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45-years of Polish-Italian collaboration in the National Laboratory of Frascati

A. Kisiel[1]*

[1]*Instytut Fizyki im. Mariana Smoluchowskiego, Uniwersytet Jagielloński, 30-348 Kraków*

*e-mail: andrzej.kisiel@uj.edu.pl

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Opisano 45-lat polsko-włoskiej współpracy w Narodowym Laboratorium w Frascati w zakresie wykorzystania w badaniach półprzewodników promieniowania synchrotronowego z pierścienia akumulującego ADONE oraz elektronowo - pozytonowego zderzacza DAΦNE.

Abstract: 45-years of Polish-Italian collaboration in the National Laboratory of Frascati is presented and describes the semiconductor investigations with the use of the synchrotron radiation from the ADONE storage ring and the electron - positon collider DAΦNE.

The beginnings and development of scientific cooperation between the Institute of Physics of the Jagiellonian University, the Institute of Physics of the University of Rome "La Sapienza" and the National Laboratory of Frascati (LNF)[1], which is a part of the National Institute for Nuclear Physics (INFN)[2] have already been described in earlier publications[1–3]. On the occasion of the forty-fifth anniversary of this scientific cooperation, it is worth recalling the preceding events that played an important role.

In the spring of 1971, during the scientific scholarship at the Institute of Physics of the University of Rome "La Sapienza", the author of this article received a proposition from his supervisor, Professor F. Bassani, to undertake joint optical studies on semiconductors in the photon energy range of 10 – 100 eV. At that time, Professor F. Bassani was the head of the Solidi Roma Group, which conducted optical research using vacuum ultraviolet synchrotron radiation generated from 1.1 GeV synchrotron of the National Institute for Nuclear Physics in Frascati. Professor Bassani's proposal was a consequence of the planned extension of studies at the Department of Experimental Physics of the Institute of Physics, Jagiellonian University, toward the fundamental light reflection studies of semiconductors in the photon energy range above 6 eV, i.e. to the vacuum ultraviolet energy range.

In the years 1972-74, during visits to the Institute of Physics of the Jagiellonian University, members of the Solidi Roma Group, Professor G. Chiarotti, Dr A. Balzarotti and Dr M. Piacentini, the assumptions of the planned cooperation were formulated and written down. In January 1975, during a four-month research stay at the National Laboratory of Frascati (LNF), the author of the article joined the optical synchrotron studies in vacuum ultraviolet of the hydrogenated palladium thin films. Unfortunately, before the end of the research, the electron synchrotron was seriously damaged and was finally decomissioned in 1976. The only trace of these joint studies is the publication on the influence of hydrogenation on the electrical properties of palladium thin films[4]. Shortly after the synchrotron was damaged, as part of the PULS[3] program, the Solidi Roma Group began construction of the laboratory of synchrotron radiation using 1.5 GeV of the ADONE storage ring[5,6], also located at the National Institute for Nuclear Physics in Frascati.

[1] Laboratori Nazionali di Frascati (LNF), Frascati – National Laboratory of Frascati, Frascati

[2] Istituto Nazionale di Fisica Nucleare (INFN) in Frascati – National Institute for Nuclear Physics, Frascati

[3] Programma per Utilizzatione della Luce di Sincrotrone - Program of Utilization of Synchrotron Radiation

