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Contribution of the Institute of High Pressure Physics PAS (UNIPRESS) to Semiconductor Physics and Technology

I. Grzegory*

Institute of High Pressure Physics Polish Academy of Sciences UNIPRESS, Sokołowska 29/37, 01-142 Warsaw, Poland

Doi: 10.12693/APhysPolA.142.597 *e-mail: izabella@unipress.waw.pl

UNIPRESS was created 50 years ago (1972) from the Laboratory of Pressure Studies of Semiconductors of the Institute of Physics PAS. An exceptionally strong foundation, based on the Leonard Sosnowski School of Semiconductors, supported by excellent foreign cooperation, has created a great opportunity for this new research center. Its leader, Sylwester Porowski, had been building an original experimental base from the very beginning. The UNIPRESS high pressure equipment quickly gained recognition in the world and allowed physicists to achieve results appreciated by the scientific community. The most visible research areas in semiconductors where UNIPRESS was active were:

- pressure studies of narrow gap semiconductors,
- pressure studies of the impurity/dopant character and recombination mechanisms,
- high pressure thermodynamics and crystal growth of GaN,
- GaN-based quantum structures and devices,
- generation of THz radiation in semiconductors.

Selected results from the above list are discussed in more detail. At the end, the most relevant new research directions developed at UNIPRESS, such as high pressure synthesis of h-BN, semiconductor–superconductor (GaN–NbN) heterostructures emitting entangled photons, integrated photonic circuits, or THz amplification in semiconductor plasmonic structures (ERC Adv.), are highlighted.

topics: high pressure, narrow gap semiconductors, impurity states under pressure, GaN crystals

1. Introduction

It is a real challenge to present the contribution of UNIPRESS to semiconductor physics and technology. The Institute has existed already for 50 years, and semiconductor physics was at its background and is still the dominating field of its activity.

I tried to select from a number of interesting and high quality results the ones that could be called important, pioneering, or even groundbreaking, according to some criteria verified by the commonly accepted methods but sometimes also based on my personal choice.

I will present achievements that have clear names, like, e.g., defect centers with strong lattice relaxation in InSb or GaN single crystals and homoepitaxial layers. A high impact of these results was usually reflected in the high quality (HQ) papers often widely cited, the HQ books — summarizing some stages of the research, or the HQ grants (like ERC AdGr obtained in May 2022).

Through this short review, I would like to leave you a message that UNIPRESS, since its prehistory until today, has contributed to semiconductor physics in a visible way. It was due to two important factors: clever and devoted people, as well as original, own scientific equipment enabling studies of semiconductors under pressure and distinguishing somehow UNIPRESS from the others.

2. Scientific roots of UNIPRESS

The scientific roots of UNIPRESS were strongly related to the Professor Sosnowski School of Semiconductor Physics.

In Fig. 1, some of the UNIPRESS pioneers, sitting on the Hoża 69 campus, can be recognized. We have here: Elżbieta Litwin-Staszewska, Ryszard Piotrzkowski, Wacław Bujnowski — the future key person responsible in UNIPRESS for high pressure equipment, and Sylwester Porowski — the leader and founder of UNIPRESS.

Fig. 1. UNIPRESS pioneers in the Hoża 69 University Campus; from the left: Elżbieta Litwin-Staszewska (then Kucicka), Sylwester Porowski, Alosza Filipczenko (not from UNIPRESS), Ryszard Piotrzkowski, Barbara Wentowska (not from UNIPRESS) and Wacław Bujnowski. Photo provided by Elżbieta Litwin-Staszewska from her private archive.

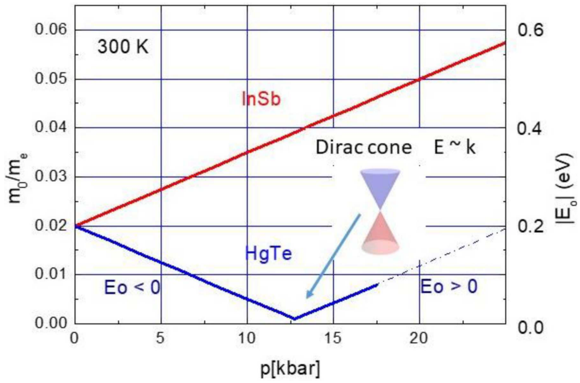

Fig. 2. The pressure dependence of the effective mass of narrow gap semiconductors with regular band structure (InSb) and inverted band structure (HgTe). Diagram prepared by E. Litwin-Staszewska for this review.

Pressure as a physical variable influences key properties of semiconductors, and this influence can be described as:

- changes in interatomic distances, which cause the evolution of energy band structure and related energy of defect states, sometimes leading to quantum phase transitions;
- changes in thermodynamic potentials in multiphase systems containing semiconductor crystals, which may allow the synthesis of these crystals under near-equilibrium conditions, or lead to structural phase transitions.

