Tribute to Ulrich Bonse: his doctoral thesis on x-ray imaging of strain fields around dislocations in germanium single crystals

Bert Müller*[a,b]

[a]Biomaterials Science Center, Department of Biomedical Engineering, University of Basel, 4123 Allschwil, Switzerland; [b]Biomaterials Science Center, Department of Clinical Research, University Hospital Basel, 4031 Basel, Switzerland

ABSTRACT

Born in 1928, the German physicist Ulrich Bonse had a challenging time as pupil before, during, and after World War II. For example, in January 1944 he had to join an anti-aircraft unit to protect a canal lock near the city of Münster from bomb attacks. Starting in 1949, he studied physics at the University of Münster, Germany. Under the supervision of Eugen Kappler, Ulrich Bonse developed an X-ray-based method to experimentally determine strain fields of defects in silicon and germanium single crystalline materials - a timely research topic closely related to the invention of the bipolar transistor. His awarded doctoral thesis was internationally recognized. Thus, he was invited to the United States in 1961 and became guest professor at Cornell from 1963 to 1965, where he developed - together Michael Hard - the first X-ray interferometer, a breakthrough for which he was awarded the Physics Prize by the German Physical Society. It is therefore no surprise that in 1970 Ulrich Bonse became Professor in Physics and the Founding Director of X-ray and neutron imaging research on the Ångstrom scale at the University of Dortmund, Germany.

Keywords: Dislocation, silicon, germanium, strain field, X-ray double-crystal method, etching pits

1. CHILDHOOD AND YOUTH

Ulrich Bonse was born in Münster, Westphalia, Germany on September 25, 1928 [1]. He had three siblings, an eight-year older brother, a six-year older sister, and a four-year older sister. His family lived in a single-family home with a big garden in a suburban residential neighborhood. After four years in primary school, Ulrich Bonse joined the Paulinum humanistic Gymnasium in 1939. The curriculum included foreign languages, mathematics, physics, chemistry, biology, history, *etc.* as well as physical training. Sports were a focal point of the Nazi ideology to gain strenuous serviceable soldiers.

Over the course of the war, his studies became more and more difficult. After bombs destroyed the Paulinum building, Ulrich Bonse attended school in the Schiller Gymnasium. In January 1944, however, he, as most of the other boys of his age, served in an anti-aircraft team [1]. During this time, attending school was only partly possible. Some formal lessons were given in auxiliary rooms of the air defense position.

Following the advice of his father, Ulrich Bonse moved to his aunt in the surroundings of Münster at the beginning of 1945 and participated in lessons of the Hittorf Gymnasium. Instead of Latin and Greek, he had to attend English courses. To close the large knowledge gap, he took private lessons as well. After the war, he continued with the school but also worked hard on his Aunt's farm. At that time, he seriously thought about becoming a farmer. Finally, his brother, who originally wanted to study physics but had lost nine years of his life because of the war, took the job [1].

In August 1946, Ulrich Bonse returned to the Paulinum humanistic Gymnasium in Münster. His English knowledge from the Hittorf Gymnasium proved to be a stroke of luck in 1948, when he was the only pupil selected for an exchange with Bryanston School in Blandford (Dorset), UK [1]. He collected extremely valuable experiences during this six-month period abroad. In February 1949, Ulrich Bonse successfully finished his schooling at the Gymnasium.

*bert.mueller@unibas.ch; phone +41 61 207 5430; www.bmc.unibas.ch

Developments in X-Ray Tomography XV, edited by Bert Müller, Ge Wang,
Proc. of SPIE Vol. 13152, 131521F · © 2024 SPIE
0277-786X · doi: 10.1117/12.3028587

2. STUDIES OF PHYSICS

Ulrich Bonse had broad interests included theology, philosophy, astronomy, physics, and agriculture, making the selection of his studies challenging [1]. On the certificate of qualification for university matriculation, he wrote *natural sciences*. His language and religion teachers were disappointed that he had not pursued a more traditional academic path because his grades in these subjects were excellent as well.

