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PROFESSOR JAN CZOCHRALSKI - DISTINGUISHED SCIENTIST AND INVENTOR

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Prof. J. Czochralski was born in Kcynia in Central Poland in 1885 and died 50 years ago in Poznan. In 1904 he moved to Berlin where he attended university courses in chemistry. He obtaining an engineering degree started to work as assistant to famous scholar Wichard von Moellendorf. Right from the beginning of his career he took interest in what can be now described as physical metallurgy. He pioneered research in plastic deformation of single crystals and contributed to crystallography. In 1929 he received an honorary degree from Warsaw University of Technology (WUT) and a year later accepted professorship position with the Faculty of Chemistry. Soon after he organized Department and later Institute of Metallurgy and Metal Science. His major interest continued to be with processing of metals and in particular he researched crystallization. Research in this field resulted in invention of the famous Czochralski method for growing large single crystals, which paved the way to modern technologies of electronic materials. He also studied elastic, plastic properties of metals and their corrosion resistance. Professor J. Czochralski was also a pioneer in what is now described as technology transfer. His inventions match excellence of scientific achievements. Obtained a number of patents in Germany and Poland.

Professor J. Czochralski lived in turbulent times. Holding two citizenships, Polish and German, and acting successfully both within business and academia he made a great number of fans and enemies. Before the World War II, he was involved in much publicized legal disputes with a staff member from WUT. During the war he continued with research in the unit approved by the German administration. This has been judged unfair by a group of professors who made him to retrieve from the University live. He continued with his inventions in Kcynia, his birthplace.

The scientific foundations build at WUT by Czochralski proved to be resistant to historical misfortunes. Faculty of Materials Science and Technology, the leading materials research institution in Poland, is proudly continuing tradition of metallurgy and metal science at WUT. This Faculty is also one of the leaders in technology transfer taking fully with the reach achievements of its famous founder.

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1. INTRODUCTION

The year 2003 is 50 anniversary of the death of Professor Jan Czochralski whose photograph in shown in Fig.1. He was on eminent scientist of who

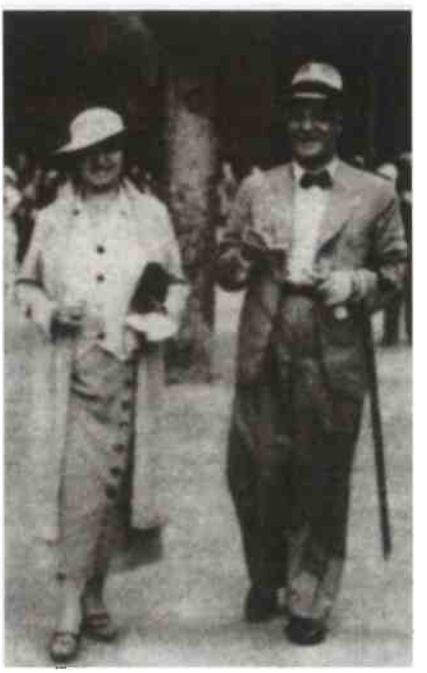

Fig.1. Photograph of Czochralski taken in 1930.

spent a great deal of his scientific career in Germany before finally settling down at the WUT. He was a very active researcher and very much involved in societal functions, including participation in business activity. During His life, He was repeatedly exposed to public scrutiny and frequently accused for wrongdoing. Some of these accusations can be explained in terms of His pioneering ventures into what now can be called technology transfer and His entrepreneurial spirit. Unfortunately to large degree He also paid the price for living in turbulent times marked by occupation of Poland, His native country, by German army. He spent occupation years in Warsaw and this by itself can be viewed as risky decision for someone who had so many international connections (He was married to pianist Marguerita Haase of Dutch extraction). After the war He has been judged acting against the unwritten rules of society resisting the occupation. Although no sentenced, He was forced to spend the rest of His live in exclusion.

As 50 years time has passed from the sad moment of His death and almost 60 from the end of the war it is almost impossible and certainly unwise to go again over the issue of Him allegedly breaking the code of conduct in oppressed society. However, with the passing time it is more and more rational to look upon His scientific achievements and His industrial activity. The reason for that is simply the fact that these achievements proved to be important for science and technology and could be good inspiration for new generations of scientists in Poland and in Europe. With this in mind, let us review works of Professor J. Czochralski in research and His contribution to the industry.