Both of these aspects were relevant in the research activity of UNIPRESS.

In 1961, William Paul proposed his famous *empirical rule* for pressure coefficients of energy gaps at different points of the Brillouin zone (BZ) for diamond and zinc blende semiconductors [1]. This rule has been applied for many years to evaluate specific features of band structures using spectroscopy under pressure. Under pressure, the energy bands minima at different points of the BZ move in quite a regular way at rates similar for all semiconductors. As a result, the physical properties of a crystal change accordingly, which what can be studied by transport or optical methods.

Figure 2 shows a summary of a beautiful observation that the evolution of the effective mass of InSb and HgTe with pressure is opposite. The meaning of this relation has been studied by pioneers of our Institute. In 1965 Sylwester Porowski defended his PhD thesis [2] titled "Band structure of HgTe" supervised by Professor Sosnowski. The work has been supported by two original papers [3, 4] and followed by PhD thesis of Ryszard Piotrzkowski in 1970 [5].

The results of the measurements of pressure dependencies of thermoelectric power, Hall constant and conductivity allowed a clear confirmation of the inverted band structure predicted by Groves and Paul in 1963 for Sn [6]. In the Groves-Paul model, the Γ_8 band was located above the Γ_6 one, in contrast to the regular case, and moreover, the Γ_8 degenerated with the band of heavy holes.

In [2–5], a reaction of the regular and inverted band structures on pressure has been considered, and corresponding consequences for the effective mass of carriers and related physical properties were deduced and experimentally confirmed. As shown in Fig. 2, for a regular band structure, the effective mass should increase with pressure, like in InSb, whereas for the inverted bands, the mass should go in the opposite direction, like in HgTe. So, by smart measurements of basic properties in function of pressure, it was clearly demonstrated that under pressure HgTe undergoes a transition from an inverted band structure, through a Dirac-cone-like one, to a regular open gap semiconductor.

As a kind of recognition of this result, in 1967, Sylwester Porowski was invited for a long-term postdoc visit to Harvard University to prof. William Paul's laboratory, where he continued studies of narrow gap semiconductors, mainly InSb and HgSe.

William Paul was a direct successor of Percy Bridgman, the Nobel Prize Winner in physics (1947), who created foundations for high pressure science and technology. The original Bridgman apparatus was donated by William Paul to UNIPRESS in 1997, as a present for the 25th Anniversary of the Institute.

In 1998, Academic Press issued a book co-edited by Tadeusz Suski (one of the leading physicists at UNIPRESS) and William Paul [7]. The book summarized the role of high pressure in semiconductor physics and showed that sometimes the *pressure was a unique tool* to decode some secrets of the band

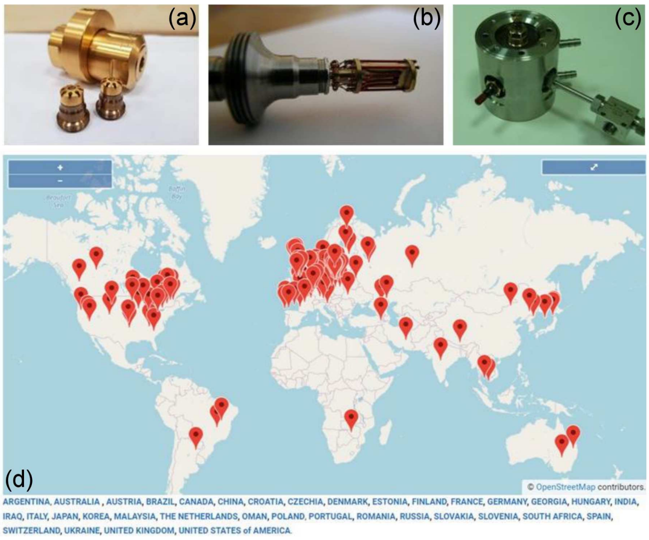

Fig. 3. Distribution of high pressure scientific equipment made by UNIPRESS. Two high pressure cells for optical measurements (a) and (c), and sample holder fixed on the high pressure plug (in the middle) (b) for transport measurements are shown. Panel (d) presents map of users of high pressure equipment delivered by Institute of High-Pressure Physics of the Polish Academy of Sciences.

structure of important semiconductors, especially low and zero gap ones, like HgTe. In the introductory Chapter 1 by William Paul, reviewing the field, more than 10% of over 200 references were the ones of UNIPRESS authors. We contributed directly to this book by writing two chapters: “Spatial correlations of Impurity Charges in Doped Semiconductors” by T. Suski in Vol. 1 and “The Application of High Nitrogen Pressure in the Physics and Technology of III–N Compounds” by S. Porowski and I. Grzegory in Vol. 2.

