5. Siemens Research Munich

5.1 Solar Cell Research

5.1.1 S-Web and Electrochemistry of Si

Culture Shock

I left IBM research July 1980 and, after the required touring of the West by VW bus, accompanied by my the girl friend and present wife, went back to Germany. Many crazy things happened within a short time span but in the end, triggered by some unforeseen developments, I ended up with Siemens Central Research in Munich Neu-Perlach. Switching form IBM central research in the USA to Siemens central research in Munich provided for a culture shock. I'll give you just two examples of what I experienced:

1. As a researcher at IBM you could come and go as you pleased. The Lab was always open. You spend many Saturdays there, worked late at night and you could use most of the infrastructure (e.g. the library) any time you liked. At Siemens you had fixed working hours. On Saturdays, Sundays, holidays etc. you simply could not get in. If you state later than 9:00 pm (violating the rules) , you found yourself with a (fortunately well-trained) German shepherd dog at your throat the minute you left the building. You were supposed top stand still, hoping that a the 'a guard would eventually coming along
2. IBM simply expected that you published lot. It rewarded you for the the patents you produced. Siemens actuality paid you a certain amount of money for publications (after subjecting you to a monstrous bureaucratic excess in allowing you to send out a paper) but did nothing for patents.

So IBM was of course more productive in R&D than Siemens? Well, yes, but only up to a point. After all. Siemens (in the form of Infineon that split off around 1990) still makes chips and major hardware of all kinds, whereas IBM (then supposedly ahead of Siemens in chip making and everything else) has long ago ceased to make chips (or much hardware).

Introduction to the S-Web

Siemens had decided to start a huge and ambitious program for making cheap but good solar cells. Solar grade Si was to be made cheaply by some process, and with this Si, flat-sheet Si was supposed to be produced by one of various approaches to be investigated. I was to do all the analysis necessary to evaluate the quality of the Si produced. I was also to be the project leader of the S-Web technology in due time.
With hindsight It is clear that the project was rather crazy from the very beginning. I will give you a very brief idea of what we did to prove this claim.

1. **How to make cheap solar grade raw Si**
   Use the standard process for making metallurgical Si (fill a reactor with "sand" (SiO_2) and carbon (coke), run a huge current through it, and out comes liquid Si containing 1 % - 2 % "dirt". Read up here about that.) Just fill in clean SiO_2 and clean carbon and out comes clean Si. How do you make (cheap) clean SiO_2? Simple. Make more or less regular glass, turn it into a glass fiber (as known form fiber optics) and then leach out the impurities (mostly metals) by immersing the fibers in acids. The huge surface to volume ratio of the fibers actually allows that. It actually worked – but wasn't cheap. Clean carbon you make by buying rather clean soot from somewhere that you "roll" into balls with a few cm diameter to feed your reactor with. That worked too but produced unbelievable messes. Making Si this way (in a small reactor) also worked, sort of. Could it be a cheap process for hundreds of tons of cheap solar grade Si? Rather doubtful.
2. **How to make thin Si sheets ready for being processed into good but cheap solar cells – Variant 1: Sintering powder**
   Grind your solar grade raw Si to dust and sinter it together using the techniques known from making ceramics / powder metallurgy (read up here about that). This also was done. Needless to say that nothing resembling solar grade Si came ever out of the high-temperature sintering furnaces.
3. **How to make thin Si sheets ready for being processed into good but cheap solar cells – Variant 2: Melt spinning technique**
   Use melt spinning techniques (Look it up here) Needless to say that after it was found out that Si expands upon solidification and is brittle, it became clear that it couldn't be be melt-spun (as one could have guessed). This project was no longer pursued after a year or two.
4. **How to make thin Si sheets ready for being processed into good but cheap solar cells – Variant 3: *S-Web***
   Make a net from high-purity graphite fibers (the ones used in carbon fiber-reinforced polymers), 1 m wide and with

mesh size of cm, and pull that net at 1 m/min through liquid silicon (through a slot in the bottom of the crucible). This (brain-child) technique was called ***S-Web*** (=supported Web). Sound crazy, appears to be rather crazy. Yes, but this is the way for making window glass with a metal net inside. However, there is no heat of solidification when you pull a glass sheet that limits the pulling speed. Nevertheless, the S-Web technique worked, sort of, after modifications were made. We even made some decent (but not very good) solar cells from the stuff.

- The program was running for many years and Siemens spend real money on it. The goals were not achieved but 20 years later or so, Germany did become the world leader in turning photovoltaic into a reliable and unbelievably cheap source of energy.

The S-Web and its Characterization

Let's focus on the S-Web and the ways to analyze the various Si samples.
The idea for the S-Web technique and the Si production technique under No. 1 above came from "glass people" who had to re-orient themselves inside Siemens since the company had abandoned R&D into glass fiber techniques. Here we have one reason why the upper echelons of the Siemens management allowed a multi-million project that was quite obviously rather crazy. The other reasons most likely were:

- Siemens simply had to do something in the direction of “green” energies. For public relation reasons and because the government wanted that (supplying a lot of money).
- There were all these researches out of a job (like the glass people, but also others) and Siemens simply did not fire people at those good old times.
- You had empty (lab) space at the new research center in München-Perlach that needed to be occupied.
- You knew (or at least hoped) that if a sufficient number of smart people with sufficient resources worked on some topic, something good would eventually result. Quite likely not what was originally intended, but something good.

