Interview with optical scientist and engineer Joseph Braat

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Joseph Braat (professor emeritus TU Delft and former research fellow at Philips Research) received the 2019 Holst Memorial Lecture Award for his important contributions in to diffraction-limited optical imaging and scanning. Photo courtesy of TU Eindhoven.

1 Introduction: Early Career and Influences

Shao: Professor Braat, thank you for joining us for an interview. Let's begin with your early career. You began your career studying physics at Delft University of Technology (TU Delft) and later worked on holography in France at the Institut d'Optique. Could you share what inspired you to pursue optics?

Braat: I think that my choice for optics has been a two-stage choice, first for physics and later for optics.

At my secondary school we had a very enthusiastic physics teacher, an electrotechnical engineer from Delft University. We used new physics books from the beginning of the 1960s, which had replaced rather old-fashioned physics books from the 1930s. All modern physics of those days was basically present in them. The classroom experiments were done with very elementary equipment, partly made by the pupils themselves. Gradually, I made my choice to pursue physics at university. TU Delft was suggested by my older brother, who had studied chemistry there.

Once at TU Delft, I was very positively impressed by two courses in optics during the first and second years, given by Prof. Abraham van Heel. He showed impressive course room experiments. Unfortunately, he passed away in May 1966, peacefully in his own garden, at the age of 67 due to a sudden heart failure. His research group, which I later joined, was temporarily headed by his two assistants.

As of September 1, 1967, a successor, Prof. Hendrik de Lang, came from Philips Research Laboratories in Eindhoven. In May 1968, there was a student protest movement in France, which shook the government of elderly statesman General de Gaulle. The protest movement ended quite soon in France, but its spirit gradually spread to other countries, for instance, to the Netherlands in 1969. The democratization of the universities and the confusing administrative changes were not welcomed by Prof. de Lang, and he left TU Delft on September 1, 1969, leaving me without direct supervision for my master's assignment in the optics research group. Fortunately, I managed to terminate my assignment that same year and started to pursue a PhD position in France at the Institut d'Optique in Paris/Orsay. The Ministry of Foreign Affairs of France provided me with a scholarship.

Shao: How did your early experiences shape your career path?

Braat: My thesis work (1970–1972) was about holography using spatially incoherent light, under the supervision of Prof. Serge Lowenthal (Coherent Optics group) at the Institut d'Optique. Since 1920, the institute has developed from an originally applied military lab to a more fundamental research institute. I remember that from the very beginning of my studies in Paris, the book *Introduction to Fourier Optics* by Joseph Goodman (first version published in 1968) was a central source of information in the Coherent Optics group. For me, as a fresh PhD student, it was a really new and fascinating subject. In general, I experienced my thesis work in Paris as a well-balanced mix of theory and experiment. Each student had the responsibility for his or her own particular experimental subject. There was no massive assignment of many individuals to a single huge setup. On the contrary, each student had more or less his own dark room with his own experimental setup. On several occasions, I shared a room with Joseph Goodman, who was preparing for his sabbatical leave at the Institute of Optics in 1973 to start writing his second famous book, *Statistical Optics*.

During my stay at the Institut d'Optique, later Nobel laureate Alain Aspect was also working in the Lowenthal group on a holographic spectrometer. Later, when I was already working at Philips Research Laboratories, Alain asked me if Philips Research could help fabricate a polarization-neutral beam splitter of sufficiently large size. After some special effort, the Philips Research thin-layer deposition facility managed to meet the stringent specifications and the element was shipped to the Institut d'Optique. The cube played a role in closing a possible loophole in the optical entanglement experiments that earned Alain the 2022 Nobel Prize in Physics.

2 Contributions to Optical Disc Systems

Shao: During your time at Philips Research Laboratories, you contributed significantly to optical disc systems, especially in designing the light path for recording and reading optical discs, and in developing the theory for reading from structures using light diffraction. For this reason, sometimes people refer to you as one of the founding fathers of optical storage that enabled the invention of CD, DVD, Blu-ray, etc. What were the key challenges you faced in this research?