3. Semiconductor physics and technology in UNIPRESS

One can distinguish a few periods or milestones during 50 years of UNIPRESS activity in the field of semiconductor physics and technology:

- pressure studies of narrow gap semiconductors,
- pressure studies of impurity states and related transport and recombination mechanisms,
- high pressure thermodynamics and crystal growth of GaN,
- physics of GaN-based quantum structures and devices (mostly at low pressure!),
- generation of THz radiation in semiconductors.

In almost all of these topics, the role of UNIPRESS experimental equipment was extremely important and internationally recognized. As it is shown in Fig. 3, several scientific centers all over the world have been equipped with instruments with the “UNIPRESS EQUIPMENT made in Poland” logo.

UNIPRESS has created new instruments for studies of semiconductors under extreme conditions of pressure, temperature, and magnetic field, rocks in a triaxial state of stress, chemical processes under high pressure, food pascalization, etc.

High pressure equipment for scientific research should provide not only safe operation in the required extreme conditions of pressure, temperature, and magnetic field, but also access to the interior of the high pressure cell, e.g., electromagnetic radiation, electric current, and various sensors (such as thermocouples or pressure gauges). This is the purpose of shaping and designing structures with the use of modern methods and modern engineering materials, accumulating knowledge over the years (technical archive), and possessing a specific technical infrastructure.

The UNIPRESS equipment is constantly being sold and used in many countries (ue.unipress.waw.pl/) all over the world. And it is still something that distinguishes us from others.

3.1. Narrow gap semiconductors at UNIPRESS today

The role of the narrow gap semiconductor physics in the creation of UNIPRESS was already shown in the previous section. At present, these fascinating problems are coming back to us through HgTe–HgCdTe quantum wells (QW), e.g., [8], that are important in topological matter physics and, as containing highly mobile electron gas, relevant for THz generation. In 2019, the International Research Agenda: The Center for Terahertz Research and Applications (CENTERA), headed by Prof. Wojciech Knap and including the narrow gap semiconductor physics, was established in UNIPRESS.

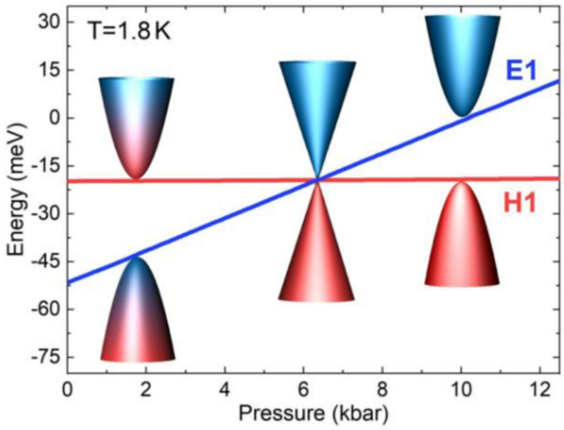

Fig. 4. The evolution of both E1 and H1 subbands as a function of the hydrostatic pressure for HgTe/$Cd_{0.62}Hg_{0.38}$ Te structure of 8nm quantum well thickness. Blue and red colors correspond to the electron-like E1, the light hole H1 subbands. Calculations were performed for (013) crystallographic directions [10], courtesy of I. Yahniuk.

As it was shown theoretically in CENTERA [9], the band structure of HgTe–HgCdTe QW could be tuned by pressure, and as expected for the QW, due to the quantum confinement, the pressure of gap opening would be significantly lower than for the bulk crystal of HgTe. There are quite recent high pressure experimental studies of the HgTe-HgCdTe QW using transport and magnetotransport measurements described in the thesis of the UNIPRESS PhD student Ivan Yahniuk [10], confirming theoretical predictions. Figure 4 (from [10]) is a good illustration of the HgTe–HgCdTe QW behavior under pressure.

In particular, the HgTe–HgCdTe systems are included in the ERC Advanced Grant recently obtained by Wojciech Knap, who is working on the generation of THz radiation in semiconductors. His proposal is based on the proof of concept experiment [11] showing, for the first time, the room temperature amplification of THz radiation in a special grated gate graphene-based heterostructure with highly mobile two-dimensional electron gas (2DEG). It was observed that in the grated gate graphene nanostructures, the resonance plasmonic absorption transforms into amplification when the current goes over a certain threshold value. The goal of Knap's proposal is to establish a nature of such resonance, playing with various systems containing 2DEG, in particular the HgTe–HgCdTe QWs and GaN–AlGaN heterostructures. In the case of the GaN–AlGaN system, the band structure is completely different than in both graphene and HgTe, however, it contains highly mobile 2DEG with (with such properties as, in particular, high drift velocity), and as it was already shown [12], it is a very promising candidate for THz amplifier.

