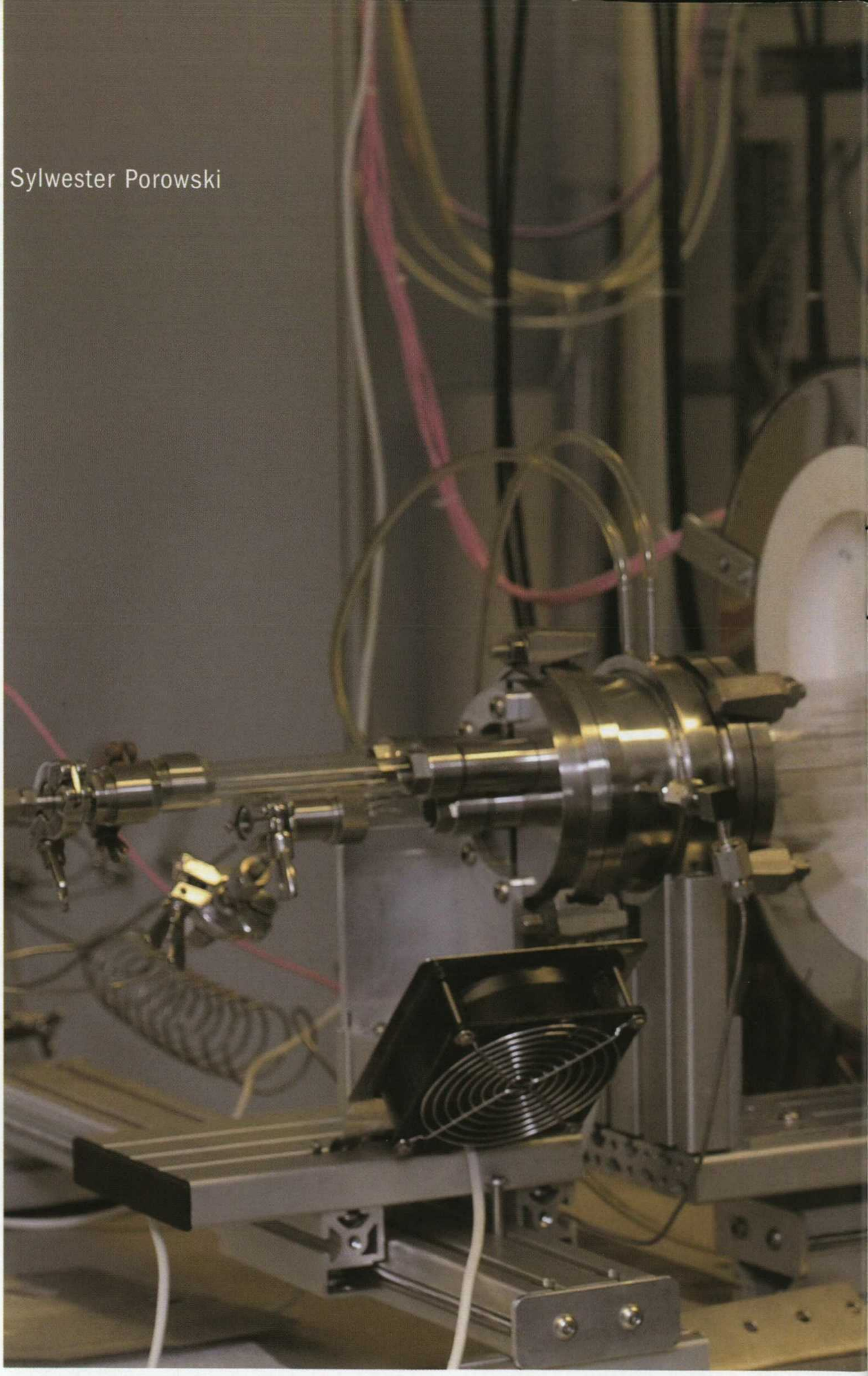
Interview with Prof. Sylwester Porowski



Academia: You are one of the most important physicists in Poland specializing in high-pressure physics.