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Braat: The invention and development of optical storage are joint efforts by many people. By no means I was one of the founding fathers. The project started three years earlier, at the end of 1969, well before I arrived at the Philips Research laboratories (on January 1, 1973). In a press conference in December 1972 for international science and technology journalists, Philips demonstrated to the audience a real-time mastered video glass disc (a so-called "master disc") with live running video of the press conference on it. The pioneers at Philips from these early days are Piet Kramer (optics, group leader), Klaas Compaan (Philips educational department), and Gijs Bouwhuis (optics, researcher). These three people received the Rank Prize for Optoelectronics in 1986 for their basic research on and the promotion of optical data storage.

When I arrived at Philips, I was assigned as the contact person for Harold H. Hopkins, a counselor of the Philips laboratory. Hopkins is well-known for his imaging theory in partially coherent light, extending the work of Zernike and van Cittert on this subject. He is at the origin of many developments in optics, such as the optical transfer function, cross-correlation coefficients, and high-numerical aperture imaging. He also invented the zoom lens and the optical endoscope for medical use. On top of that, he was an extraordinary teacher! I am very lucky to have been able to collaborate with him on subjects such as lens design and diffraction theory.

Key subjects for me in those early years were the precise focusing and tracking of the optical information spiral on an optical disc and the possibility of further increasing the information density. Together with Hopkins, I worked on a scalar diffractive read-out model for optical discs. At a later stage, I extended this model to the read-out of digitally encoded and modulated signals for the compact disc standard and its subsequent digital successors.

I also played a role as a gateway between Philips Research and its suppliers for optics. In this framework, I wrote an optical design tool with an optimization option based on singular value decomposition (SVD), allowing, among others, in-house aspherical surface design and optical tolerancing. At the beginning of the 1980s, I used my program to design lithographic projection lenses with an emphasis on tolerancing and manufacturability. I mention that early work on optical tolerancing was carried out by Geoff Adams, who later wrote a PhD thesis on this subject (Imperial College London, 1988).

At Philips, the IBM 360/370 mainframe computers, which only accepted punched cards as input, became rather a bottleneck for computing. At a certain moment, my 40,000 punched cards (with a weight of 2.5 grams per card) suffered an accident. Not all of them, just two boxes with some 5000 cards, fell to the ground and lost their precious order. It took me two entire days to put all the cards in the correct order again. Fortunately, a short time later, input via personal terminals was made possible at the laboratory. It must have been in the year 1985 that I could happily throw away my 100 kg of punched cards!

CD research started in 1975, inspired by the optics research on the video disc. The video disc (VLP, video long play disc) was commercialized in 1978 in the USA but it became a commercial failure. Only the Pioneer company survived in that market. They continued the "laser disc" until the advent of DVD in 1994. The marketing of the new CD product (discs and players) by Philips and Sony took off in the autumn of 1982. Sony went for high prices and reliability, while Philips tried to penetrate the mass consumer market from the very beginning with low prices for the players.

An internal campaign at Philips was launched with the "3 × 25 dollar" slogan: 25 for optics, 25 for mechanics, and 25 for electronics. In practice, it has led to the early introduction of plastic optical and mechanical components. Philips introduced an aspheric lens with a glass half-sphere covered by a plastic asphering layer as the nucleus to cut prices. Although this lens was a reliable product, the massive introduction of plastic mechanical components in the CD-player led to a high call rate from the field and a bad reputation for this Philips product. After a few years, Philips had a 15% market share, Sony more than 40%. Fortunately, per disc, Philips got a 60% royalty share, Sony 40%, because of the patent rights distribution.

The partnership between Philips and Sony continued until the advent of DVD. The strategy of both companies was to exploit the owner rights of CD products for as long as possible. The numerous other companies that produced optical media and players became increasingly jealous and asked for reduced royalties. They gradually started research on a new, more advanced system.