3.2. The impurity states physics

The impurity states in semiconductors are related to the energy bands depending on the nature of these states. The shallow hydrogen-like ones are usually following the corresponding band extrema, whereas the other ones, called traditionally deep centers, are much more complex in their relation to changes in the band edge positions. Sometimes the impurity states are in resonance with a band, and the pressure can push them into the gap. It has consequences in the behavior of basic physical properties like carrier concentration or radiative recombination energy when the pressure starts to modify the entire structure in a specific way.

An interesting group of states is donor impurity states related to side minima of the conduction band [13]. Their ionization energies weakly depend on pressure (like in the hydrogen-like case), whereas values of these energies are high, which suggests a deep character of the states. The magnetotransport and far infrared (FIR) magnetooptical pressure studies performed in UNIPRESS contributed a lot to understanding the physics of these systems. In particular, energies of Te, Se, S, and O impurity states related to the L-minimum in InSb were evaluated (Fig. 5 [14]). Moreover, the pressure behavior of co-existing hydrogen-like states ladder related to minimum Γ was also established.

It allowed for the first experimental observation of a theoretically predicted anticrossing effect [15, 16] when two impurity states of the same symmetry but related to different band minima approach each other, as shown in Fig. 6 [17, 18]. When under pressure, the deepest donor level related to minimum L approaches the deepest level related to minimum Γ, and the anticrossing effect is observed. In particular, it has been shown that for InSb at a pressure range

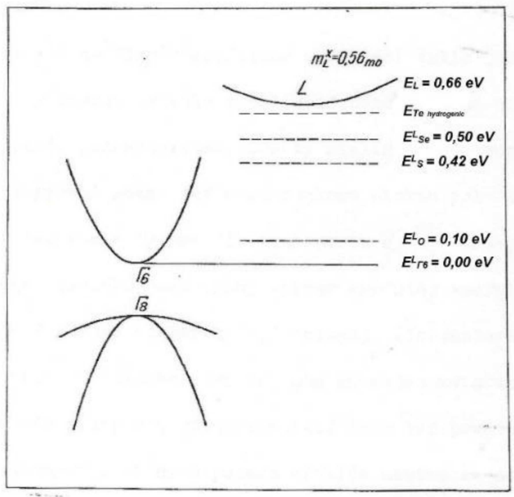

Fig. 5. Band structure of InSb. Dashed lines represent the energy levels corresponding to 4 substitutional donors related to L-minimum: Te, Se, S, and O from [14]. Courtesy of S. Porowski.

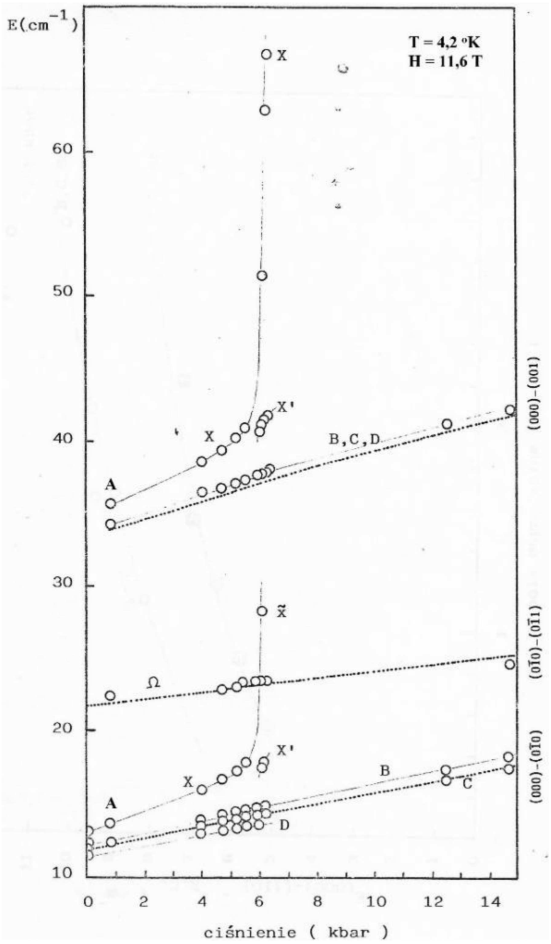

Fig. 6. Impurity magneto-absorption peaks in InSb as a function of pressure at 11.6 T magnetic field. At about 6 kbar, a crossing of the L and Γ associated levels is seen for donor A. Courtesy of Z. Wasilewski.

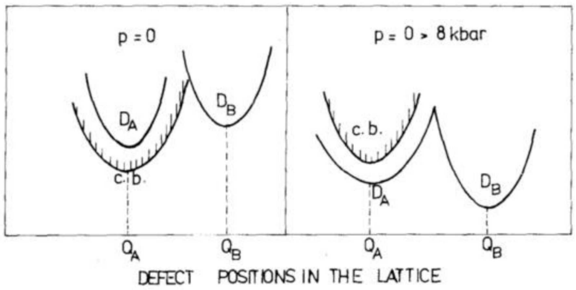

Fig. 7. Configurational diagram of defect changing its position under pressure, thus inducing lattice rearrangement, which is the source of metastability [21].

