for a 1 MV electron microscope they had built for Kyoto University. Since the filter was not yet fully designed, the order stated that the specification was "in Dr. Krivanek's mind". The instrument was delivered a few years later, after Ondrej and his team fine-tuned the optics for full second order aberration and distortion correction in a 200 kV version of the filter, and also developed electronic image recording that could withstand 1 MV electrons without suffering major radiation damage.

The Gatan Imaging Filter, which was the outcome of this work, was easy to operate, and it could produce spatial distribution maps of most elements at a resolution of a few nm in a few tens of seconds. However, while working on this project in the late 1980s, it was clear to Ondrej that there was a better way to go: spectrum imaging with an efficient spectrometer, in a STEM able to pack a large beam current into an atomic-size probe. This approach seemed likely to give atomic resolution elemental mapping with maximum possible dose-efficiency and hence minimum radiation damage. Several things had to come together before it could happen, such as STEM aberration correction. Ondrej knew that the possibility of atomic-resolution elemental mapping was out there, and this provided a large part of Ondrej's later motivation to work on improving the performance of the STEM.

Other Ondrej-led developments at Gatan included pioneering the use of slow-scan CCD cameras for electron microscopy and developing efficient microscope aberration diagnosis and tuning algorithms [10,11]. Those who can still remember the days of developing film in a dark, strange-smelling room in order to see the results of a hard day's work have a special appreciation for the development of electronic cameras. Related to image acquisition, Ondrej also initiated the development of DigitalMicrograph, which went on to become the world's leading electron microscopy image acquisition and processing software for many years [12].

5. Spherical aberration corrector

Years earlier, Otto Scherzer showed that it was impossible to avoid spherical aberration with round lenses (1936), and he also came up with possible solutions (1947). Over the years, various systems were built to test these principles but none actually succeeded in improving the resolution of an electron microscope by correcting its spherical aberration. A notable series of developments by Albert Crewe at Argonne National Laboratory advanced the art of electron microscopy significantly, but their aberration correction effort was also unsuccessful. Hence, the end goal of resolving individual atoms in solids using 100 kV electrons, a long-standing goal with major scientific implications, remained elusive.

While designing imaging filters, Ondrej developed significant expertise in using sextupoles to correct second order aberrations and distortions. This gave him the confidence to tackle the correction of third order aberrations, particularly spherical aberration. However, since the famous Albert Crewe had tackled the problem and failed, the correction of spherical aberration, at least in the United States, was known as an unsolvable problem with an aura of impossibility. This is probably why Ondrej, after asking around about applying for funding in the US, was told through the grapevine by the person holding the purse strings at DOE that the project would be funded “over my dead body”. This convinced Ondrej that securing support for an aberration correction project in the US was not realistic (in the 1990s), and he turned his attention elsewhere [13].

In 1994 Ondrej applied, successfully, for support for developing a STEM aberration corrector to the Royal Society in the UK (jointly with L. Michael Brown FRS and Andrew Bleloch). He then took an unpaid leave of absence from Gatan, starting in the summer of 1995, and came back to Cambridge’s Cavendish Laboratory, this time together with Niklas Dellby, both with young families in tow. The grant from the Royal Society was for 80,000 pounds, but its value was much more than financial—it granted access to office space in Cambridge, the Microstructure Group at the Cavendish contributed one of its three VG microscopes to the project for Ondrej and Niklas to develop a corrector for, and there was great support from Mick Brown, both during the initial project and later on, help from skilled local collaborators, and access to the Cavendish Lab’s machine shop.

In 1997, this led to the first operational STEM aberration corrector [14] - a major milestone in the history of aberration correction. A parallel (and more generously funded) effort in Germany by Harald Rose, Max Haider and Joachim Zach in TEM and SEM aberration correctors was also starting to show promise around this time. The UK/US and the German projects benefitted from a healthy competition, with each reaching certain milestones first [15].

Ondrej realized from the very start that the benefits of correction in the STEM would be two-fold: better spatial resolution *and* better analysis made possible by aberration correction giving *increased* beam currents in *smaller* electron probes. He also saw that using cold field emission (CFE) electron sources with their narrow energy spreads would provide the brightest electron beams possible and at the same time minimize the problems posed by the principal uncorrected aberration – the chromatic one. Subsequent developments proved him right: aberration-corrected STEM instruments now predominate in the materials science and physics areas of electron microscopy, and cold field emission guns have greatly grown in popularity. The detailed history of aberration correction, in which Ondrej’s and Niklas’s contributions form a significant part, is described elsewhere [16].

