

# There, and Back Again: How Adolf Goetzberger Got to Solar Energy

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**Editor's note:** This month we bring to you an article based on the Engineering and Technology History Wiki's Oral Histories collections. For the IEEE oral histories, IEEE History Center staff and volunteers have conducted more than 600 interviews, all of which are available on the website, [www.ethw.org](http://www.ethw.org).

Scholars in a range of fields have drawn extensively on these interviews as have writers and producers of popular books, articles, exhibits, and documentaries. Some editing has been done, along with the addition of a few illustrations, to make the article more suitable for a journal publication.

In 1994, Rik Nebeker of the History Center interviewed Adolf Goetzberger (see Fig. 1), founder of the Fraunhofer Institute for Solar Energy Studies, former president of the International Solar Energy Society, and now IEEE Life Fellow. Recipient of over 30 patents, most published after he retired, Goetzberger has been recognized with the J. J. Ebers Award by the IEEE Electron Devices Society for his contributions to MOSFET innovation; with the William R. Cherry Award by the IEEE Photovoltaic Specialists Conference and the European Commission's Becquerel Prize for significant contributions to photovoltaic energy conversion; and with Germany's Federal Cross of Merit in 1992. In 2009, the European Patent Office honored him for a lifetime of achievement as one of its Inventors of the Year (see Fig. 2). Since retiring from the Institute for Solar Energy Studies in 1994, Goetzberger has remained engaged with that technology. As recently as 2013, he applied for a patent to enable agriculture in the same field as a solar panel array.<sup>1</sup> Dr. Goetzberger's quotations below come from this

*This article discusses Adolf Goetzberger, the founder of the Fraunhofer Institute for Solar Energy Studies. Goetzberger has been recognized for his contributions to MOSFET innovation and photovoltaic energy conversion.*

interview, which is available in full at [http://ethw.org/Oral-History:Adolf\\_Goetzberger](http://ethw.org/Oral-History:Adolf_Goetzberger).

## I. GROWING UP IN NAZI GERMANY

Adolf Goetzberger was born in November 1928 in Munich, Germany, and made his way through school under the National Socialist rule in the 1930s, and despite bombings of the city as World War II neared its end in 1944–1945. Indoctrination did not take hold “because although my father died when I was very young, my mother was opposed to the regime, so I was usually up to date on what really to think of these things.” By the age of 14, Goetzberger decided he wanted to be physicist, as his efforts to build radios demonstrated that he was “not a very practical person.”

## II. DOING MORE WITH LESS IN GERMAN EDUCATION AFTER THE WAR

Goetzberger attended a Munich high school, or gymnasium, “in a very bad condition then because most of the buildings were destroyed. Equipment was missing and so on. I think I did not have a very good education as far as the material conditions are concerned. But I learned very early that this is not of much importance.” Nor did the students have many books, relying instead on transcripts of the professors' lectures.

For his doctorate, Goetzberger studied under the distinguished Walter Gerlach, “one of the old scientists who still was grasping the entire range of physics.” He actually

<sup>1</sup>Georg Bopp, Adolf Goetzberger, Tabea Obergfell, and Christian Reise, “Method for the Simultaneous Cultivation of Crops and Energy Utilization of Sunlight,” DE 102012002551 A1, published 14 August 2013.



**Fig. 1.** Prof. Dr. Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems ISE, 1981, Freiburg, Germany Fraunhofer ISE.

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**Fig. 2.** Adolf Goetzberger, winner of the European Inventor of the Year Award in the category Lifetime Achievement, and Alison Brimelow, President of the European Patent Office EPA at the award ceremony in Prague on April 28, 2009. Europäisches Patentamt.

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learned to work on his own “because soon after I had started my thesis work with him, he became head of the university.” Goetzberger pursued a

rather obscure topic, and that is, the crystallization of evaporated amorphous films of antimony which had an interesting property which still attracts researchers today. When you evaporate it, it is first amorphous, but this is a meta-stable phase, and then it changes to the crystallization state from certain nucleation points. You could see how these points grow. I did some experiments looking at the kinetics of this transition.

Lacking quality was an advantage here; for example, “the vacuum in our evaporator was not so good that this effect was actually enhanced. I might not have found it in a very good vacuum.”

There was no application whatsoever. It was just the physics of it. The one thing that I added . . . was that if you evaporate these films rather rapidly then you have a rather thick film and these are so unstable that they recrystallize in an explosive phase. So in an explosive version these things go very rapidly. I took some high speed photographs of that and this was actually the new thing that I was able to add. This now led to the result that my doctoral thesis was finished relatively quickly.