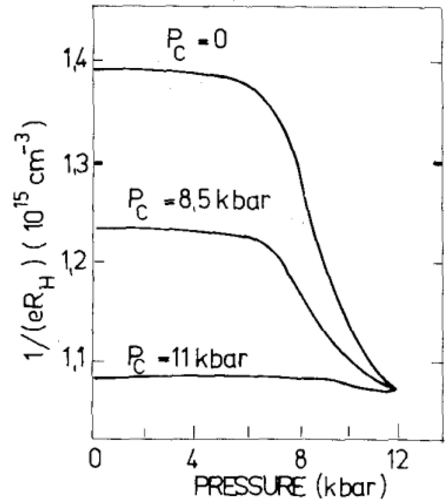

Fig. 8. Dependence of electron concentration on pressure in n-InSb at 77 K, cooled down at three different pressures: ambient; 8.5 kbar; and 11 kbar, from [21].

as small as 500 bar, the wave function of the impurity center can continuously transform from weakly to strongly localized, and its size decreases several dozen times.

One of the most sound early contributions of UNIPRESS researchers into the impurity states physics was the one interpreting pressure behavior of InSb as a *result of impurity–lattice coupling* involving special defect states commonly known as DX centers. A good frequently used illustration of these effects are configurational diagrams showing relations between the total energy of the system in function lattice displacement.

The corresponding early publications on InSb [19–21] were really pioneering since they were published well before the one by Lang and Logan of 1977 [22] introducing the DX centers. The UNIPRESS papers were just second after Wright et al. 1968 [23] suggesting the large lattice relaxation mechanism. As it has been noticed by J. Langer in his comprehensive review [24], Porowski et al. [19, 20] presented sound arguments for a lattice rearrangement at such a defect, which is a source of metastability effects. The essence of the model has been the possibility of the defect moving in a lattice from A to B positions characterized by different elastic and electron energies. It was suggested that the potential barrier between states relevant for metastability was mostly due to a lattice motion. A simplified configurational coordinate model at different pressure was proposed (see Fig. 7).

A corresponding example of the experimental result leading to the model of Fig. 7 is given in Fig. 8.

If there is no pressure applied during a cool-down cycle to 77 K, at low temperatures only level A (Fig. 7) is active in a pressure dependence of carrier concentration. In contrast, if the cooling pressure was high, all electrons were trapped by level B at low temperatures even after pressure release. Therefore, as shown by the bottom curve in Fig. 8, level A is not active, and the carrier concentration (due to background doping) became pressure independent.

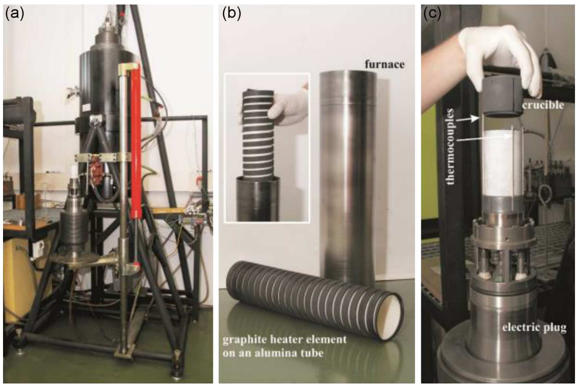

Fig. 9. Big volume gas pressure reactor: (a) general view of the high pressure chamber with internal diameter of 100 mm, (b) components of the graphite furnace, (c) preparation of high pressure–high temperature experiment: BN crucible with set of thermocouples is placed on the bottom electrode of the furnace connected to the high pressure plug.

This DX line of research has been continued and extended in UNIPRESS, resulting in a number of valuable contributions. The ones up to 1998, were described and referenced in William Paul's Introductory Chapter and Chapter 5.3 of the book [7].

In the corresponding original papers, both high pressure and temperature have been used as tools for tuning electron concentration by the high pressure freeze-out and annealing, since relative positions between relevant states can be tuned by the pressure. Then the properties of a sample could be investigated in dependence on electron concentration and occupation of the DX states.

In this way, very interesting phenomena related to the correlation of remote impurity charges in heterostructures, expressed in a significant increase in mobility of 2DEG, were observed and investigated (Chapter 5.3 of [7] and references therein).

One of the most important results on impurity physics using pressure as a tool was the *identification of the dominant donor in GaN* [25, 26].

In [25], it was shown that in GaN, the dominant donor level is resonant with the conduction band and can be pushed down into the gap by applying pressure. In a highly n-type GaN, a quite strong absorption by free carriers was observed. At pressures of about 20 GPa (very high — achievable only in diamond anvil cell (DAC), this absorption disappeared, and the crystal became transparent since the donor level entered into the gap. In this work [25], the donor has been identified as N-vacancy, but it was not a fully correct interpretation. As it was concluded in [26], where results of Raman scattering in DAC were compared to SIMS data, the dominant donor in GaN behaving like N-vacancy was oxygen substituting nitrogen in the lattice of GaN.

