Relationship and Work with Georg Wahl

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I started my dissertation at the Technical University of Braunschweig, IOPW (Institut für Oberflächentechnik und Plasmatechnische Werkstoffentwicklung) at the start of the winter of 1996, and I had the good fortune that Georg was my boss. He was very talented in acquiring scientific projects, so almost all doctoral candidates led a project. They were paid by the projects and Georg usually transferred the control of the project budget to the project leader. Working in his group meant doing freely applied science with one's own budget! I am very grateful for this freedom, which was unusual at the university. I worked for projects from Europe (BriteEuRam, ESF/EFRE), German ministries (BMBF, BMWi), the VW-foundation, the Helmholtz association and industrial partners. Many times, when I was discussing the project tasks with Georg I was swamped with new ideas. Always he was open for any questions and scientific discussions. His inquisitiveness and wide knowledge were exceptional. However, sometimes I inconspicuously operated my own experiments in order to be safe against his pressure to test all his ideas. I am grateful that I finished my thesis under his leadership. With his support we founded the company PerCoTech AG in 2007, which I led until the end of 2013 (figure 1). Although he retired and I became a teacher, we were in continuous contact until February 2018.

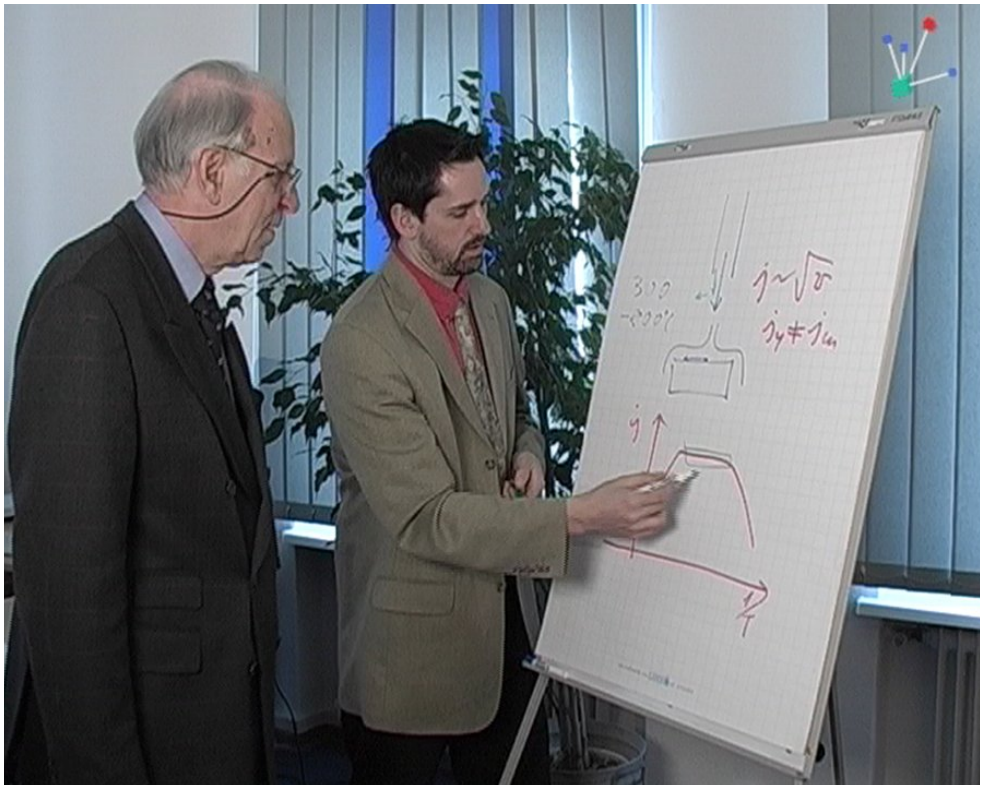

Figure 1: Meeting at PerCoTech in 2008 (Georg and Oliver Stadel)

He demonstrated his constitutional mobility besides science on several excursions (figure 2) of the institute and during many scientific visits. I cannot remember all the unbelievable situations with him, but I would like to choose the following: I was well

trained in eating fast, because I had three older brothers – we were always hungry. Nevertheless, Georg always was the first who finished any meal at any meeting. Only one time he failed, when he was decelerated by fishbones in the canteen of Moscow State University.

Figure 2: Excursion to the Harz mountains in 2003 (our secretary Birgit Stumpf, Georg and Igor Korsakov our Russian friend from the group of Andrey R. Kaul)

Scientific group of Georg Wahl

The research highlights and dissertations of the IOPW in the period of 1996 to 2005 were based on CVD. Materials were perovskites like superconductors [1, 2] or oxygen membranes [3]. Substrate surfaces for those coatings were often aluminium oxide and yttria stabilized zirconium oxide, and CVD of those compounds were investigated, too [4, 5]. Additionally, some dissertations were focused on CVD of silicon oxides [6,7], and a separate topic was CVD/CVI of boron nitride [8]. Arnold Nürnberg organized our everyday life at IOPW. I will keep him and other scientific colleagues like Inga Tröster, Ulrich Krause, Christian Metz and Klaus Nubian who did not finished their dissertations at IOPW in good memory.

MOCVD of YBCO and buffers on metal tapes

My work at the university and at PerCoTech was focused on thermal MOCVD of multi-component oxide systems. Georg, several colleagues (Ruslan Muydinov, Jürgen Schmidt, Sergej Samoylenkov, Hartmut Keune and others) and I developed new evaporators and reactor designs, which enabled coatings of YBCO and buffers in a continuous process on metal tapes.