6. Nion

6.1. Second generation aberration corrector

Following the two years in the UK, Ondrej returned to the US with his family, but not to Gatan, whose ownership had changed after Peter Swann retired, with the decisions-making power shifting from scientists to businessmen and accountants. He therefore took a position of Research Professor at University of Washington, in Seattle. Niklas Dellby and his family also moved to Seattle, and Ondrej and Niklas started Nion Co. in the fall of 1997. The first Nion project was to design and make a second-generation STEM aberration corrector for Dr. Philip Batson of IBM TJ Watson Research Center. The focus had now moved from proof-of-principle to a commercial product, and in 2000 this corrector became the first commercially delivered electron microscope aberration corrector in the world. Insightfully operated by Phil Batson in his VG STEM, it delivered a sub-Å electron probe, and therefore the first electron microscope images with direct sub-Å resolution [17].

Nion thereby focused on making correctors for VG CFE STEMs, and the resulting instruments produced a series of “firsts”, which contributed greatly to the popularization of the technique. Using sub-Ångstrom probes made possible by the Nion correctors, Oak Ridge National Laboratory obtained the first directly interpretable sub-Å resolution electron microscope images of a crystal lattice [18] and the first EEL spectra of single atoms in a bulk solid [19]. The Nion corrector at the Daresbury SuperSTEM laboratory was used for the first atomic-resolution EELS mapping [20], and helped solve important interface structures that had defied conventional high-resolution EM [21]. Overall, aberration correction was a scientific and commercial “hit”. Nion made 10 correctors, all for VGs. Meanwhile, CEOS GmbH (the “offspring” of the German aberration correction effort) made correctors for the major microscope manufacturers, in large numbers.

6.2. Whole microscope columns, and a 200 kV CFE gun

From the early days of Nion, Ondrej and Niklas knew that producing correctors for microscopes from VG, a company which had been bought and shut down (by ThermoFisher), just as they started making correctors for its microscopes, was not a viable long-term strategy. Rather than compete head-on with CEOS by producing correctors for other electron microscope manufacturers, they had a different idea—to build a whole new electron microscope. Their design was a major departure from the traditional electron microscope designs, with many innovations including: a high-performance quadrupole/octupole C3/C5 corrector which corrected or minimized all aberrations up to $C_{5,6}$, a metal-sealed fully bakeable column with ultra-high vacuum at the sample, a rotationally symmetric sample stage construction to minimize thermal drift, full modularity in which round lenses, aperture/pumping modules, aberration corrector and other column elements all had the same mechanical interfaces and could be stacked on top of each other in any order, self-monitoring computer-controlled high-stability, high-precision power supplies, and so on. They also followed the VG approach and placed the electron gun at the bottom of the instrument, where it enjoys maximum immunity to vibrations, and easy access for tip changes and gun bakes. This placement also allows for easy microscope upgrades, since taller columns can be built on the same gun base without having to modify the gun-supporting frame of the microscope.

The development of the microscope column was financed in part by corrector sales, and in part by microscope sales to Cornell, Daresbury, and Oak Ridge. These early Nion instruments went on to produce many world-leading results, such as atomic-resolution elemental mapping [22], damage-free imaging in which every individual atom is resolved and identified [23], fine-structure EELS analysis that probed the atomic environment of individual atoms [24,25], and elemental identification of individual atoms using energy dispersive X-ray spectroscopy [26].

Nion also developed a 200 kV cold-field emission electron gun (CFEG), partly supported by an SBIR grant from DOE and by an early order from CNRS Orsay. This gun is distinguished by its improved Extreme-High Vacuum (EHV), which allows it work for

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Fig. 2. (left) Ondrej, George Corbin (Nion's first employee), and Niklas Dellby (co-founder) outside Nion shortly after its founding (right) about one hundred people, including many famous microscopists, outside Nion's new premises during the open house in 2015.

hours without flashing, and also by its optimization for a range of primary voltages, from less than 40 to 200 kV [27]. See Figure 2.