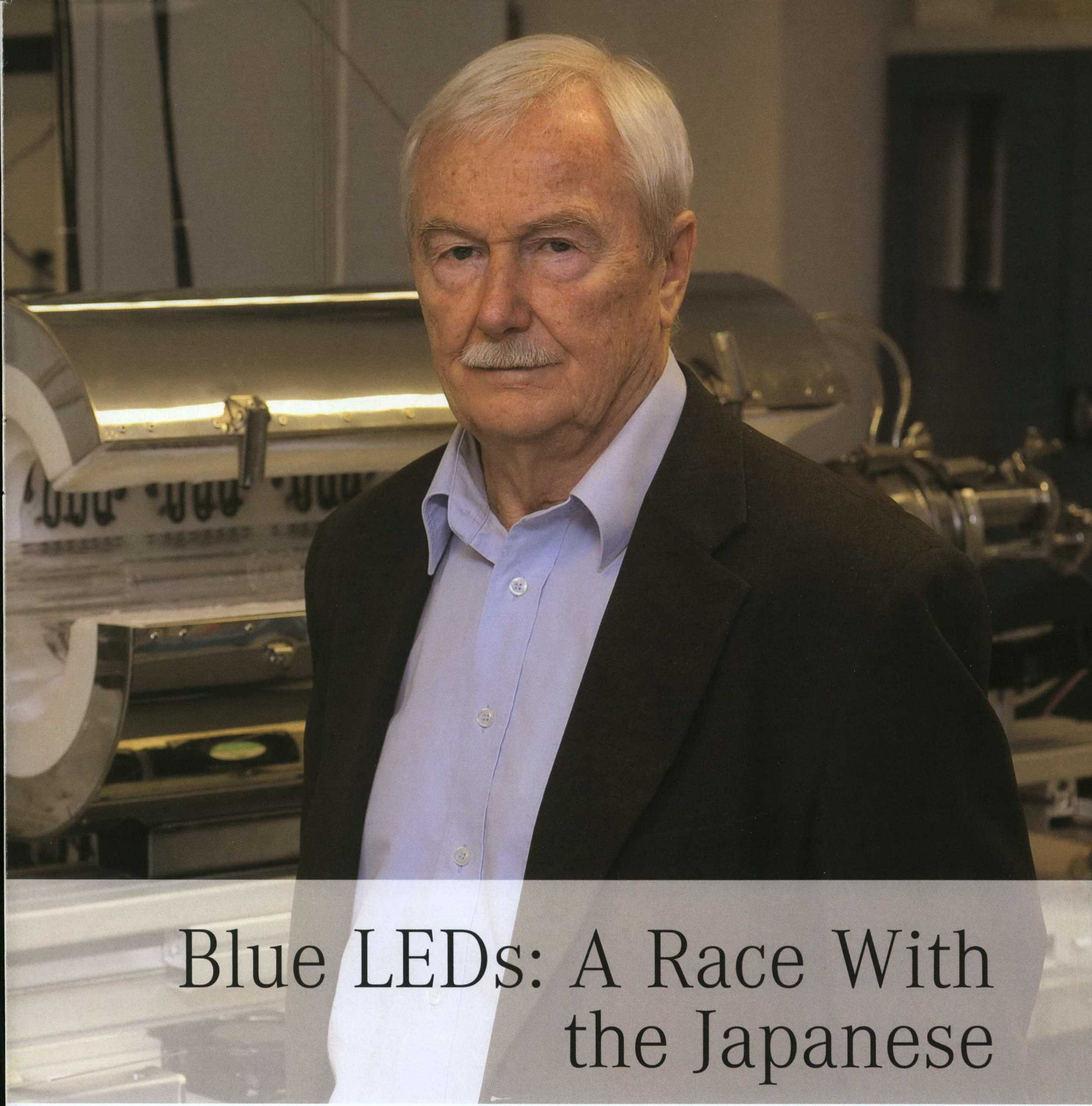
Prof. Sylwester Porowski: *Well, our Institute of High Pressure Physics of the Polish Academy of Sciences is one the well-recognized institutes in the international community in this field. It was founded precisely to recreate the conditions found deep in the Earth, at depths of to 500 or even 1000 km below ground. Having such an extreme environment under laboratory conditions means that we can conduct research in physics at the very basic level. On the other hand it allows us to develop practical applications for high pressures, which may have a profound effect on properties of materials. This helps us devise new materials and improve existing ones.*

What kinds of new materials have been developed using high pressures?