In the summer of 1994, ten companies (mainly Japanese companies) announced a new optical product, DVD, for video playback and recording. Philips and Sony were intentionally discarded. In the patent battle that followed, the two companies had to be accepted because of some very basic patent rights they still possessed, but their income from royalties was strongly reduced in the new DVD system. Personally, I was glad to see that an optical radial tracking method, patented by me in 1976 (see Fig. 1), but judged too complicated for CD in those days, had been incorporated into the DVD standard.

After DVD, Philips and Sony worked together on a new standard for optical recording using the blue laser wavelength of 405 nm. This was the last standard in optical data storage; further research on quasi-contact (solid immersion) optical recording was carried out (two PhD theses on this subject were defended at TU Delft), but the new standard never reached the general public. The much more efficient MP3 data format made its way to solid-state memory, and data streaming was the second new means for carrying data to the home of the consumer. After 2015, hardly any new notebook or desktop computer contained an optical disk drive. After forty years, the game was really over!

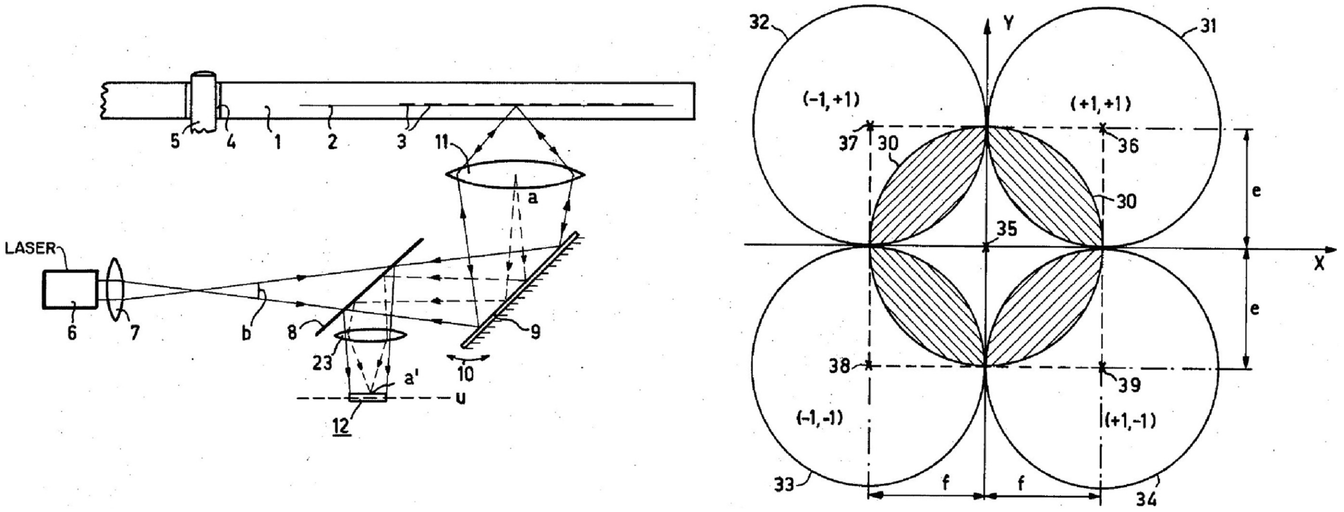
As a pure coincidence, at the moment of my formal retirement at Philips Research in December 2006, the company stopped all research and production activities in optical data storage.

Shao: How do you see its impact on current data storage technologies? Does optical storage still possess potential in the era of information and data explosion?
Braat: No, I do not think so! The spatial density of optical data storage has proven to be insufficient with respect magnetic and, more recently, solid-state storage devices. Moreover, the need for a cheap, portable, and home-storage medium has disappeared because of the omnipresent internet, cloud storage, and data streaming.

3 Early Stages of Lithography

(Braat, cont'd.) In the optics research group at Philips, at the beginning of the 1960s, there was a mask-making lab to enable the production of optical patterns (initially binary black–white) on substrates for integrated circuit boards with individual electrical components. When the first integrated circuit was made in the USA (Fairchild, 1959), this mask laboratory focused on producing patterns for integrated planar transistors. At the beginning of the 1970s, the research people who started optical data storage also devoted time to this mask lab and to the new lithographic technology.