In December 1975, during a visit to the Institute of Physics JU, professor Bassani met with the Rector of the Jagiellonian University, professor M. Karaś, and encouraged him to prepare a direct collabo-ration agreement with the University of Rome I "La Sapienza". This agreement would allow the free exchange of employees and scientific ideas, as well as the financing of joint scientific research using synchrotron radiation. Professor Bassani had to demonstrate a great ability to convince, because just a few days after this conversation, Rector Professor M. Karaś sent intention letters to the President of the National Research Council (CNR[4]) and the President of the National Institute for Nuclear Physics (INFN). The direct collaboration agreement between the Jagellonian University and the University of Rome was finally negotiated and signed at the end of 1979. At that time, it only included joint research in the field of application of synchrotron radiation in solid state physics. Over the years, other fields of science were incorporated into this agreement and in this form has survived to this day. The signing of the agreement coincided with the commissioning of the PULS Laboratory in Frascati and the launching of the first synchrotron radiation beamline for the X-ray absorption spectroscopy measurements, which was led by Prof. S. Mobilio. A few months after the launch of this beamline, joint Polish-Italian studies began, which focused on the analysis of local coordination of atoms in $Cd_{1-x}Mn_xTe$ ternary compounds with the use of the Extended X-ray Absorption Fine Structure (EXAFS) analysis. Our collaborating group consisted of Prof. A. Balzarotti, Dr P. Letardi and Dr N. Motta from the Italian side, and Dr M. Czyżyk, the author of the article, Dr M. Podgórny and Dr M. Zimnal-Starnawska form the Polish side. The obtained experimental results could not be explained based on the previously existing models of the local structure in ternary semiconducting crystals. Therefore, we developed a new statistical model of the local structure of atoms that correctly described the results obtained for tetrahedrally ordered ternary compounds[7–9]. Our model, known as a "rigid cation model", has since been used and cited in publications by many authors (see in Fig. 1 - more than 560 times).

After the start of operation of the second X-ray beamline in the PWA[5] laboratory, led by Prof. E. Burattini and operated in hard X-ray energies up to 25 keV, new research opportunities in X-ray absorption spectroscopy (XAS) emerged in Frascati. Thanks to informal cooperation with the laboratories of growing crystals, i.e. group of Prof. A. Mycielski from the Institute of Physics of the Polish Academy of Sciences in Warsaw and group of Prof. W. Giriat from IVIC, Centro de Fisica in Caracas, high-quality crystals were obtained for research. Obtained II-VI semiconductor compo-unds, as well as their ternary semiconducting crystals and ternary alloy compounds with transition metals, were comprehensively studied in terms of the electronic structure of the conduction band using the X-ray Absorption Near Edge Structure (XANES) method. XANES analysis provided important information about the density of states in the conduction band of semiconductors (for instance in the paper[10,11]), which was also described in details in the review article[9]. In 1988, after the agreements on direct cooperation between the Jagiellonian University and the University of Trento as well the Rome University "Tor Vergata", XANES research was significantly intensified. Since then, close and effective collaboration has been established between the author and scientists from the University of Trento: professor G. Dalba, professor P. Fornasini and Dr F.Rocca. As a result, the time dedicated to measurements at the PWA X-ray beamline has increased, which allowed studying of many semiconductor materials[10,11].

The launch of the synchrotron beamline for the optical studies in vacuum ultraviolet (VUV), led by prof. M. Piacentini, made it possible to undertake joint research on the fundamental reflectivity of light for compounds from the II-VI group in the energy range of 10 – 30 eV. These studies complemented the fundamental reflectivity results obtained at the Institute of Physics of the Jagiellonian University which informed on the electronic transitions from the valence band to the conduction band for group II-VI compounds and their ternary alloy compo-unds with transition metals. Synchrotron studies revealed new important information about the electronic transitions from the highest occupied

[4] Consglio Nazionale delle Ricerche

[5] PWA - Programma Wiggler ADONE

atomic states to specific singular points in the conduction band of the studied materials[12–14].

The ADONE storage ring was permanently closed in 1994. Before this date a large group of researchers, presented in Table I, worked in the experimental studies of EXAFS, XANES and the fundamental reflectivity of light in the vacuum ultraviolet as well as in the field of theoretical analysis of the obtained experimental results.

Tab. I Polish and Italian collaborators in the PULS – ADONE program.