Evaporator: Based on a former version invented by Lutz Klippe and Georg, we constructed an evaporator which was based on a solution, but we avoided any solvent vapour in the reaction chamber. In the first zone (70-100°C at 15 mbar) was the solvent, and in the second zone (300°C at 5-8 mbar) the precursors were

evaporated [9]. A ring of a heat-resistant metal spring filled with a fibre was used for the transport of the solution. In the last evaporator version, which had a vertical design, the spring was dipped into the solution at the bottom. Between the two heated zones two flow resistances allowed the separation of the solvent vapour and precursor vapour. Between the two flow resistances the solvent drying gas flow was introduced. The inlet of another gas flow was at the beginning of the precursor evaporation zone and transported the precursor vapour into the deposition chamber. The solvent was separated and recycled in a cooling trap. It was water free m-xylene, which made a high precursor concentration possible. This evaporator enabled the drying of 100 ml of solution per hour and the evaporation of 7 gram per hour of a Y-, Ba- and Cu-tmhd-precursor mixture.

Gas distribution: The gas distribution system [10] fulfilled the following demands: high gas flows, equal distribution to every outlet and a homogenous temperature of 270-280°C at a distance of about 10 mm to the entrance of the hot wall reactor. For high gas flows in combination with equal distribution we chose to compromise with a pressure decrease of about 2 millibars at geometrically (exact) identical lines to each outlet. Figure 3 shows the lines for the coaxial gas (top) and the precursor gas (bottom). Aluminium is a material with a high thermal conductance and with low reactivity with tmhd-precursors. Aluminium was used for the gas distribution and for the heat transfer between the heaters and the standard steel tubes, which connected the evaporator and the deposition chamber. A coaxial gas flow around the precursor gas flow avoided any premature reaction of precursors at the reactor entrance. The inner precursor nozzle was protected by a silver tube, which was conducting the coaxial gas. A silver sheet was fixed onto the aluminium plate, in order to reflect the radiation from the hot wall reactor.

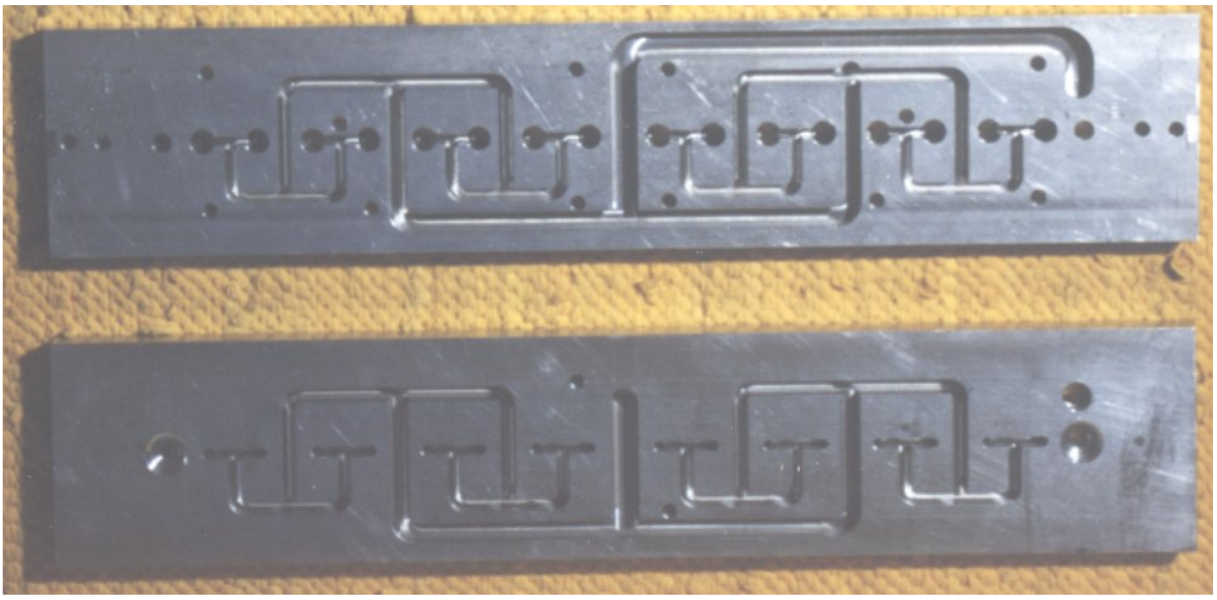

Figure 3: Aluminium plates for equal gas distribution; top: coaxial gas; bottom precursor gas.

Hot wall reactor: The growth of YBCO requires a constant temperature at the surface. The reflection coefficients of the metal tape and the thick YBCO film are very different. During the growth of 1 µm thick YBCO films the surface temperature of the film can decrease some tens of degrees because of thermal radiation. Therefore, we constructed an almost closed hot wall reactor, which had a small hole at the top and some radiation shields with holes at the bottom. The tape was pulled onto a metal

table, which consisted of an Inconel sheathing with an inner copper core. Temperature measurements by thermocouples in the table showed deviations of 3°C maximum at a length of 50 cm at 800°C. In order to reduce heat transfer from the hot wall reactor to the nozzle and the vacuum chamber the reactor was shielded by silver sheets. The oxygen partial pressure was controlled by a λ-sensor. This was necessary because this sensor detects any solvent at the wrong working parameters of the evaporator, and the change of oxygen partial pressure because of precursor reaction.

Tape speed was 5-20 m/h and YBCO film thickness was between 400 nm and 1000 nm. The reel to reel chamber made a tape length of up to 200 m possible. The precursor yield was between 16% and 22% depending on the gas flow adjustment [2, 11]. The same reactor design was used for MgO and CeO_2 deposition at low oxygen partial pressure, which was measured by a λ-sensor. A gas mixture of water and hydrogen enabled us to avoid any formation of NiO onto the metal tapes and to form fully oxidised carbon-free buffer layers at the same time [12].

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