The initial lithography technology was so-called "contact lithography." The only optical principle involved was Fresnel diffraction, which determines the gradual blurring of the mask features as a function of the distance between the mask and chip surface in quasi-contact. Contact lithography with unit magnification reached its limits at roughly 2-micron feature size in the optical domain. The maximum lateral size of a chip was of the order of 10 cm. Smaller details were feasible by a shift to shorter wavelengths, such as X-ray wavelengths.



(a) (b)

Fig. 1 Figures used in the patent "Centering Detection System for an Apparatus for Playing Optically Readable Record Carriers" (US Patent 4.057.833). (a) illustrates the experimental setup. (b) shows the zeroth order (35) and the first orders (36-39) of the beam diffracted by the information structure on the optical disc when reading with a focused spot. The centering error can be estimated using the phase change in the overlapped areas and, hence, allows precise tracking when reading the information. A similar approach was used later for overlay metrology in the lithography scanners.

A step forward was projection lithography, using the same masks and the same 1:1 magnification. At Philips, a system with 0.20 numerical aperture (NA) was built, but the optics were inevitably complicated and bulky. The way out was reduction lithography combined with the stepping principle to increase both resolution and field size (step-and-repeat). The first reduction projection lens at Philips, with a track length of 60 cm, was produced by the French company Cerco, a specialist in astronomical imaging and space optics. As requested by Philips, this projection lens used both the g-line and the h-line of a mercury high-pressure lamp to smear out the standing wave patterns in the exposed photo-resist. Cerco was able to deliver some well-engineered prototypes but later struggled with the production of larger quantities. Moreover, the as-designed field quality was rather low at the edges of the field.

In the mid-1970s, a new projection lens was designed with 0.30 NA and a 10 mm × 10 mm square field of view. Such a design should have more relaxed tolerances as compared to the previous design. The first prototype was unfortunately not OK. It also turned out that at several locations within the projection lens, very tight tolerances had to be respected during manufacturing. These alarmingly tight tolerances were discovered in an analysis of the fabricated lens using my own design program. Unfortunately, Philips could not obtain a satisfactory number of projection lenses for its first series of step-and-repeat wafer steppers because of the insufficient quality of lens fabrication at Cerco.

For various reasons, Philips had the intention to sell its lithography activity and invited potential buyers, including a two-week in-depth technical visit of optical and mechanical professionals from Perkin-Elmer to Philips Science and Industry (1979). They were dissatisfied with both the projection lens system (dispersion issues and the field quality) and the mechanics (wafer stage transport using oil hydraulics). Finally, in 1984, Philips's lithography division became a joint venture with ASM (a Dutch clean-room equipment company managed by Arthur del Prado) and the new company got the name ASM-Lithography (ASML).

Shao: Could you share some insights into your role in the early development stages? What were the situations then, and what were the key challenges?

Braat: In 1982, Philips made an official visit to Carl Zeiss to see if a specific lithographic lens could be manufactured for Philips. I very well remember from my visits to Carl Zeiss their top optical designer, Erhard Glatzel, from the Mathematische Abteilung. He was treated with much esteem by his colleagues. He also demonstrated in discussions a keen understanding of the mechanical, optical, and metrological capabilities of the Zeiss workshops and the match needed between these capabilities and the optical and mechanical tolerances of optical systems. A special design by Philips with two wavelengths was not accepted by him because of the dispersion issues in the deep blue spectral region. The numerical aperture of the lens had to be limited to 0.28, in accordance with an existing projection lens that had already been sold by Zeiss to US and Japanese customers. The Zeiss-designs remained proprietary, in the sense that the design data could not be made available to the user. This situation persisted until 1998 when ASML's and Carl Zeiss's lithography divisions established a much closer relationship.

Despite the new collaboration with Carl Zeiss, Philips stuck to its principle that for key elements of a product, a second supplier was indispensable. For this reason, Martin van den Brink, former president and CTO of ASML, and I, as an optics expert, were asked to find such a second supplier in Europe. Our choice was the Swiss company Wild at Heerbrugg, now a branch of Leica. For a lithographic lens, we were sent to the aerial photography department, renowned for its excellent systems for cartography.