3.3. High pressure thermodynamics and crystal growth of GaN

In parallel to the high pressure equipment for measurements of electric and optical properties of semiconductors, UNIPRESS has developed big volume gas pressure reactors for studies of materials at high temperatures (Fig. 9). The reactors of 30–100 mm internal diameter and equipped with multi-zone furnaces with precise temperature control enabled experiments at 1–2 GPa gas pressure and 1500–2000°C.

It allowed starting "the GaN era" in UNIPRESS. It happened in the early '80s. Then, the *basic thermodynamic properties of GaN* were determined, showing that GaN decomposes at high temperatures, and to suppress this process, high pressure of nitrogen is necessary. The famous equilibrium curve for GaN and its constituents was first published in 1984 [27] (see Fig. 10) and, quite recently, extended up to 9 GPa and corresponding temperatures exceeding 3000 K [28].

The N in Ga solubility data [28], even at temperature as high as over 3000 K, clearly indicated that the system was still far from conditions of the congruent melting of GaN. From the solubility data, the melting temperature in function of pressure has been evaluated [28], and the resulting dependence was in very good agreement with conventional molecular dynamics studies by Harafuji et al. [29] (Fig. 11), although in disagreement with Van Vechten model [30] and experimental suggestions of Utsumi et al. [31].

Our current understanding of the relations of decomposition and the supposed melting curve of GaN is that at "low" pressures (lower than 10–12 GPa), at heating, GaN decomposes before melting. This is illustrated in Fig. 11, where the relevant experimental data on both the decomposition and melting as

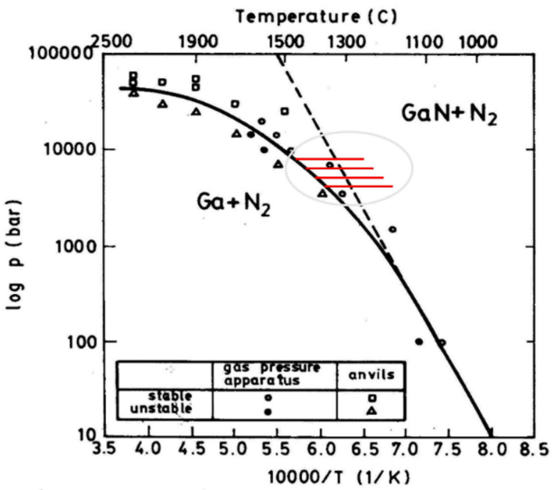

Fig. 10. Equilibrium curve of GaN [27]. The area distinguished by red lines indicates conditions used for GaN crystallization.

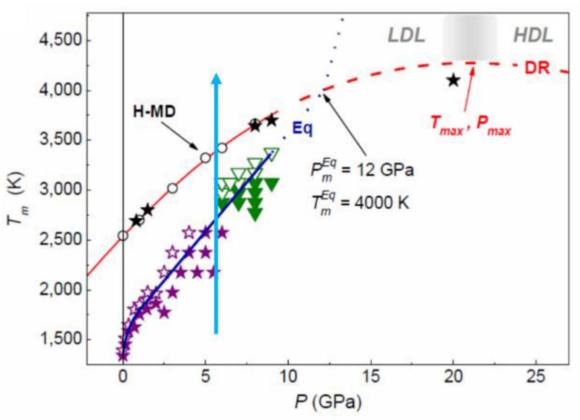

Fig. 11. Decomposition and melting curve of GaN: blue line — decomposition curve based on high pressure experiments [27, 28], red line — supposed melting curve based on indirect evaluation from solubility experiments (black asterisks) [28] and MD modeling (open circles) by Harafuji et al. [29]. Blue vertical arrow shows that at lower pressure, at heating, GaN decomposes before melting.

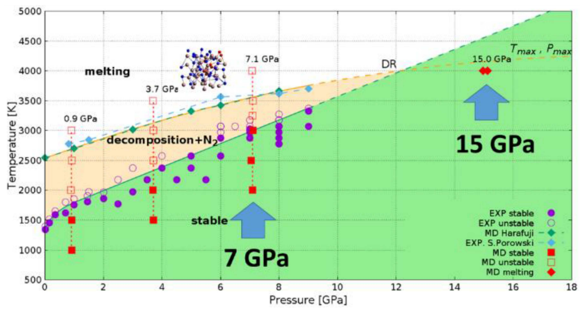

Fig. 12. Phase diagram of GaN: decomposition vs congruent melting. Red points are results derived from *ab initio* MD [33].

well as Harafuji's [29] MD (molecular dynamics) results are shown. The vertical arrow indicates the "low" pressure heating of GaN.