Ulrich Bonse's specific interest in experimental physics was influenced by his older brother, who had tolerated the presence of Ulrich during electricity experiments in the basement of their house. Their father established a wood workshop with electrical machines for do-it-yourself repairs and creating Christmas presents [1]. This facility was especially important close to the end of World War II because of shortages of almost everything.

Before and during his studies, Ulrich Bonse improved his manual and technical skills performing internships in companies for metal processing as well as for measurement and control technology. These experiences were formative for his studies of physics.

At the end of 1949, Ulrich Bonse started studying physics in Münster. In the nomenclature of the present university system, we would say that he passed his bachelor in physics in November 1953 and the master in physics in November 1955 [1]. Subsequently, under the supervision of Eugen Kappler, Ulrich Bonse became a doctoral student. He studied crystalline defects in germanium and silicon crystals, a subject that gained interest because of the discovery of the bipolar transistor.

3. X-RAY-BASED IMAGING OF THE STRAIN FIELD OF INDIVIDUAL DISLOCATIONS IN GERMANIUM SINGLE CRYSTALS

During his doctoral thesis Ulrich Bonse developed a method based on a double-crystal X-ray spectrometer [2]. His X-ray source could generate an almost parallel X-ray beam. It was reflected at a nearly ideal reference crystal and then at the crystal planes of the crystal of interest. The rotation of the second crystal by an angle as small as 20 μrad led to intensity drops by 50%, which was detected by X-ray film [2]. This highly sensible double-crystal arrangement allowed investigating the strain fields of single dislocations within the crystal of interest.

U. Bonse, with the support of his supervisor, performed such experiments for many sets of crystal planes. For example, in (711) reflection, spots were hardly detected on the X-ray film, whereas in (171) reflection, many spots could be detected [2]. Such features were also present on optical micrographs after surface etching. Therefore, the arrangement of spots on the X-ray film could be related to the position of the etching pits, *i.e.* the detected dislocations. The availability of a comprehensive dataset allowed for the determination of the Burgers vectors in <011> directions of the germanium single crystal [2].

The thesis result was surprising, because individual dislocations, often related to atomic distances, were detected even with a magnification of just 28:1. The angular sensitivity of the developed method was so high that the dislocation-induced strain fields with micrometer extension were clearly visible and correlated to the features on optical micrographs after surface etching.

The discovery of U. Bonse, however, had further impact, since the X-ray setup enabled the identification of dislocations not found using etching. The etch features became only large enough for dislocations with certain angles to the crystal surface. Because the double-crystal spectrometer does not rely on the etching procedure, Ulrich Bonse had discovered a non-destructive method for the detection of dislocations in single-crystalline materials.

The University of Münster recognized the value of this scientific work with the "Promotionspreis" award in 1958. The related publications (in German) were also well-received by the international community. As a result, J.B. Newkirk (Cornell University Ithaca, New York) invited Ulrich Bonse to the conference "Direct observation of imperfections in crystals", which took place in St. Louis, Missouri, in March 1961. He formed personal relationships with leading scientists in his field and was spontaneously invited to visit the Bell Telephone and Electronics Lab in Bayside, New York and the

Department of Physics at the University of Virginia, in Charlottesville, Virginia. Ulrich Bonse recognized the importance of his English knowledge for example for preparing the related paper [1].

4. MY FIRST REMINISCENCE OF ULRICH BONSE

Born in East Germany, I had restricted access to scientific and other literature. The German Physical Society's "Physikalische Blätter" was subject to these restrictions and only thanks to the generous sponsoring of a scientist from West Germany could I read this popular scientific journal in a more or less regular fashion. Therefore, I studied the articles with special attention. This habit has not changed after the unification of Germany and, thus, I also read Bonse's 1997 article [3] with the highest interest. In that year, Ulrich Bonse established the conference series "Developments in X-ray Tomography".