Affiliation	Collaborators
Institute of Physics, Jagellonian University	Dębowska D., Czyżyk M., Hołda A., Kisiel A., Konior J., Kozubski R., Łażewski J., Markowski R., Rodzik A., Podgórny M. & Zimnal-Starnawska M.
Institute of Physics of the Polish Academy of Sciences, Warszawa	Ławniczak-Jabłońska K. & Mycielski A.
Institute of Physics of the Military Technical Academy, Warszawa	Demianiuk M.
Istituto di Fisica Universita di Roma "Tor Vergata", Roma	Balzarotti A., Motta N. & Letardi P.
Istituto di Struttura della Materia del C.N.R., Frascati, and Dipartimento di Energetica, Universita di Roma "La Sapienza",	Antonangeli F., Lama F., Piacentini M. & Zema N.
Laboratori Nazionali di Frascati, Frascati	Boscerini F., Burattini E., Mobilio S. & Pascarelli S.
Istituto di Fisica, Universita degli Studi di Trento, Trento	Dalba G., Fornasini P.& Rocca F.
Physics Department, Lancaster University, Lancaster	Ali Dahr A-I. i & Lee P.M.
IVIC, Centro de Fisica, Caracas	Giriat W.

After the shutdown of the ADONE storage ring, the scientific collaboration with LNF continued. For the next several years, we theoretically processed the collected experimental data. During this period, the collaboration between the Institute of Physics of Jagiellonian University[6] and Diparti-mento di Energetica of Rome University[7] focused on resonant photo-emission study of ZnMnSe, CdFeTe and CdFeSe ternary compounds using the synchrotron radiation from ALADDIN at the Synchrotron Radiation Center in Wisconsin[8].

As part of this collaboration, ternary alloys of II-VI compounds with transition metals were studied using photoacoustic spectroscopy. The results of these studies were published in 5 scientific articles.

In 1998, theoretical work began on improving the statistical model of rigid cations, published by us in 1984. As a result of these studies, a statistical strained-tetrahedra model was developed and proposed by Dr B.V. Robouch, the author of the article and Prof. J. Konior[15,16]. In comparison to the model of rigid cations, the strained-tetrahedra model gave better fits to the

[6] The following people participated in the research: Dr Dębowska D., Prof. Kisiel A., Dr Rodzik A. & Dr Zimnal-Starnawska M.

[7] The following people participated in the research: Dr Felici A. C., Dr Lama F., Dr Mangiantini M., Prof. Papa T., prof. Piacentini M., & Dr Zema N.

[8] An Italian-American collaboration with the Synchrotron Radiation Center in Wisconsin was used.

experimental results obtained from the EXAFS analysis. The model was then adapted to the analysis of phonon spectra[9], which, like EXAFS analysis, well describes the local, preferential distribution of atoms in the crystal and expressed by the Site Occupation Preference (SOP) coefficients.

In the hall, after dismantling the ADONE storage ring, the electron-positron collider DAΦNE[4] was built and put into operation within four years (1998). DAΦNE was characterized by the particle energy of 510 MeV and the expected colossal beam current of 5 A. Three years later, in 2001, the DAΦNE-L Synchrotron Laboratory (led by professor E. Burattini), with three beamlines of synchrotron radiation, was launched. These beam-lines allowed for research in the field of: (1) soft X-ray radiation, (2) infrared radiation (FIR and MIR) (SINDBAD line) and (3) vacuum ultraviolet. The X-ray beamline is managed by Dr A. Balerna and the SINDBAD beamline is led by Dr M. Castelli Guidi.

At the DAΦNE-L Laboratory, research was funded based on awarded grants. As a result, the previously concluded direct cooperation agreements between the Jagiellonian University and the Universities of Rome and the University of Trento have lost their original, very important significance. The advantage of the new grant system was the possibility of greater participation in synchrotron research also by other Polish scientific institutions. The Polish users focused primarily on research with the use of infrared radiation beamline (SINDBAD) and soft X-ray beamline (XANES and EXAFS analysis).