Our recent *ab initio* MD studies [32] confirmed this conclusion showing that at lower pressure and at sufficiently high temperature, the GaN crystal lattice is destroyed, and N_2 molecules are formed, indicating the decomposition of the crystal. For 15 GPa at otherwise the same conditions, the formation of N_2 molecules is suppressed. The N_2 formation is a factor distinguishing the decomposition and congruent melting of GaN.

The agreement of the *ab initio* results with available experimental data (Fig. 12) is very encouraging for further consistent modeling of this system. This is important because despite the enormous development of GaN and its excellent figures of merits for significant applications, the phase diagram of GaN, in particular its melting curve, is still an open question [33].

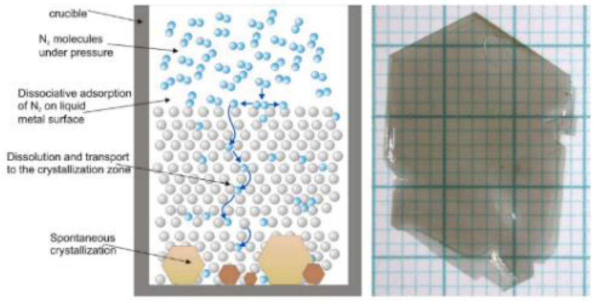

Fig. 13. Crystal growth of GaN from solution of atomic nitrogen in liquid gallium.

The background we had already in the '80s was sufficient to start experiments on *growing GaN crystals* from solutions in gallium at N_2 pressure up to 1–1.5 GPa (the high nitrogen pressure solution HNPS method). The experiments were supported by modeling the interaction of N_2 with Ga showing a catalytic effect of gallium for the dissociation of N_2 molecules, thus indicating solution of atomic nitrogen in the liquid metal [34] as the growth a solution for GaN.

It allowed us to grow the crystals, which were of surprisingly high structural quality and, as the first in the world, were suitable for evaluating the basic physical properties of GaN. Figure 13 shows a schematic illustration of the growth method and an example of a pressure-grown single crystal of GaN.

Quite soon, the material was considered a reference for single crystalline GaN. It is well visible in the content of one of the first databases [35] on GaN and related semiconductors published in 1998, edited by leaders in the field, two of whom were future Nobel Prize winners. There are 7 subchapters authored by UNIPRESS researchers. They include:

- structural, mechanical, and thermal properties of group III nitrides;
- bulk crystal growth of GaN and related compounds;
- epitaxy of III-N layers on GaN substrates.

Some examples of UNIPRESS results on basic physical properties of GaN, of the high impact in terms of their citation numbers, can be indicated: elastic constants [36], solid–solid phase transition [37], native defects [38], lattice parameters [39], excitons in homoepitaxial GaN [40, 41].

The "high pressure" crystals were of very high structural quality in terms of dislocation density, but usually, they contained a high number of point defects. Really pure GaN crystals of high structural quality were grown in UNIPRESS by the gas phase HVPE (hydride vapor phase epitaxy) method [42], on the seeds from the ammonothermal method developed by Robert Dwiliński and his group [43].

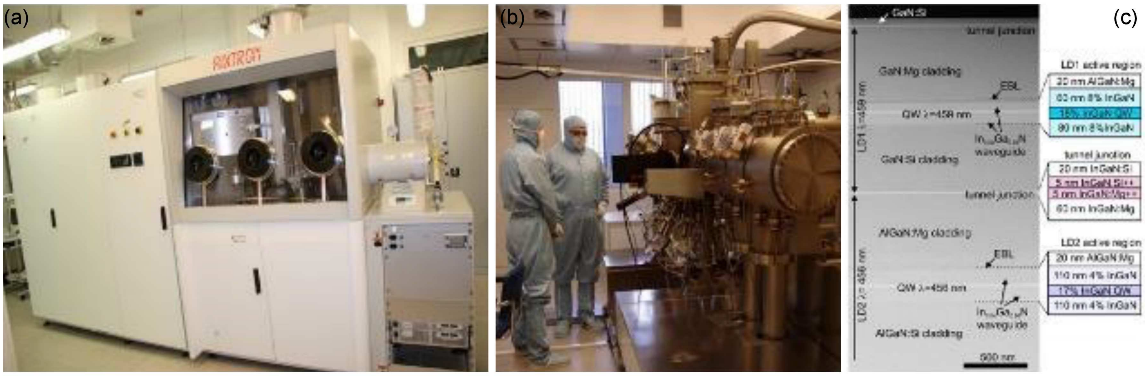

Fig. 14. Nitride Semiconductors Physics and Technology Centre GaN-Unipress: (a) reactor for epitaxy of nitride semiconductors by MOVPE, (b) reactor for epitaxy of nitride semiconductors by PA MBE, (c) vertically integrated laser diodes with tunnel junctions grown by PA MBE.