Historically, the first challenge for high pressure physics was to synthesize diamonds in a laboratory. It was known long time ago that natural diamonds are composed of pure carbon atoms. Nature creates diamonds deep in the Earth. Today, high-pressure diamond synthesis is already an industrial process. Nowadays gallium nitride (GaN) crystals created under high pressures are considered even more valuable than diamonds. Moreover, high pressures allow us to create nanocrystals of metals, ceramics, and special glasses with excellent mechanical properties. We are also conducting research on biological materials. For example, food products are exposed to high pressures to eliminate bacteria and the other pathogens, thereby preserving these products' nutritional value.

How did it all start?

The concept of the High Pressure Physics Laboratory, which later became the PAS Institute of High Pressure Physics, was first proposed by Prof. Leonard Sosnowski. In 1960, when the Laboratory was founded at the PAS Institute of Physics, Prof. Sosnowski already had a clear vision that semiconductors are materials which would shape our civilization. He believed that progress in the field would largely depend on the introduction of new research methods, and that Poland should become involved in high-pressure research on semiconductors. To start with, we studied the effect of high pressures on the properties of narrow-gap semiconductors. This was a very current and important topic at the time. Already the first experimental results were fascinating. They revealed that in one of the most important semiconductors in this group - mercury telluride, HgTe - high pressures can change the order of energy levels Γ_{15} and Γ_1, which give rise to the main bands: the valence band and conduction band. This was a key which allowed us to understand the properties of this semiconductor, which has become an essential material in the development of the physics and technology of infrared detectors. It also paved the way for our close collaboration with the Laboratory of High Pressure Physics at Harvard University. This collaboration has been very important for our research and helped us accelerate the development



Blue LEDs: A Race With the Japanese

of new high-pressure methods, which in turn are important for studying the physical properties of metals, superconductors, ceramics, and biological materials.

In 2013, you were awarded the prize of the Foundation of Polish Science – one of Poland's highest scientific distinctions.

Yes, for developing in our Institute's high-pressure method of synthesizing almost structurally perfect monocrystals of gallium nitride, GaN. We were the first team in the world to develop a method of obtaining these crystals. That was in 1993, after many years of research on the properties of gallium nitride at high pressures. The Foundation also stressed the importance of the crystals for the physics of gallium nitride and for solving practical problems which allow optoelectronic devices to be constructed using this semiconductor – mainly blue lasers.

That was a success of a large team. All the staff members at the PAS Institute of High Pressure Physics collaborate smoothly and if necessary help each other selflessly. I think this cooperative attitude allowed us to develop a blue laser in Poland. And that is extremely satisfying for me.

This year's Nobel Prize in physics was awarded for research devoted to gallium nitride, GaN.

It was given to the Japanese scientists Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura for inventing efficient blue-light emitting diodes (LEDs). The

Nobel committee stressed that the invention made it possible to construct efficient, environmentally-friendly sources of white light. We were very happy when we heard about the award. The winners are our colleagues - we frequently meet and we have co-published several papers - so we congratulated them very warmly. How important their discovery was is shown the by dramatic increase in efficiency of electric energy conversion into white light. The 19th century was all about Edison's lightbulb, generating 16 lumens from 1 watt of energy. In the 20th century, the most efficient fluorescent lamps generated 70 lumens from 1 watt, and in the 21st century, white LEDs using the Nobel Prize winners' discovery emit 300 lumens from 1 watt. The US Department of Energy predicts that by 2030, the gradual introduction of LED lights will result in the reduction of total energy consumption for lighting by around 46%. That means a total savings of $250 billion in the USA during this period. This clearly shows the scale of the revolution in lighting brought about by the discovery of these Nobel Prize winners.

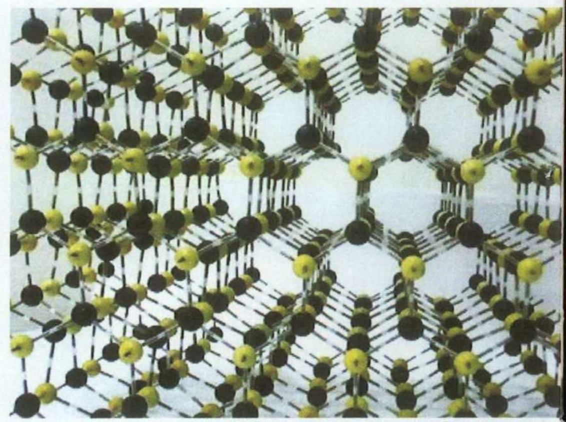
Green and red LEDs have been around for a long time. Why has it taken so long to develop blue ones?