The life and achievements of Professor J. Czochralski have been commented in a number of essays and scientific papers (an excellent review is given in particular by Professor P.E.Tomaszewski [1], the readers could find some additional information in (very personal and subjective) memoirs of Prof. M. Smialowski [2]. What makes this particle attempt to review His activity different from the other is the affiliation of the authors. Professor S. Mankowski is the current Rector of Warsaw University of Technology – work place for Czochralski for over 15 years. On the other hand Professor K. J. Kurzydlowski is former Dean of Faculty of Materials Science and Engineering at this University, the institution proudly linking its roots to the Institute directed by J. Czochralski prior the second World War. As results the present text is meant not only to provide the readers with commentary and data but also to reflect upon J. Czochralski perception by the University in the past and now.

2. SCIENTIFIC EXCELLENCE

The major field of research interest for J. Czochralski was what now can be described as physical metallurgy. He approached this field with the background in chemistry studied in an extramural way at Charlottenburg near Berlin. At the beginning He was involved in what are now standard metallographic procedures leading to revealing details of the microstructure of materials. It should be noted, however, that even nowadays, these procedures are not trivial in their implementation and the progress made in this field over last 90 years is not impressive. Dealing with these not very exciting problems He still was able to show a lot of creativity. He suggested to combine metallographic observations with measurements of conductivity (Fig.2) and proposed a method for quantifying content of non-metallic inclusions from measurements carried out on sections of metals explained in Fig.3. This method has been re-invented later a number of times and is now one of the pillars of modern stereology.

At a later stage of His scientific career He joined the laboratory founded by W. Moellendorff. At the laboratory He carried out research on substitutional

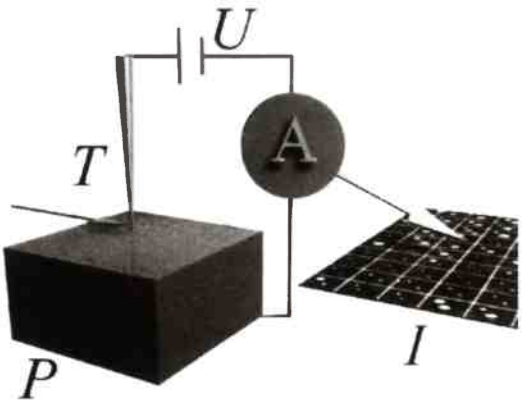

Fig.2. sketch of the experimental setup designed by Czochralski.

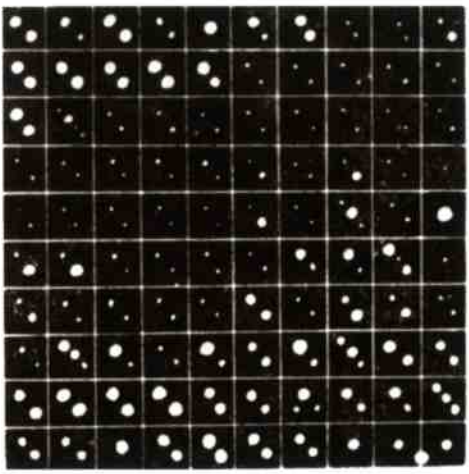

Fig. 3. A method for quantifying non-metallic inclusions suggested by Czochralski.

alloys, mainly containing Pb. He also researched aluminum alloys, which those days were very new in industrial practice.

Within the thematic constraints of the metallurgical laboratory J. Czochralski undertook research in the fields reaching far beyond straightforward development of new alloys for industrial applications. He studied equilibrium phase diagrams, recrystallization of deformed metals, properties of single crystals and X-ray methods of characterizing engineering materials. Within this interest in more fundamental issues He published in 1913 with W. Moellendorff a paper on „movement of atoms" during plastic deformation of single crystals (Fig.4).