6.3. Monochromator

In 2008, Ondrej was invited to give a talk at a Royal Society-sponsored meeting on "New Possibilities with Aberration-Corrected Electron Microscopy". (The meeting was held in the same room at the Royal Society headquarters in London as the one in which Ondrej was honored with a Royal Society Fellowship two years later.) Correctors were becoming an established technology by this point, and Ondrej decided that it would be more interesting to strike out in a new direction. Together with Jonathan Ursin, a summer student from UW, and others, he explored a new design for a monochromator, largely based on the multipole optics technologies Nion had developed for aberration correction. The new monochromator departed from "traditional" designs in several key aspects, such as placing the monochromator outside the electron gun, at ground potential, and using several linkage schemes for improved energy stability [28]. The predicted eventual energy resolution was 10 meV – a major leap relative to what was achievable in atomic-resolution STEM-EELS in 2008. Based on the paper describing the theoretical design and Ondrej's strong reputation in instrument design, Nion received an order (from Arizona State University) for the first of the new monochromators before the mechanical design was begun, and two more orders before it was finished. In 2010, Nion hired Tracy Lovejoy (one of the authors of this paper) to work on finalizing the monochromator's electron-optical design, and the subsequent building and testing of the first device for ASU.

The newly designed monochromator led to the first demonstration of vibrational/phonon spectroscopy in an electron microscope in 2014 [29], and in 2016 to demonstrations of a) damage-free vibrational spectroscopy in a biological material (guanine) [30] and b) the possibility of achieving nm-scale spatial resolution with the phonon signal [31,32]. It can now reach < 8 meV energy resolution at 60 kV while maintaining an atom sized probe, and further improvements are on the way.

Today (early 2017), 4 years after the delivery of the first Nion monochromator, the ultra-high energy resolution EELS project is in a similar state to where EELS was when Ondrej entered the field while at UC Berkeley. There have been many interesting applications, but as a whole, the surface has hardly been scratched.

6.4. Ondrej's role at Nion today

Ondrej continues as the President of Nion, a position he has held for nearly 20 years, while two of the authors of this paper are Nion's Chief Operating Officer (COO) (TCL), and Chief Scientist (ND). Under Ondrej's guidance, Nion has outgrown its garage beginnings, and in 2015 moved into a large and extensively remodeled building, with a full-fledged microscope assembly line, 5 separate microscope construction bays, and a significant number of production and R&D staff (>25 as of this writing).

Ondrej is also an Affiliate Professor at Arizona State University, where he lectures at the annual Winter Schools on Electron Microcopy, the first of which he organized as an ASU Assistant Professor, in 1981.

Ondrej remains actively involved in many design projects at Nion, though details about these will not be discussed here. He is also an avid cross-country skier in winter, and enjoys hiking in the summer, as well as sailing, sculling, kayaking and travelling to off-the-beaten-track locations.

7. Summary

Ondrej Krivanek has made many pioneering advances in electron microscopy and its instrumentation, starting with an early serial EELS spectrometer at UC Berkeley. Later generations of spectrometers, imaging filters and cameras that he and his team designed, and software whose development he initiated, became commonplace in electron microscope laboratories all over the world. Ondrej's contributions to the correction of spherical aberrations in STEM were significant, and his efforts through the company he co-founded, Nion, were key to the early popularization of aberration-corrected microscopy. Nion has since moved on to make whole microscope columns, which have produced many world-leading results. A new electron monochromator introduced by Nion has opened up the study of phonons in the electron microscope, with unsurpassed spatial resolution. The full implications of the new capabilities are still developing.

Throughout his scientific career, Ondrej has shown a sharp sense of which directions electron microscopy and related techniques should explore next, and an ability to cut a clear path through the tangle of problems such explorations inevitably lead to. He has been both a visionary and an on-the-frontlines pioneer, and electron microscopy, spectroscopy, and science in general have advanced greatly because of his work.

7.1. Publications and awards

Ondrej has published 5 book chapters and over 250 articles in refereed journals and conference proceedings, and he holds fifteen US, two European and one Japanese patent. His work has been recognized with the R&D100 award for the imaging filter design (together with A.J. Gubbens and N. Dellby 1993), the Seto prize of the

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Japanese Microscopy Society (1999), the Duddell Medal and prize of the British Institute of Physics, a Distinguished Scientist Award of the Microscopy Society of America (2008), election to the Royal Society (2010), Fellowship of the American Physical Society (2013), Honorary Fellowship of the Royal Microscopical Society (2014), the Duncumb Award of the Microbeam Analysis Society (2014), and the Cosslett Medal of the International Federation of Microscopy Societies (2014).

Acknowledgments

The biographical information in this article is based on a series of sources including personal experiences and correspondence with Ondrej. This is not the first biographical account of Ondrej's life and achievements, but some are not available digitally and/or are difficult to find. Since he takes special joy in historical accuracy and precision, Ondrej's own autobiographical accounts tend to be the most precise, including refs [8] and [13]. Much of the early life section is based on an interview that took place on January 1, 2017 in Winthrop, Washington after a weekend of cross-country skiing.

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