Around 1985, they made a design, and in parallel, I designed a lithographic lens with my own software (Fig. 2). The specifications were 0.38 NA, single wavelength (h-line), and 10 mm × 10 mm square field. In my design, I paid extra attention to manufacturability, achieving comfortable mechanical tolerances of the order of 1 to 2 microns

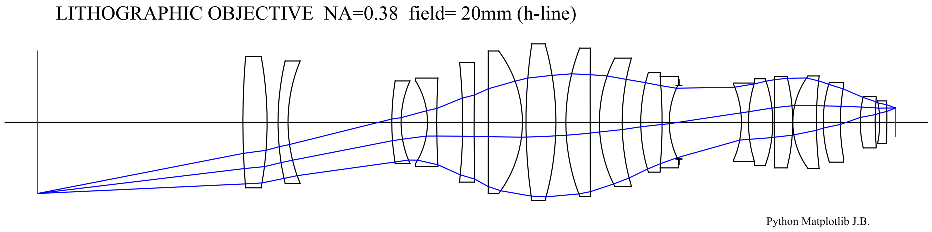


Fig. 2 An example of the 0.38 NA lithography projection lens designed by Joseph Braat published in "Quality of microlithographic projection lenses," *SPIE Proc.* Vol. 811, pp. 22-30 (1987). Figure courtesy of Joseph Braat.

for decentering and of the order of 25 micro radians for tilt angles. These tolerances were rather equally distributed throughout the optical system. The two designs were completely different. It struck me that Wild's design was made using ray aberration data, while mine used wavefront aberration for optical system optimization. Being a devoted pupil of Harold Hopkins, this should not be a surprise; he published his famous book *Wave Theory of Abberrations* as early as in 1950! The resulting optimum settings with respect to, for example, lens distortion, turned out to be quite different as a function of the residual aberration, even having opposite sign in some cases!

Finally, the second supplier project became a failure. No lens could be produced with diffraction-limited quality due to the narrow manufacturing tolerances of Wild's design. In retrospect, we realized that we had landed in the wrong department of this company. Aerial photography systems of those days were approximately a factor of three away from the diffraction limit, while lithographic lenses had to be designed and manufactured with a quality substantially better than the $\lambda/4$ diffraction limit. Cartography also requires a much larger field-angle than lithography. These differences in system requirements led to a different mindset of the designers and engineers. We would probably have been better off in the microscopy department of the same company, but there the people would be upset by the large size of the components in a lithographic lens. So, the conclusion was that for such extreme-quality optical systems, the second-supplier idea is not realistic. Instead, a close and professional collaboration between producer and client is a better recipe for high-tech products. Finally, worldwide, the production of lithographic lenses or mirror systems with extremely high quality has been limited to three companies: Zeiss, Nikon, and Canon. Nowadays, only Zeiss can produce mirror systems for extreme UV in large numbers!

I just mentioned the importance of "zero" distortion in lithographic imaging. However, for quite some time, the optical measurements at Zeiss and the opto-mechanical measurements on exposed wafers at ASML (after transport of the lens from Germany to the Netherlands) showed substantial differences in residual distortion. I had a closer look at both methods, including the effects of the illumination aperture and the collector aperture at the detector side of the set-up. It was possible to theoretically model the minute effects of changes in these aperture values on the measured distortion. As a result, a much better convergence of residual distortion could then be achieved by correctly taking into account the aperture settings.