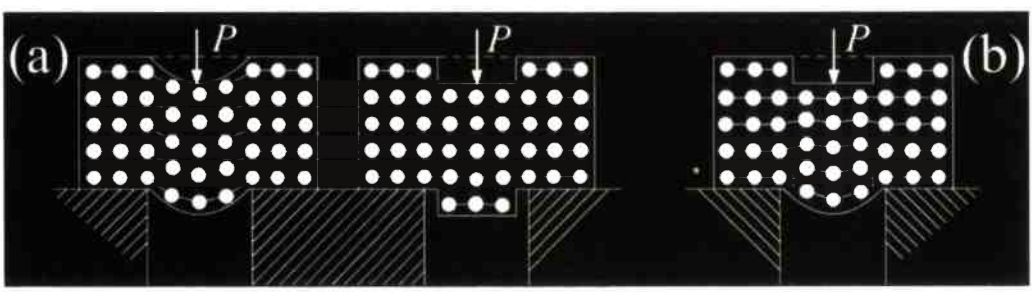

Fig.4. a) drawing from the original paper by Czochralski, b)famous model proposed by Taylor, Polanyi and Orowan.

The hypothesis put forward in this paper can be viewed as preceding the work of Polany, Taylor and Orowan who laid down foundations for theory of dislocations in crystals, which had a major impact on solid state physics and metallurgy and paved way to modern materials science.

One of the biggest achievements of J. Czochralski, which originated during His work in Germany, is related to studies of crystallization rate. In order to measure crystallization kinetics He invented a set-up in which a solid metal is grown by drawing a metallic fiber out of molten metal bath (Fig.5). A bit by chance it turned out that the fiber has single crystalline character and the same

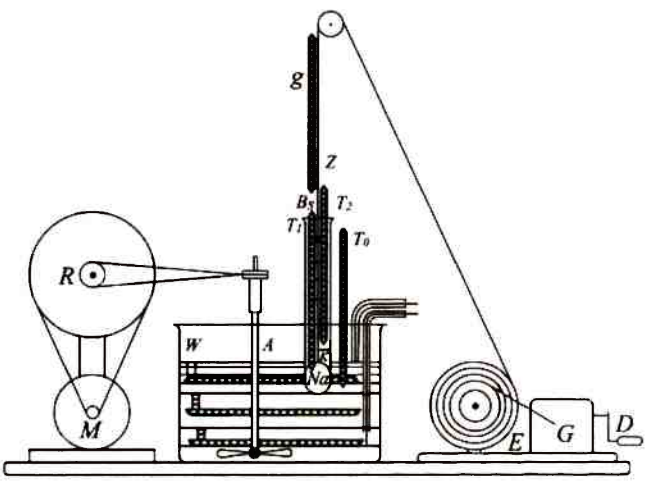

Fig. 5. Schematic explanation of the equipment used by Czochralski to study crystallization.

technique can be used not only for measuring crystallization rate but also for growing single crystals. At the time of His activity in this field such single crystals were needed for basic research. Later on they proved to be fundamental to the development of electronic materials. Large size silicon single crystals have been used for over 40 years now as a standard material in semiconductor industry all over the world.

The method of growing single crystals described by J. Czochralski in 1918 proved to be cheap and flexible for various modifications. It can be adopted for producing materials in magnetic field and with strictly controlled chemical composition. There is an anecdote treasured by His family that He discovered this powerful technology accidentally by immersing his pen into a pot with molten metal (tin), instant of dipping into an ink container. This could have happen to many scientists, but only few of them could understand the value of this event to development of science and technology of XX century.

Professor J. Czochralski invented famous method for growing single crystals in His experiments with crystallization. (Crystallization is the process of forming crystal solids out of the liquid phase of practical and theoretical importance). He studied also processes of re-crystallization, which is a thermally activated process-taking place in metals subjected to substantial plastic deformation. In this field He discovered such well known now phenomena as critical strain, recovery and grain size dependence on the amount of cold working. It should be noted that this particular area of physical metallurgy has been cultivated successfully at WUT long after His death by Professor W. M. Grabski. Prof. W. M. Grabski worked in the same institute as Prof. S.T. Jazwinski, student of Professor J. Czochralski, and one of the authors (KJK), student of Professor W. M. Grabski.