- Shortly after I joined the solar Si group, I pointed out (by simple calculations) that the heat of crystallization would, for sure, make a growth rate of 1 m/min utterly impossible for vertical growth. Horizontal growth was different and that’s what was eventually implemented.
  Looking back, I'm amazed how far the S-Web technique could be pushed (thanks not so much to me to me but to people like Dr. Falckenberg). More (lots more) about that in the "reports" page.

The S-Web technique was just one of the many techniques developed to produce “flat plate” silicon. The basic idea was that cutting bulk Si into flat plates produces a lot of Si saw dust and thus used up too much of the expensive Si. As turned out later, the way to cheap solar cells was to develop cutting techniques that produce little waste and had a high productivity (meaning multi-slice wire saws). Well – live and learn.

- At this point it is perhaps in order to point out the following:

Modern high-quality low-cost mass production of Si solar cells was almost exclusively pioneered in Germany

5.1.2 Publications

While we did not *publish* all that much, we did produce a lot of internal reports. They are utterly irrelevant by now but I’ll preserve a few for eternity (however long that will last) in this archive. If humanity survives the next few 100 years (I’m rather sceptical), it will serve its energy needs mostly by solar cells for sure, and people then might wonder how this supremely important technology came into being in the later 20th century. They quite likely will not find much detailed information any more. Here I will give some background about traveling down one of the many blind alleys one needed to explore.

Link Hub to S-Web Reports

We produced a number of conference proceeding that attracted little attention. Some, actually were rather full-fledged papers but never punished in decent journals. Publishing simply was not the main priority at this project.
In essence, there are 5 publications with my name on it. It is interesting (up to a point) that we never published in journals, only in conference proceedings. Considering that a vast amount of money has been spent on the S-Web technique (not to mention the other ones noted above), this may appear surprising. But Siemens R&D was not publications oriented (in contrast to IBM and Bell Labs R&D), and, more to the point, there just weren't any journals around with a focus on "green" energy.

However, publications 55 and 56 are rather long and detailed for conference proceedings. They contain, in essence, everything related in the earlier publications and that's why I give them to you. Of course, they are totally irrelevant from today (2023) point of view but not from my point of view.

- They provide just for one example that – contrary to popular believe – not only plenty of researcher were concerned about the impeding climate changed but also the nowadays much maligned companies like Mobile Oil, IBM or Siemens. They spent large amounts of money looking into solar energy already end of the 790ties / beginning of the eighties. It did not lead to immediate success but opened the way for the later triumphs.
- My fooling around with electrochemical methods for analyzing all these unconventional Si was not only successful but lead to major discoveries in the field of semiconductor electrochemistry.

Here is the list:

48 GRABMAIER, J.G., FÖLL, H., AULICH, H.A., FREIENSTEIN, B.: The supported-web method for growing silicon sheets at high velocity. Proc. 3rd Symp. on Mat. and New Processes. Techn. for Photovoltaics, eds. J.P. Dismukes et. al. (ECS Proc. Vol. 82-8), p. 391
First publications concerning the (in)famous “S-Web”..

49 GRABMAIER, J.G., FÖLL, H., FREIENSTEIN, B., GEIM, K: Fast Si-sheet growth with the supported-web method. Proc. 4th E.C. Photovoltaic Energy Conf., eds. W.H. Bloss and G. Grassi (D. Reidel Publ. Co), Stresa 1982, p. 976

52 GRABMAIER, J.G., FALCKENBER, R., FREIENSTEIN, B., GEIM, K., FÖLL, H.: Si-ribbon growth with the S-web technique. Proc. 5th E.C. Photovoltaic Solar Energy Conf., eds. W. Palz and F. Fittipaldi (D. Reichel Publ.), Athens 1983, p. 1058

55 **LEHMANN, V., FÖLL, H., BERNEWITZ, L., GRABMAIER, J.G.**: A high-speed characterization technique for solar silicon. In: Proc. Flat Plate Solar Array Project Res. Forum on the High-Speed Growth and Characterization of Crystals for Solar Cells; Florida 1983 (JPL Publ. 84-23), (1984) 527
Here we encounter for the first time the name **(Volker) Lehmann**, about whom I will have a lot to say further down. This is probably his first publication (many more were to follow) and he is the first author because he did most of the work.

56 **GRABMAIER, J.G., FÖLL, H.**: The S-web technique for high-speed growth of Si-sheets. as 55 above; p. 261
I wroteit. Looking back, I think it is amazing what the group achieved. However, a lot of people and money was involved. I’m pretty sure hat nobody believed that the S-Web technique would ever make it to a low-cost solar cell production. My boss, Joseph Grabmaier most certainly would be the first author. After all, the S-Web was his brain child.

At this point I want to honor Volker Lehmann. He joined my group as a student doing some practical work. It was immediately clear that he was a “high potential” and I was glad that he decided to do his Diploma thesis in my outfit (with a remote university Professor as the official advisor, of course). This lead straight to his Ph.D work and then to a position with Siemens Research. Volker Lehmann became a good friend to me and to Uli Gösele. We collaborated for many years and were quite productive.
Volker Lehmann died unexpectedly and tragically on the 26th of May in 2006. I will honor his outstanding work by giving you his *diploma thesis* (not easily found but still good to read, especially for young scientists who want to get acquainted with the topic) and the *obituary* I wrote together with Uli Gösele (whose obituary I had to write a few years later!).

Diplma Thesis V. Lehmann
Obituary V Lehmann

The obitual actually qualifies as a proper publication; it's No. 256 on the list.

5.1.3 Pictures

I will give you some of the pictures contained in the two linked publications above plus a few auxiliaries. The picture quality is not very good since they originated form “slides”, these little square things that predated charts with overhead projectors (look it up in some ancient history book).

S-Web pictures