The history of LEDs does go back a long way. The phenomenon of electroluminescence was discovered in 1907 by H.J. Round, although it wasn't understood until 40 years later. Round observed that when electric current is passed through a SiC crystal, a bright light is emitted. The phenomenon was finally explained after the development of band theory for solids, then the understanding that in semiconductors, electrical current can be conducted by carriers in the valence band (p-type semiconductors) or the conduction band (n-type semiconductors), and lastly the development by Prof. Sosnowski's theory of p-n junctions, which are formed at the interface between the two types. Current flowing through the p-n junction means that carriers from the valence band - known as holes - and electrons from the conduction band flow into the junction and recombine there generating light (Lehovec et al. 1951).

But even once the physics of the phenomenon was understood, it took another 10 years for Nick Holonyak to construct the first red LED and another decade before Fairchild Electric started mass production.

So when were the first GaN blue LEDs made?

Even though physicists have known since the 1960s that it should be possible to make a blue LED using gallium nitride, the development proceeded at a far slower pace than for the red LED. The first diodes from GaN emitting blue light (blue LEDs) were made in 1972 at the American radio company RCA by Jacques Pankove and his team. Because gallium nitride crystals weren't available at the time, they used a sapphire crystal substrate with GaN deposited on top using chemical methods. Unfortunately the LED diode was extremely inefficient, and when it wasn't improved during the next years of research, studies were discontinued in 1974. However, in 1973 Pankove outlined his recommendations for what would need to be achieved to make GaN useful