Further developments in optical lithography were the use of shorter wavelengths (193 nm) and an increase in the numerical aperture. In this respect, the use of water as immersion liquid allowed NA-values larger than unity, up to typically 1.25. For further progress in optical resolution, a major change in wavelength was needed and the interest has turned towards EUV wavelengths. The very first EUV image in photoresist was produced in 1986 by Hiroo Kinoshita of the Japanese firm NTT. But also in the Netherlands, research was carried out on this subject by Fred Bijkerk, on EUV sources and the printing of features at such wavelengths. I collaborated with his group and with Steef Wittekoek of ASML in the field of multilayer design (together with Mandeep Singh), the design of reflecting imaging systems and potential surface repair methods to cancel the wavefront aberration due to tiny surface defects on mirrors. My first designs of lithographic projection systems had 5 or 6 mirrors. I also participated in at-wavelength metrology for EUV mirror surfaces, using an improved version of the classical Ronchi test (published in 1999). It was a remarkably interesting period of time of making initial steps towards full-grown extreme UV lithography. Today we observe that these extremely complex lithographic machines have been successfully manufactured and marketed by the company ASML.

Shao: How do you see EUV lithography, or optical lithography in general, evolving towards the future?

Braat: Reasonably speaking, the anamorphotic EUV projection system by Carl Zeiss seems to yield the highest achievable aperture (0.55) for the current lithographic wavelength (13.4 nm). A shorter wavelength, for instance, of the order of 6 nm, is possible on the paper, but the anti-reflection coatings on the mirror surfaces become so thin that intralayer material diffusion occurs during deposition. Experiments in the past have shown a big offset between the theoretically predicted reflection coefficient and the measured value. Progress is extremely limited in this field. The 11 nm Be-based wavelength is environmentally extremely dangerous. Would EUV eventually stop at 13.4 nm and 0.55 NA?

The end of optical lithography has been predicted many times before. I mention the following years in which a successor to optical lithography was said to be ready for take-over:

1972: X-ray lithography (XRL, Spears and Smith)
1980: Electron beam pattern generator (EBPG, Philips company)
1995: Nanoimprint lithography (NIL, Chou)
2000: Electron beam parallel writing (Mapper lithography, Kruit et al.)
2010: X-ray interference lithography (XIL)

An inspection of the competing systems from the past shows that they either use 1:1 lithography or no mask at all. In the first case, the mask-making process becomes very expensive, and dust becomes a huge problem. In the second case, the data transfer becomes a bottleneck for the speed of the system and hence severely limits the number of wafers that can be printed per hour. For various reasons, massless "optical" photons have turned out to be superior channels for reliable and fast information transfer from the mask to the photoresist layer through the optics. At this moment in time, other future options are still not obvious. A further wavelength reduction in a non-contact imaging system, the main driving force towards higher resolution systems for a long time, is not a short-term option.

4 Transition to Academia

Shao: In 1988, you transitioned to an academic role at Delft University of Technology, eventually becoming a full professor of optics (Fig. 3). What was your motivation for making this move? How do you compare your work and life before and after? How did your industry experience influence your approach to teaching and research in academia?

Braat: I think that coming from an industrial company, my experience with the practical realization of research results has given an extra dimension to my teaching. Of course, this practical experience has also influenced the kinds of projects I have applied for on the national and European scale. I have also had a long-lasting positive connection with the company ASML at TU Delft. They gave us a large amount of liberty in the execution of their research questions and our suggestions for solutions. The amount of bureaucracy was minimal, quite different from the heavy administration required for Dutch and European projects.

Fig. 3 Joseph Braat in front of the Optics Research Group at TU Delft, where he worked as a professor from 1988 to 2008 (photo courtesy of Roland Horsten).

5 Leadership in Optical Societies

Shao: As a former president of the European Optical Society and a member of various prestigious societies, what is your vision for the future of optical science and its role in solving technological and societal challenges?

Braat: With respect to my work for the European Optical Society, let me say that I have been educated (rather than some people today would say “brain-washed”) with a positive attitude to European collaboration. Although I was born just after World War II, I have heard a lot from my parents and at school about this human and economic disaster. It has taken the Netherlands fifteen years to recover from World War II. It is clear to me that we should emphasize in Europe (and worldwide) the economic and intellectual properties that unite us and stay away from the ridiculous theories about ethnic or racial superiority that have been at the origin of most wars. Defining common economic goals and applying mutual solidarity will have a long-term positive outcome. This contrasts with the nationalistic agendas that provoke conflicts between people.