The HNPS GaN crystals were the first substrates for the homoepitaxy of GaN, which allowed to define a new standard for optical and other physical properties of GaN, e.g., [40, 41].

3.4. Homoepitaxy, quantum structures and devices

The *homoepitaxial challenge* we faced at that time was summarized twice in Oxford University Press books in 2002 [44] and in 2013 [45]. The chapter in the earlier one summarized pioneering results on homoepitaxial layers and structures on the HNPS GaN substrates grown in collaborating Laboratories in Europe.

In the later one, the "Homoepitaxial challenge" chapter was much more advanced and showed how the nitrides physics at UNIPRESS has developed over 10 years, starting from small pressure-grown crystals up to the creation of vertically integrated research structure including: crystal growth of GaN, epitaxy of GaN-based structures grown by MOVPE (metalorganic vapour-phase epitaxy) and PA MBE (plasma-assisted molecular beam epitaxy) methods, processing of optoelectronic devices and advanced structural, as well as electrical and optical characterization.

Institute of High Pressure Physics PAS UNIPRESS is Europe's second (after IMEC in Belgium) academic center in nitride semiconductors and one of the most important laboratories of this type in the world. The infrastructure built in UNIPRESS (Fig. 14) was included in 2020 in the Polish Map of Strategic Research Infrastructure as "Nitride Semiconductors Physics and Technology Centre GaN-Unipress".

Laser technologies developed in UNIPRESS are commercialized through the spin-off company, TopGaN Ltd. Currently, they are being developed in parallel within the spin-off and at the Institute. TopGaN Ltd. was founded by UNIPRESS and a private investor in 2001 in order to commercialize the technology of GaN-based laser diodes. At that time, it was already obvious that the nitride laser diodes must be made on native substrates with low dislocation density, and UNIPRESS was then the only manufacturer of such substrates in the world. TopGaN, along with hi-tech companies (Nichia, Panasonic, OSRAM), developed all segments of nitride laser diode technology and is able to provide these devices with the required parameters (for example, with a precisely selected wavelength of the emitted light). Such instruments are needed for the construction of quantum devices of the future — super-accurate atomic clocks [46], gravity sensors, etc. With TopGaN laser technology, the Scottish partners (CST, Optocap, and Glasgow University) can develop cutting-edge quantum technologies that are expected to revolutionize many areas of our lives in a few years. In [46], the use of TopGaN lasers in the latest generation of atomic clocks is described. The excellent results of the UK–Poland *Quantum Cooling using Mode Controlled Blue Lasers* project, in which TopGaN participated as an inventor of a new generation of diode lasers fulfilling stringent requirements of the project, are presented.

Nitride semiconductors create the core of new global markets (LED lighting, UVC LED sterilization, high-power transistors, laser diodes for image projection, etc.). On the other hand, they are technologically much more difficult than other semiconductors and still poorly understood. Therefore, the field of nitride semiconductors belongs to the most important in solid state physics, optoelectronics, and electronics.

4. Research prospects

Thanks to the potential UNIPRESS has developed, we are able to continue our adventure with semiconductor physics and technology in many aspects. The most challenging and fascinating recent projects are:

- physics
    1. Towards On-Chip Plasmonic Amplifiers of THz Radiation (TERAPLASM) — ERC AdGr 2022;

   2. High-Performance Photonic Circuits at Visible and Near-IR Wavelengths (VISSION) — the EU Horizon grant;
   3. Monolithic Integration of Superconductors with Semiconductors on the Nitride GaN-NbN Platform — the national OPUS grant;
   4. GaN Melting Curve — in preparation for ESRF proposal on XRD in Laser Heated DAC.

- technology
   1. Vertically Integrated Technology Chain for Vertical GaN-on-GaN Power Electronics: from GaN Substrate to Intelligent Energy Bank — Techmatstrateg III National R&D Grant;
   2. GaN for Power Applications (GaN4AP) — the Horizon 2020 EU grant;
   3. Growth and Physics of hBN Crystals — in collaboration with scientists from Ukraine.

We hope they will result in valuable contributions recognized in the international scientific community.

5. Conclusions

The results of UNIPRESS research in the field of semiconductors have enabled the Institute to achieve a high international position. This is reflected by a high number of citations of published papers (e.g., in the TOP 2% ranking by Stanford University, there are 8 researchers from UNIPRESS), holding positions in important international organizations and institutions, being entrusted the organization of major scientific events, editing monographs and special editions of scientific journals. Thanks to its position, the Institute is a recipient of strategic national and international grants (including Horizon and ERC AdGr).

I would like to leave you a message that UNIPRESS, since its pre-history until today, has contributed to semiconductor physics in a visible way. It was due to *clever and devoted people* and the original own *scientific equipment*, enabling studies of semiconductors under pressure and distinguishing UNIPRESS from the others.

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