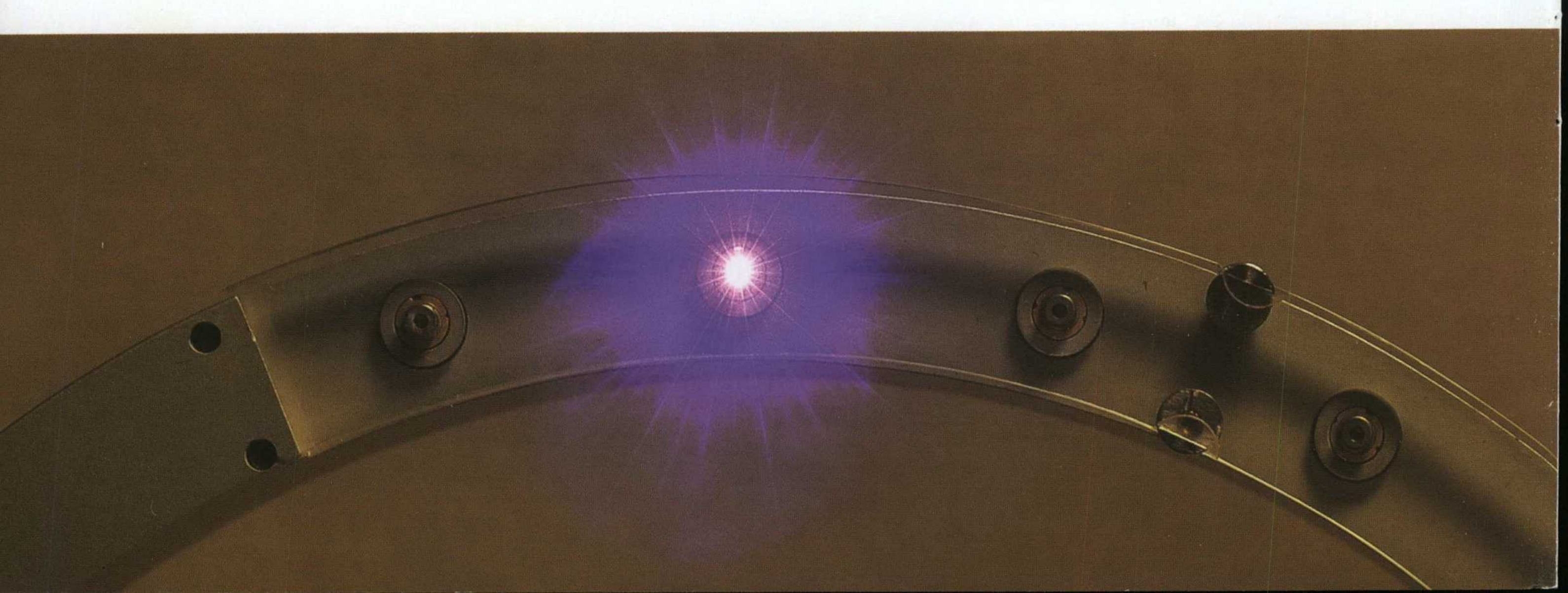


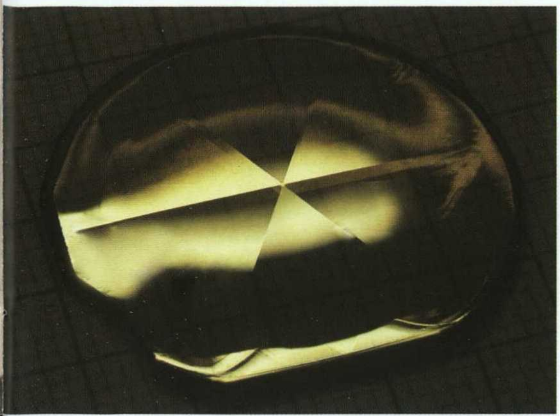
in practice. They proved to be so accurate that they were listed in the justification of the Nobel Prize. Pankove advised the solution of two key problems: developing a method for synthesizing perfect GaN monocrystals, and devising a technology for synthesizing p-type GaN in order to make true p-n junctions.

How did the PAS Institute of High Pressure Physics become involved in research into GaN?

In the mid-1970s we observed that GaN decomposes at high temperatures even at a high nitrogen pressure. We wanted to find the pressure required to stop this process. As a result, in 1984 we determined an equilibrium curve describing the temperature and pressure conditions at which GaN is stable and those under which it decomposes. This was a good basis for starting our work on synthesizing GaN monocrystals necessary to make efficient devices, as recommended by Pankove in 1973.

What were today's Japanese Nobel laureates doing at the time?





New-generation GaN crystals. High growth speed of 200-240 µm/h

In Japan and other countries, systematic research was being conducted into improving methods of depositing thin layers of GaN on sapphire substrates. The structural quality of the layers was greatly improved as a result, although the number of defects (known as dislocations) remained too high for LEDs made using other semiconductors. The breakthrough came when Amano and Akasaki synthesized p-type GaN in 1989, since it turned out that GaN LEDs emit blue light with a great efficiency in spite of a large number of defects.

This rapidly led to the development of the first technology for industrial production of blue LEDs. In 1999, "Forbes" magazine predicted a coming revolution in the lighting market, spearheaded by Shuji Nakamura – now one of the Nobel laureates. In 1996, Nakamura also constructed the first blue laser. However, it turned out that while GaN layers on sapphire are of sufficiently high quality to construct efficient blue LEDs, their structural defects were significant enough to make them unsuitable for lasers, as it limited their power and lifetime. Our structurally better GaN single crystals created the opportunity we needed to become involved.

So the 1990s were crucial in the development of devices using GaN-based LEDs and lasers. How did the development progress in Poland?

Unlike Japan, Poland didn't have the equipment or technology necessary to make gallium nitride LEDs and especially lasers. However, in 1993 we were already synthesizing GaN crystals with a density of defects 10 million times lower than those made in Japan. In structural terms, our crystals were almost perfect. This gave us a powerful motivation to work on the development of the physics and technologies of optoelectronic devices, in particular lasers. Unfortunately we had to wait seven years for the Polish Government's "Strategic Program of the Development of Blue Optoelectronics."

In the meantime, in 1999, Nakamura strengthened our belief in the importance of our work constructing a blue laser on one of our crystals. The laser worked in the continuous mode of operation generating 30 mW and lasting 3000 hours, which was a world record at the time.

The same year, still before the start of the Strategic Program, we were joined by a private investor whose support made it possible for the Institute to start building a laser laboratory.

The Strategic Program finally kicked off in 2000, dedicating around 10 million zlotys to the development of GaN lasers. The combined private and public funds soon allowed us to demonstrate a first laser emission (emission of coherent blue light). Already in 2001, we built Poland's first blue laser with active structure grown by the metalorganic vapor phase epitaxy (MOVPE) method. In 2004 we built the first laser in the world using molecular beam epitaxy (MBE), which we patented and which remains our specialty.