After the launch of the DAΦNE-L Laboratory, Polish-Italian cooperation in LNF was resumed by the author of the article and Dr P. Zajdel from the Institute of Physics of the University of Silesia. Earlier, Dr P. Zajdel, as a PhD student at the Institute of Physics of the Jagiellonian University, in cooperation with PULS-ADONE, theoretically processed the experimental results of the XANES analysis for sulfides and selenides of transition metals. At the DAΦNE-L Laboratory, he partici-pated in middle infrared (MIR) research for hydrogenated CdTe and in XANES and EXAFS studies for chromium and antimony copper sulphides and in XANES research for rare earth intermetallic compounds[9]. Currently, habilitation Dr P. Zajdel and his team are preparing the next publication together with the DAΦNE-L Laboratory.

The author of the article convinced the group from the Institute of Physics of the University of Rzeszów, led by professor E. Szeregij, to undertake synchrotron studies of phonon spectra in far infrared (FIR) for a series of ternary and quaternary semiconductor compounds from groups II-VI. Valuated researchers from institutes in Russia also participated in the research[10]. The obtained phonon spectra were used in the strained-tetrahedra model to determine the atomic site occupation preference (SOP) in deformed elementary tetrahedrons of the studied ternary and quaternary semiconductor compounds.

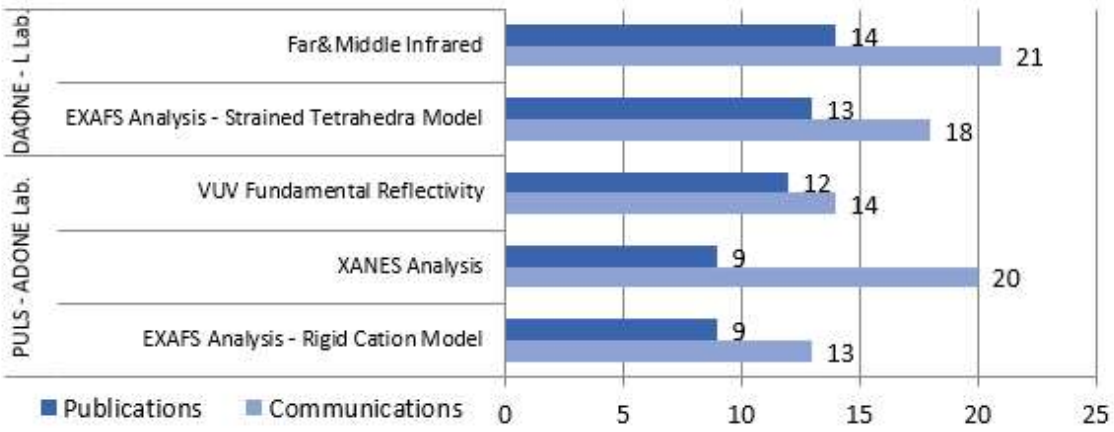

Fig. 1 Number of communications presented at conferences and number of published articles from completed research studies in the PULS-ADONE Laboratory and DAΦNE-L Synchrotron Laboratory.

[9] Authors: Dr Robouch B. V., prof. Kisiel A. & prof. Szeregij E. M.

[10] Prof Ivanov-Omskii, V. I., prof Kutcharenko I. & prof Vodopyanov L.

