Miloslav Frumar: In the footsteps of the chalcogenide semiconductors

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The year 2021 is the year of the 85th anniversary of the birth of Professor Miloslav Frumar the enthusiastic chemist who dedicated his whole professional life to the study of amorphous and glassy chalcogenides which are used in numerous applications like copying machines, laser printers, DVDs or memories.

Key words: Miloslav Frumar, amorphous chalcogenites, semiconductors.

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1 Introduction

Amorphous and glassy chalcogenides (AGCs) form a large group of noncrystalline compounds and alloys. They contain sulfur, and/or selenium and/or tellurium, and one or more of the other elements (As, Sb, Ge, Si, Al, Ga, In, Ag, Cu, etc.).

The discovery of the semiconducting properties of AGCs triggered intensive research and opened up new possibilities for their applications. In a short time, the high dark resistance of amorphous Se and its large decrease with illumination was applied in copying machines of Xerox type and later in laser printers.

The finding of large changes of resistivity of AGC in high electrical fields (threshold and memory switches) started a further boom of interest in AGC, promising construction of fast electrical switches and electrical nonvolatile memories with high density, high capacity, low switching voltage, and low price.

The AGCs doped with Ag⁺ ions have also important applications. They have an increased index of refraction, decreased solubility in inorganic etchants, and high ionic conductivity. They can be applied in high-resolution photoresists, optical IR gratings, optical waveguides, as ionic sensors, in solid and thin-film batteries, and in electrochemical nonvolatile memory elements.

The last boom of interest in amorphous chalcogenides (ACs) is connected with their fast phase changes and with their application for optical data storage that resulted in optical data disks (CD, DVD and Blue-ray). A further application in high-density nonvolatile phase-change and

Figure 1: Miloslav Frumar

multi-level electrical memories that supposedly will replace the so popular flash-type memories soon. These memories based on phase-change materials will be characterized by lower energy consumption, higher data density, and smaller size.

2 Childhood and study

Miloslav Frumar was born on 18th July 1936 as one of the twin boys in a small Czech village Horky nad Jizerou. His father Josef wanted to become a priest however, experiencing the horrors of the First World War, he interrupted his studies. When he returned from the Italian front, he did not believe in God anymore. Josef was a very respectful and well-read person despite the fact he was not educated. From 1938 to 1945, he was working as a mayor of the village and as a fire-fighter commander. Miloslav's mother Marie was working as a respected castle cook by the aristocratic families of Buquoy and Nostic before marriage. Both parents had a little farm with small fields and a couple of animals. They were both hard-working. Miloslav had two siblings - 5 years older sister Věra and twin brother Jindřich. Despite living during World War II they had a quite happy childhood. When they become older they worked with their parents in the fields.

Miloslav attended the primary school in Brodce nad Jizerou. He liked it so much. He was a very enquiring and gifted pupil. As he was very interested in natural science he started to study secondary school of chemistry in Kolín. Together with his schoolmates they undertook many geological expeditions in their surroundings and played amateur theatre. During his studies at secondary school, he fell in love with chemistry. It was love at first sight. He was such a keen chemist that he performed chemical experiments not only in school labs but also in his parents' backyard. These days he also started taking photos which became his lifelong hobby.

In the period 1955 – 1959 he attended the Prague Institute of Chemical Technology, his branch was Analytical chemistry. From 1959 to 1961 he studied Physical Chemistry at Mendeleev Institute of Chemical Technology in Moscow where he got the MSc diploma with a thesis on ZnS and CdS powders doped by sulphur and various metals. There was his first experience with the chemistry of semiconductors which enchanted him and become his lifelong passion.

3 Research and teaching career

In 1961 started his research and teaching career at Pardubice Institute of Chemical Technology which lasted almost 55 years. In 1965 he received his PhD degree with a thesis on luminescence and crystallographic defects of CdI₂ based powders and thin films. In 1981 he defended his DrSc thesis at Charles University in Prague. In 1983 he was appointed professor.

Professor Frumar has been a demanding university teacher who was indelibly written into students' minds especially to those who did not pass his exam several times. He has led several dozen diploma, candidate and doctoral theses. He has educated generations of excellent and qualified graduate engineers, many of whom have become recognized capacities in their field and successfully

work in the Czech Republic and abroad.