A number of the later works of Professor J. Czochralski dealt with properties of metals. He studied anisotropy of elastic and plastic properties of metals and their corrosion resistance. He also was a precursor of X-ray diffraction in studies of processes taking place in metals. Again, this line of research has never been neglected at WUT and is in the very main stream of activities of Materials Characterization Laboratory at the Faculty of Materials Science and Engineering.

One of the favorite research fields of Professor J. Czochralski, in addition to the studies on crystallization, was corrosion. His view on corrosion can found in the paper published in 1936 [6], where He wrote that "Investigations of the corrosion are hampered by the lack of standards" and that "in order to compare corrosion resistance one should use this property of materials which is mostly sensitive to this process". From that point of view He criticized commonly used methods related to the processes taking place at the outer surface, such as the measurements of the lost mass, analysis of corrosion products and visual examinations of the corroded surface. As an alternative He proposed experiments taking into account corrosion effect on mechanical properties of materials which reflect changes in the internal properties of materials. Reading these comments one can come to the conclusion that some of His ideas have been implemented only recently, and their wider use is still ahead of us.

Another topic undertaken Professor by J. Czochralski were thermal effects related to the annealing of heavily deformed metals. In this field He described the phenomenon of the recovery as a separate stage, taking place upon annealing of metals. Using a special calorimeter He measured the heat released during annealing of quenched aluminium alloys. In the papers published in Polish in 1936 [7], He phrased this phenomenon as "self improvement" which is very close to now wider accepted term "recovery".

He published almost 100 papers. It does not sound impressive nowadays, nevertheless their impact is inspiring even under currently used methods of measuring the influence of scientific papers. In the Chemical Abstracts, which dates back to 1907, one can find almost 15 000 documents referring to J. Czochralski (by name or the method)[1]. The latest of them at the moment of writing this paper is dated March, 2003 and the oldest, 1921. In more general index of Institute of Scientific Information there are 121 citations of his papers within the years 1974-March 2003, i.e. for the period of time starting 21 years from the year of His death. (Out of that number 34 citations appeared after 1996, 43 years from 1953).

Most of His papers were addressed to specialists, some of them to a more general audience interested in science and technology. Although this number is modest the present standards, their quality and impact on the modern science remain a challenging example to almost anyone. He certainly is one of the founders of modern materials science. He came to physical metallurgy with the background in chemistry and the great skills in physics. Exercised truly interdisciplinary research of metals which is now viewed as one the pillars of modern materials science and engineering.

It can be noted from the current perspective that the topics studied by J. Czochralski almost a century ago are still to large degree researched in various laboratories worldwide. This certainly applies to the phenomena of recovery in deformed metals, combined effect of environment and plastic deformation on corrosion resistance and famous studies of crystallization rate. What is new, however, that nowadays these subject are investigated by much more sophisticated techniques and with the used of equipment undreamed of in His age. He carried out experiments with very modest experimental setup, which is exemplified in Fig.2. Most of these pieces of scientific equipment were designed by Him and build according to His ideas. In some of them one can see resemblance to the very modern tools, such as AFM, which operates with much, much higher precision but in the way similar to the electro-probe shown in Fig.2.

The fact that J. Czochralski was able to develop new ideas, some of them of great importance to of world science and technology, by using relatively simple experimental gears is a prove of His powerful mind. It also confirms His devotion to the science, which had taken Him out from parents house before finishing high school, and iron consequence in pursuit of unknown.

With this in mind it is desirable to spend a moment to reflect upon current trends and positions assumed by modern researchers. It is certainly impossible to start today experiments with the equipment used by J. Czochralski. Howe-

[1] 14 815 as of March 2003, none of them with Czochralski among authors

ver, in the complex modern laboratory environment there is even more need for thinking, devotion and consequence.