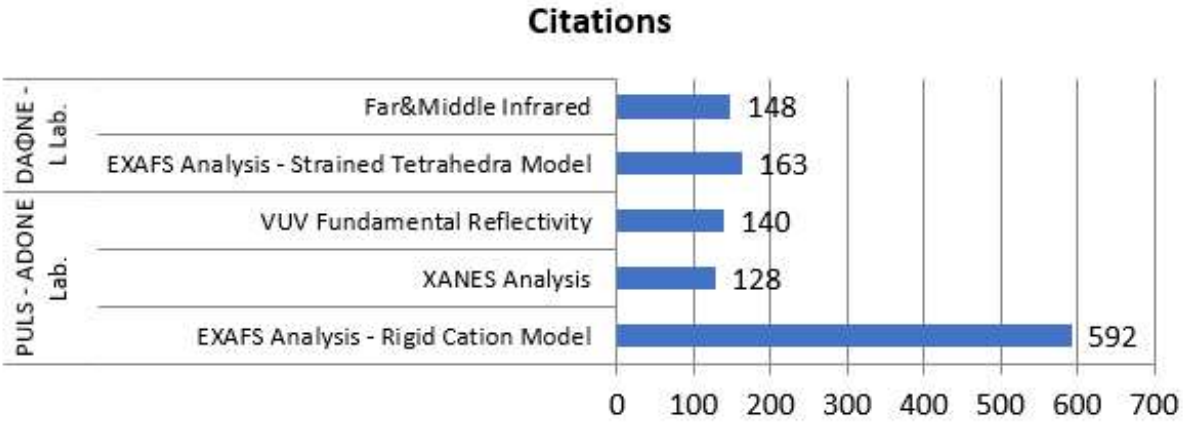

Fig. 2 The summarized citations of publications from the completed research programs.

Tab. II Cooperating with the Synchrotron Laboratory DAΦNE-L.

Affiliation	Collaborators
Synchrotron Laboratory DAΦNE-L Far infrared beamline	Arcangeletti, E. Calvani P., Castelli Guidi M. (principal), Marcelli A., Nucara A., Pastorino P., Piccinini M. & Sacchetti A.
Synchrotron Laboratory DAΦNE-L Soft X-ray beamline	Balerna A. (principal), Burattini E., Cinque G. & Robouch B.V. (earlier Associatione EURATOM-ENEA sulla Fusione, Centro Ricerche Frascati)
Institute of Physics, Jagiellonian University	Kisiel A., Konior J., Kocurek K. & Stanek J.
Institute of Physics, University of Rzeszów	Cebulski J., Hus R., Pociask M., Polit J. & Szeregii E.M. (principal)
Institute of Physics, University of Silesia.	Fijałkowski M., Szubka M., Talik E., Zajdel P.
Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow	Kwiatek W.M., Banaś A. & Podgórczyk M.
AGH University of Science and Technology in Cracow	Długosz E., Hasik M., Paluszkiewicz C. & Wesołucha

In 2002, Prof. W. M. Kwiatek from the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow joined the collaboration with the DAΦNE-L Laboratory. With his team, he conducted comprehensive research of biological materials using a synchrotron X-ray beamline and far infrared beamline. Further, groups from the Institute of Nuclear Physics PAS the Institute of Physics JU and the AGH University of Science and Technology participated in the research on biological materials.

Assessment of Polish-Italian cooperation during the period of using synchrotron radiation from the ADONE storage ring and the electron-positron collider DAΦNE seems to be very positive.

The results of joint scientific research have been presented at many international conferences and published in prestigious journals. Fig. 1 presents the effectiveness of completed synchrotron studies in the PULS-ADONE program and in the DAΦNE-L Laboratory. The dark blue bar shows the sum of communications presented at conferences and articles published in journals that do not record citations. The light blue bar gives the sum of publications in journals informing about the number of citations of an article. Figure 2 presents the summarized

citations of publications from the five completed research programs.

The analysis of Figure 1 and 2 confirms that the completed research programs are of a high scientific level. The statistical model of rigid cations, describing the local structure of tetrahedrally ordered ternary compounds crystals, has proved to be a highly valued and widely cited contribution. Moreover, the scientific value of the remaining completed research programs, assessed by citation factors, ranges from 10.6 to 14.2 citations per publication and therefore significantly exceeds the average citation factors for the most renowned English-language physics journals (except Nature).

The cooperation of Polish scientific institutions with the National Laboratory in Frascati lasts 45 years. Currently, the research groups of prof. W. M. Kwiatek and dr hab. P. Zajdel actively cooperate with the DAΦNE-L Synchrotron Laboratory. These groups are writing the current and future history of collaboration with the National Laboratory in Frascati.

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