It is thus not surprising that I have volunteered to participate in European collaboration in the field of optics. A first step was the foundation of Europtica in the 1980s. In 1991, the European Optical Society (EOS) was founded, as a fusion by a number of national optical societies. France has been the most active, and Germany was slightly reluctant. This fact is explained by its important optical industry and its well-established local optical society, the Deutsche Gesellschaft für Angewandte Optik (DGaO). But after this initial hesitation, Germany became an active member of EOS and housed its offices in Hannover for more than ten years.

The European Optical Society has taken off during the 1990s and showed a steady growth during the first decennium of this century with a new journal (JEOS-RP) that got a certain reputation (I was its editor-in-chief from 2010 to 2014). Some financial problems have necessitated administrative adjustments, but EOS is flourishing again in Europe.

The role of optics is omnipresent in science and technology and has major societal relevance. Let me start with astronomy, in which optical components still play important roles, despite the existence of radio-astronomy, X-ray astronomy and, quite recently, the preparation of gravitational astronomy. It is with the aid of astronomy and astrophysics that we can hope to elucidate the open questions in physics about dark matter, dark energy, dark holes, the Big Bang, etc. Optics also plays a crucial role in optical communication, integrated circuit fabrication and signal encoding and encryption. The future of optics is simply bright!

6 Career Reflections

Shao: Looking back on your illustrious career, what do you consider your most significant achievement, and what advice would you offer to students and researchers starting in the field of optics and photonics?

Braat: I think that my strength was in applied physics, such as designing and improving high-tech products using a broad knowledge of optics. The companies Philips and ASML felt the urgent need for patenting inventions, but they did this in an efficient and fast manner. It meant that publishing my work has never been hampered by patent issues. I appear as an inventor on more than 60 US patents on optical data storage and optical lithography, assigned to either Philips or ASML. Simultaneously, a comparable number of publications have appeared during my period at Philips Research, often in a one-to-one relation with submitted patent applications. Of course, later in academia, the emphasis was more on publishing in journals. Patent applications are a more complicated matter at a university. The main reason is that broadly educated patent attorneys are lacking there. The reason is simple: they are very expensive to hire!

What has amused me in the field of optical disc systems and optical lithography is that the same basic theory applies (diffraction-limited imaging) in drastically different environments. In a consumer product, the optical quality at the sub-wavelength level (typically 100 nm) must be achieved at extremely low cost in huge-volume production. On the contrary, in a lithographic environment, the much smaller wavelength creates problems for materials and metrology at the level of the nanometer. These problems are encountered everywhere in the imaging system as well as in the positioning and alignment of mask and wafer.

With respect to the very reduced room for robust solutions in a consumer product, a special inventiveness is required there, with a minimum of cheap, compact, and stable measures in the system. For solutions in a lithographic machine, money is less of a constraint and advanced metrological control at the nanometer level is allowed during the lifetime of a machine. A third field of interest is optical astronomy, where the manufacturing is restricted to one single novel piece or prototype system. In advanced telescopes, the required subwavelength precision extends to large volumes, typically over tens of meters. Active or adaptive optics are required to have a robust observation instrument.

I have been able to publish papers and obtain patents in all these three fields. If I must make a choice about my preferred field of research, it is optical recording, that was probably the most fun. Although the disc systems have been fully abandoned now, the final larger European research project in this field around the year 2000 was very enriching. We obtained solutions with a broader field of applications, at the edge of what is technically possible in optical imaging and data scanning.

Regarding university students, I would recommend them to effectively use their brains in the years when they function at optimum performance and capacity. At a technical university, do not hesitate to choose the more theoretical parts of the curriculum. Studying such subjects in later years is more difficult and the acquired knowledge will disperse more quickly. Let me also stress the ethical side of science. Honesty and exactness are properties that each scientist should have acquired. There will always be external pressure to speed up research progress and to present immature results. Or there can be political influence to present "colored" results. A student or researcher should never forget that an individual cannot change the mainstream of scientific advance. The measured data will always force the adjustment of scientific models so that they can better explain the measurement. That is how applied science works!