3. INDUSTRIAL INNOVATIONS

Professor J. Czochralski was also a pioneer in what is now described as technology transfer. He started education and to large degree continued through the positions held with a number of small and large companies. At the age of 1916, still in Prussian Ocuppation, He worked as assistant to chemists. Soon after moving to Germany he started to work in Pharmacy and after receiving an engineering degree he joined an AEG copper refinery as production manager. He worked with this company for 10 years. Later, working with Metal Laboratory of Metallgeselschaft He developed and patented new economic alloy for bearing production. Another alloy invented by J. Czochralski was special alloy for railway applications, known as B-metal. The patent for its production was purchased by USA. In Poland this alloy were used by National Railways Company since 1932.

In 1919 He contributed to the foundation of German Metallurgical Society. His idea was to foster better relationship between the research institutions and the companies. As a President of the Society in 1927 J. Czochralski organized an exhibition of engineering materials in Berlin, bringing there not only large number of scientists but first of all industrialists. As the President of the Society He contributed to over 470 communications totaling to over 2100 pages.

His inventions match excellence of scientific achievements. Professor J. Czochralski obtained a number of patents in Germany and Poland for new alloys and testing methods. In year 1923 during a visit to the United States He met with Henry Ford. Nowadays this certainly can be viewed as the meeting of the leading personalities of technology in XX century. His views on the needs of industry can be found in the paper published in 1929 in the Journal Technology Review [4]. In the text entitled "The drive to technology" He underlined the role of science and fundamental research for development of industry. He also emphasized the role of innovations, competition on international markets and expressed a stiff opposition to protectionism. Characteristically, in this paper He referred a number of times to European context in addition to the comments on the Polish industry. In another paper published in 1929 [5] Professor J. Czochralski commented on the role of materials science. Within this context he highlighted the need for materials research, control and testing urging the industry and science community to use quantitative specifications as fundamental to developing new materials and their wider applica-

tions. He also writes in this essay that "development of technology can only maintain due to fluctuations of brain wave currents". At the same time He underscored the harmony between the research directions and the needs of industry.

Professor J. Czochralski has brought to the materials science not only deep interest in fundamental phenomena but also interest in applications and economics. One of His great hopes was to produce advanced materials at a possible low cost. Judging from the present situation in Poland with lengthy debates about proportions between applied and fundamental research and the ways of assisting Polish industry with innovative products and technologies one can say that He found brilliantly simple answer to these dilemma. He simply carried out all these efforts simultaneously, doing fundamental research in physical metallurgy, applying results in developing new materials and patenting them for the use in industry. Perhaps what we can learn from His example is that personality counts more that outcome of long-lasting disputes.

4. WAR AND THE POST-WAR TIMES

Professor J. Czochralski was born in Wielkopolska, however, His scientific career developed in Germany who granted Him higher education and challenging employment opportunity. During the 24 years spent in Germany (1904-1928) He actively contributed to the life of German metal science community, among others as one of founders and Chairman of the Metallurgical Society. He also obtained a number of patents, some of them of military importance.

Contacted by the President Moscicki he decided to interrupt His German career and in the age of 43 moved to Poland with His family. He rejected also an attractive offer of position with Ford Co. in the USA. In 1929 He was nominated professor of WUT and this from legal point of view re-established His Polish citizenship. In a sense from that point on. He had double citizenship – German and Polish. With the growing tensions in Europe, having Germany and Poland on the collision course, it certainly did not help Him to build good relationship with opponents at the University, one of who accused Him of deliberate acting against interest of Polish army. He was eventually cleared of this accusation in 1936 by court. However, the matter surfaced again in 1939 when from German occupation authorities the permission open Department of Material Research within the premises of the University closed by the same office.

After the end of WWII Professor J. Czochralski was detained and the State Protection Agency (UB) checked His wartime activity. After 4 months in custody He was cleared of all charges and released. Despite that, His request

for re-establishing as professor at the University has been flatly rejected in a procedure, which from viewpoint of current standard was highly flawed. He spent rest of life in Kcynia, His birthplace. Professor was banned from the University partly due the action of His former colleagues, some of whom before the War had been in an opened conflict with Him. This mere fact again in the modern days provokes mixed feelings. However, one should avoid re-examining His case applying nowadays procedure and under contemporary public opinion on science, cooperation and in particular on German-Polish relationships. As He had as many opponents as friends, attempts have been made to revoke the University position expressed in Senate rejection of His appeal in 1945. The last time this case was discussed at the Senate meeting in nineties and the motion has been passed which fully confirms that scientific achievements of Professor Czochralski are an integral part of the proud University heritage. At the same time it has been declared that with the time passing by the University has no intention for further considerations of legal aspects of the decision made in 1945.