The article of U. Bonse initiated my interest in X-ray tomography. I was especially impressed by his description of phase tomography and the related "advantage factor". This term describes the potential sensitivity gain using phase contrast instead of the absorption contrast. It is at least one hundred times larger for all elements of the periodic table. Even at a time when I had not yet dealt with medical research, I recognized that for the elements present within the human body this advantage factor is several thousand. Therefore, one could reasonably expect that X-ray-based phase contrast is much better suited to image the physically soft tissue of the human body than the established absorption-contrast computed tomography.

5. ULRICH BONSE – A ROLE MODEL

5.1 Outstanding scientist

We know Ulrich Bonse as an outstanding expert in the fields of X-ray physics and the development of related experimental methods. With limited financial and technical means but with well-developed skills as well as sound manual and technical experience, he advanced X-ray methods to an unexpectedly high level. His insightful interpretation of the experimental data was striking.

5.2 Family and research

It is impressive that Ulrich Bonse together with his wife raised seven children born between 1959 and 1970. This family work coincided with successful scientific work *inter alia* two years in the United States. As guest professor at Cornell from 1963 to 1965, he developed - together with Michael Hard - the first X-ray interferometer, a development recognized by the German Physical Society's Physics Prize.

5.3 University professor

From August 1969 Ulrich Bonse was a highly appreciated teacher. Starting in September 1970, he created a very successful school of X-ray sciences at the University of Dortmund, Germany. He enjoyed working with young scientists and always acknowledged the work of his 32 doctoral students. U. Bonse published a concise list of important aspects of the profession of university professor, see Appendix of ref. [1] (in German). It is extremely difficult to translate this code of practice from German to English. It is written for university professors but also holds (partially) valid for students. It reads:

1. ***High-level identification with the responsibilities*** [of the profession],
   i.e. with the university and its tasks in teaching and research
2. ***Scientific approach in both research AND teaching***
   on an international level with the *minimal* requirement that the topic not yet have been addressed,
   but *better* that it provides essential gain for the human future
3. ***"Fun" in the scientific result itself***,
   which includes *e.g.* joy in the success of others, always the best
   should be appointed

4. ***"Market" of science***
   Competition; obligation to partially self-finance *via* third-party funding

5. ***Objectivity***
   For example, avoiding personal advantage, prestige; decision-making based solely on facts instead of pecking order.

6. ***Fundamental equality among all colleagues***
   acknowledging inherent differences

7. ***"Privileges"*** ("freedom") are always coupled with ***self-obligation***
   e.g., freedom to choose the topic of research, flexible working hours, *etc.*, require critical ***self-monitoring*** regarding the achievement of agreed goals.
   "Inner guidance"—*i.e.*, acting in the spirit of goals, not just adhering to the letter of the law (Spare the boss the dreary task of external control and improve the workplace climate).

8. ***Proper motivation of staff***
   e.g. beyond payment involving them in decisions and ***allowing them to contribute***;
   when possible delegate and allow to work with personal responsibility, provide ***justification*** and explanation of decisions.
   This applies—*mutatis mutandis*—to ***students*** as well.

6. PERSONAL REMARKS

It is my pleasure to honor Ulrich Bonse and his life's work. He became a model for many of us. I can understand the challenges related to growing up in a totalitarian regime. As a consequence, his CV is not straightforward and was interrupted by practical work at a farm and in industry, but nevertheless resulted in brilliant work in experimental physics. It was a joy to experience him at the synchrotron radiation facilities and as Conference Chair of "Developments in X-ray Tomography". Together with Ge Wang, it was my privilege to chair the last five conferences of this series. Let us keep in mind a great personality.

ACKNOWLEDGEMENT

The author gratefully acknowledges the linguistic support of Griffin Rodgers.

REFERENCES

[1] Bonse, U., Lebensläufe aus eigner Hand **13**, 4-35 (2008).
[2] Bonse, U., and Kappler, E., Zeitschrift für Naturforschung **13a**, 348-349 (1958).
[3] Bonse, U., "Röntgen-Mikrotomographie," Physikalische Blätter **53**(3), 211-214 (1997).