7 Book Authorship (*Imaging Optics*, published by Cambridge University Press)

(Braat, cont'd.) During the year 2006, I had a five-month sabbatical leave at the University of Rome, in the laboratories of Concita Sibilia and Mario Bertolotti, with the task to write a chapter on the "Assessment of optical systems by means of point-spread functions" (published in the book series *Progress in Optics*, edited by Emil Wolf). It was a very gratifying experience, a longer period of work devoted entirely to scientific research. It strengthened an earlier idea of mine: the writing of a book on optical imaging for novice or mature researchers in optics. Together with a close colleague, Peter Török from Imperial College London, we had previously made a list of contents for such a book. It should unite optical subjects, starting from basic electromagnetics, going to geometrical optics and optical design, to diffraction optics, and then to various subjects in optical imaging. The list got updated, and we started writing the book. For me, it coincided with my retirement from university. It allowed me to work on the book subjects in a quiet room of the university while simultaneously staying in close contact with my former colleagues. I soon discovered that book writing is time-consuming. I typically wrote a hundred (densely) printed pages a year. The progress of both authors was not comparable for the simple reason that Peter had a full-time job and a research group to run; I had the advantage of being free of any management obligations. The original 50-50 distribution of work was not possible in practice, and this meant that the book writing took more time for me than the initially projected four to five years. The almost 1000-page book *Imaging Optics* (Fig. 4) was published in May 2019 by Cambridge University Press and was well received. In my view, it now serves as one of the reference works that the professionals, engineers, and scientists in optics want to have close at hand. The book has also proven to be useful as a general introduction to optics for younger generations during their training period.

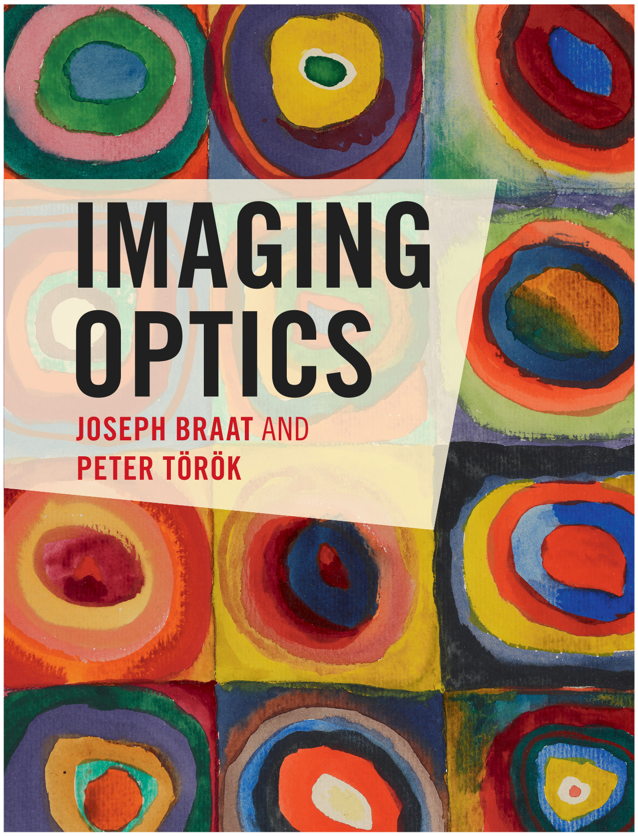


Fig. 4 Cover of the book *Imaging Optics* authored by Joseph Braat and Peter Török, published by Cambridge University Press.

Shao: Thank you, Professor Braat!

Yifeng Shao is a postdoc researcher from the Optics Research Group at the Delft University of Technology. During 2013–2018, he studied in the Optics Research Group at Delft University of Technology as a PhD candidate. His PhD project involves the study of optical system design methodology and computational imaging algorithms. Currently, his research focuses on optical metrology applications for the semiconductor industry, including aberration retrieval and image restoration for the scanning electron microscope (SEM) and EUV lensless diffractive imaging using ptychography.