Professor J. Czochralski in 1945 was deprived job position with the University, but He never ceased to be Its Professor. The most vivid prove for that statement is given by the activity of His students and the development of metal science at WUT. The Department of Physical Metallurgy was moved after the War from the Faculty of Chemistry to Faculty of Mechanical Engineering and directed by S.T. Jazwinski who worked with J. Czochralski. The Department was transformed to the Institute of Materials Science and Engineering in 1978 by Professor S.Wojciechowski and later into Faculty of Materials Science and Engineering.

The Faculty of Materials Science and Engineering is now one of the most dynamically developing units of the Warsaw University of Technology (more information about the Department can be found on the website under the following address *www.inmat.pw.edu.pl*). It offers education to over 350 Master Degree and 50 PhD students. The State Committee for Scientific Research ranks the Faculty number 1 in Poland. Active research fields include nanomaterials, metals, ceramics, composites, magnets and biomaterials. Among them one can find some research projects which address the same problems as studied by J. Czochralski. In particular these are studies of non-metallic inclusions in metallic materials. In this field currently available tools can be used to determine chemical composition of such inclusions at microscopic and nano-level (Fig.6).

As in the past in the Institute directed by Professor J. Czochralski, much of the efforts are directed to the cooperation with the Polish industry. The Faculty has also remarkable international cooperation a large part of which is related to European Union and Germany in particular. It can be concluded that 75 years

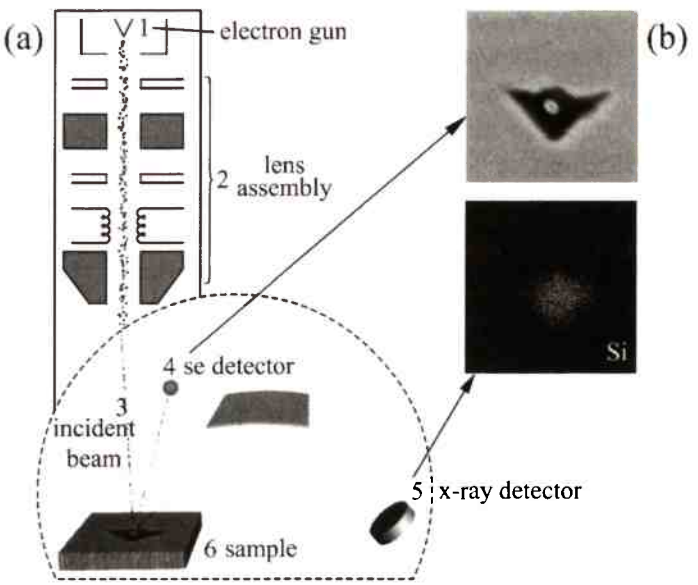

Fig.6. Modern implementation of the methods used by Czochralski in His studies of non-metallic inclusions: a) schematic explanation of SEM; b) the reslult of X-ray micro-analysis.

from the moment when Professor J. Czochralski entered WUT, His ideas fully flourish in a new environment created in more permissible times.

5. CONCLUDING REMARKS

The authors of this short essay hope that the readers will share with them the view that Professor J. Czochralski was one of the outstanding personalities of XX century. History confirms that He was distinguished scientist and inventor. It should be also underlined that He had very modern views on the role of engineering sciences. Many of His research was driven by the needs of industry and the search for new technologies. Despite that He was able to maintain the highest possible standard of methodical pursue and proved possibility of contributing to science by developing technology.

Professor Czochralski lived in turbulent years for Europe and in view of many He paid unfair price for His systematic and pragmatic position. The fifty years after His death proved the value of His research to world science and technology. The current development at Faculty of Materials Science demonstrates also His contribution to Warsaw University of Technology who proudly lists Him among Its greatest scientists.

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