This was a major achievement for our Institute, and it motivates us to continue developing research on the physics and technology of GaN devices.

We know that GaN is taking the world by storm, and not just in terms of lighting. How is the field developing in Poland?

Scientific research into the physics and technology of GaN is being conducted at 11 institutes. It's difficult to estimate the total number and quality of publications written in Poland on the subject, but our Institute alone has published over 800 papers with around 15,000 citations.

Poland's GaN research community belongs to the strongest in Europe. The most important results concern GaN crystals synthesized using three methods: ammonothermal, Halide Vapor Phase Epitaxy (HVPE) and high pressure methods (HNPSG), as well as the physics and technologies of lasers built using these crystals. Our results are state-of-the-art.

The scientific research is being commercialized by two hi-tech companies – Ammono SA (crystals) and TopGaN Sp. z o.o. (crystals and lasers) formed by scientists with the participation of private capital. Each company employs dozens of people, which means they are able to continue developing the technologies and conduct low-scale production of GaN crystals and lasers.

To achieve full market success, it will be necessary to expand the scale of these activities to enable mass production. According to the most recent statement (5 Nov 2014) by PAS Division Three (Mathematics, Physics, Chemistry and Earth Sciences), "To make the most of the scientific and technological potential of the institutes and companies Ammono and TopGaN, we need the involvement of large Polish industrial enterprises. Only organizations with experience in mass production and extensive distribution networks will be able to convert the new technologies into products used widely by global companies and their suppliers."

How is research into GaN progressing elsewhere?

Studies into gallium nitride are developing rapidly. However, in spite of several decades of research, the technology of GaN monocrystals is still far from perfect. It can be compared to the state of play with silicon technology around the 1960s. I am certain we are going to see many more momentous discoveries in the coming decade. It is already understood that the lighting revolution inspired by blue LEDs is just the tip of the iceberg

Molecular beam epitaxy (MBE) apparatus (for crystallization from Ga i N_2^+ molecules)

Prof. Sylwester Porowski

is a physicist specializing in solid state physics. Between 1964 and 2010, he directed the High Pressure Research Laboratory at the PAS Institute of Physics, which became the PAS "Unipress" Laboratory of High Pressure Physics and Technologies in 1972 and the PAS Institute of High Pressure Physics in 2004. He has also done research abroad, at the University of Harvard (1967-69) and the University of Montpellier (after 1978). He is a member of the Polish Physical Society, the European Physical Society, and AIRAPT, of which he was president between 1999 and 2003.

of the new emerging markets related to GaN.

The most important coming applications of GaN are laser projectors and laser lighting, as well as other applications in telecommunications, energy, medicine, and further in the future, laser terahertz radiation and spintronics. But the further development of crystal quality is crucial for all these applications. This is a great opportunity for us, because Poland is still the leader in the field on the global scale. Our crystals still have the best structural qualities.

This is especially applicable to the new-generation crystals obtained thanks to the collaboration between our Institute and Ammono SA. The new method allows for the efficient and rapid growth of crystals, and it also preserves their highest structural quality and chemical purity, making it ideal for expanding into mass production.

Has your activity revealed any particular problems of collaboration with institutions?

Problem with collaboration mainly arise as a result of the poor structure of many of our institutions, and a certain mental attitude - both hangovers from the previous political and economic era. But there are also many institutions and companies where people strive to work together for a common goal and support each other without these hangups. Of course this doesn't mean that we haven't encountered problems linked with these issues, but for us they are always to do with external institutions and the high level of administrative bureaucracy. Actually the majority of our problems were due to the years we wasted waiting for the start of the Strategic Program aiming to develop blue optoelectronics. In applied research, when you are dealing with competition, it is essential to act fast to guarantee success.

You have told us about some fascinating issues. Do you have a feeling you are a man of success?

I think so, yes. The Institute is very important to me, and I am very happy with how it has been developing. I haven't been its director for four years now, yet the Institute continues to achieve increasingly good results. It's like a tree, growing and thriving. We have mainly talked about research into gallium nitride, and I am very pleased with our position in this field. But, to me, what's even more important than our scientific achievements is that the applications of our research and the experiences gained by the companies Ammono and TopGaN are increasingly likely to be widely implemented in the Polish economy. ■

Interviewed by **Agnieszka Pollo** and **Anna Zawadzka**; photos: **Jakub Ostałowski**