In 1982 he spent one year at the University of Edinburgh by Professor Owen where he dealt with the issue of photoinduced changes in amorphous chalcogenides and employing Raman spectroscopy to study changes of their structure during those processes. After 1989 he has lectured at many prestigious universities and research institutions around the world.

4 "Pardubice school" in the field of crystalline and amorphous semiconductors

Professor Frumar devoted his scientific research mostly to the field of Solid State Chemistry and Material Science. He is considered by the domestic and international scientific community as the founder of the so-called "Pardubice school", which is globally recognized especially in the field of crystalline and amorphous semiconductors. He and his co-workers contributed basically to the understanding of the mechanisms of photo-induced changes and the elucidation of the physico-chemical properties of chalcogenides.

These phenomena are the basis of several technological applications in the development and production of micro-optical circuits, optical gratings of waveguides and optically and electrically induced phase changes, suitable for the preparation of so-called non-volatile memories. A review of his research can be found in [1].

During his professional career, he has worked in many professional advisory bodies, scientific councils, the Accreditation Commission, and on the boards of international journals and conferences.

5 The conference series "Solid State Chemistry"

The conference series „Solid State Chemistry“ was founded by professor Frumar as a symposium for scientists working in the field of solid-state chemistry, chemistry and physics of novel inorganic materials in 1986. New concepts, approaches, fundamental understanding, as well as the application aspects of inorganic materials have been discussed. The conference has become a truly international event with a worldwide geographical distribution of participants.

6 Czech and international awards

He also participated in the management and development of Pardubice university workplaces - the Department of Inorganic Chemistry of today's Faculty of Chemical Technology, the Joint Laboratory of Solid

Figure 2: Order of Academic Palms. The Ordre des Palmes académiques (French for "Order of Academic Palms") is a national order bestowed by the French Republic on distinguished academics and teachers and for valuable service to universities, education and science [2]. Originally established in 1808 by Emperor Napoleon as a decoration to honour eminent members of the University of Paris, it was changed into its current form as an order of merit on 4 October 1955 by President René Coty, making it one of the oldest civil honours bestowed by the French Republic [3].

State Chemistry of the Institute of Chemical Technology with the Czechoslovak Academy of Sciences and the Research Centers "Perspective Inorganic Materials and Compounds". For his scientific work, innovative results and published work, which significantly contributed to and influenced the development of basic research and potential applications, he received several Czech and international awards, such as the State Prize for Research in Amorphous Semiconductor Chemistry (1985) and Medal of Czech Scientific and Technical Society (1994), S. R. Ovshinsky Prize (2006), Hanuš Medal (2006), or appointment as a Knight of the Order of the Academic Palm of the French Government in 2002, Medal of Merit for the University of Pardubice in 2004 or the Award of the Learned Society of the Czech Republic in 2007. He was a recognized figure in Czech science.

He is an author or co-author of more than 300 papers and more than 20 patents.

Professor Miloslav Frumar will forever remain inscribed in the chronicle of the life of the University of Pardubice and its Faculty of Chemical Technology not only as an extraordinary personality of our academic life, a prominent scientist and a great, demanding, university teacher, but also as a fair, enlightened and honest person and dear colleague. He had an extraordinary relationship with many scientific colleagues from all over the world which was based not only on the professional level but also on a friendly one. They describe him as a wonderful human being and one of the best and brightest people they ever met, a man who always treated people with care and kindness and was full of positive energy, whose spirit never aged.

Throughout his life, he was interested not only in chem-

ical bonds but also in family ones. He was not only a brilliant chemist but also a marvellous father and grandfather.

References

- (1) Frumar, M.; Wágner, T.; Shimakawa, K.; Frumarova, B. In *Nanomaterials and Nanoarchitectures (A complex review of current hot topics and their applications)*; Springer – Netherlands: 2015, pp 151–238, ISBN: 978-94-017-9937-9.
- (2) Hieronymussen, P. O., *Orders, medals, and decorations of Britain and Europe in colour*, 2d ed; Blandford Press ; distributed by Sterling Pub. Co: London : New York, N.Y, 1970, p 162, ISBN: 9780713704457.
- (3) Ordre des Palmes académiques, en, Page Version ID: 1034766604, 2021, https://en.wikipedia.org/wiki/Ordre_des_Palmes_acad%C3%A9miques (accessed 10/11/2021).