Again, sophisticated equipment was unnecessary. Goetzberger did not need a high-speed camera because “it was something you could do with normal equipment. You just had to run a normal camera at its highest possible speed. This permitted us to get this effect resolved.”

### III. KEEPING UP WITH THE AMERICANS IN TRANSISTORS AT SIEMENS

In 1955, dissertation in hand, Goetzberger “stayed in Munich. Munich is a very attractive city. If you live there you don’t go away so easily. So I found a job in Munich which was at Siemens.” He joined the semiconductor manufacturing department “working on alloy germanium transistors which were at that time the standard product. Specifically, I developed a medium-powered germanium transistor because at that time they had only a low-powered transistor, and they wanted to expand it . . . to power little radios . . . . That was about the state of the art at that time.”

He stayed for three years, working under AT&T and other corporate licenses for transistor technologies, becoming increasingly frustrated because the “work mainly consisted of getting literature from the United States and then trying to repeat what they had done before.”

### IV. GETTING ALONG WITH DR. SHOCKLEY

In 1958, a former classmate working for Beckman Instruments’ spectrometer factory in Munich told Goetzberger that another Beckman company, run by Nobel laureate William Shockley, needed staff. After an initial rejection letter, Goetzberger was surprised by a phone call, and then an interview with Shockley and his wife: “I later learned that she was very influential in who he hired because she was a psychologist.”<sup>2</sup> Goetzberger was one of several, less rebellious, central Europeans hired as scientists at the company in Palo Alto, CA, USA, replacing the “Traitorous Eight” who left Shockley’s employ to start their own company.<sup>3</sup> Shockley liked his originality in a design for a germanium drift transistor, which did not bear fruit as the semiconductor industry was shifting to silicon. “[H]e asked about some details and was satisfied that everything worked. This convinced him that I could do some original work.”

Shockley had already begun the transition to silicon as the semiconductor for the four-layer diode on which he hoped to revolutionize switching technologies and make his name. Silicon was far trickier to process than the germanium with which John Bardeen, Walter Brattain, and he had initiated the solid-state revolution, however, and the PNP layers of his diode proved extremely difficult to combine consistently for the desired effect. Goetzberger was “given the job of discovering the workings of P-N junctions, to look at the qualities of P-N junctions and to look at reasons for breakdown phenomenon at high voltages.” Assigned a technician to put his ideas into practice, it was “a rather good set up because it was a wide open field.”

Goetzberger had a productive working relationship with Shockley on the operation of P-N junctions.

Maybe one reason was that he was an excellent theory man. Anybody who did theoretical work in his laboratory had a hard time because he knew the theory better and usually he was right. So I had agreed that I would be in charge of the experiments and he would do the theory and this turned out a very good collaboration.

Operating through government contracts, Shockley encouraged publication. Beyond being “extremely smart,” Shockley

was impatient, but on the other hand, he was interested in the practical problems. He had coined an expression which he discussed in many meetings. . . . “respect for the scientific importance of practical problems.” He said that every practical problem has a

<sup>2</sup>Goetzberger’s best friend, Hans-Joachim Queisser, tells a similar story about Shockley’s wife, along with a useful analysis of Shockley and many details of working for Shockley in *Oral History of Hans Queisser*, interviewed by Craig Addison (February 27, 2006), Computer History Museum ref. no. X3453.2006.

<sup>3</sup>See Joel Shurkin, *Broken Genius: The Rise and Fall of William Shockley, Creator of the Electronic Age* (New York: 2006), p. 186.

scientific background, and so whenever we had a problem in the laboratory, we described it to him and he started to think about what would be the reasons for it. He would design new experiments to find out, so when we made slow progress with his new devices, we could always interest him in the reasons why it didn't work.

One problem

was to understand why P-N junctions would at times have a very soft characteristic and break down. . . . Shockley . . . came up with the idea that there are metal precipitates in the P-N junction. If you heat up the silicon [at] the diffusion stage, then small traces of metals might get into the material. Solubility is higher at a higher temperature and so when you cool it down, those will form very tiny crystallites. If one of them happens to be in the P-N junction, then, of course, it will short out the P-N junction. Shockley had developed this theory . . . and so he outlined several experiments that one could do in order to prove that point.

We did a very beautiful experiment in which one of my technicians did a potential map with a flat diode. The potential map showed concentric rings with one point where the current was flowing through the junction. This indicated that we had at least localized current flow and that formed a part of an important publication we made.<sup>4</sup> But having recognized this effect, one had to find ways around it . . . More or less by accident I found a technology which gave us perfect junctions every time. This is the gettering step which is customary today in semiconductors. It's actually a special variation of the normal diffusion. If you have a highly phosphorous, doped film of glass on the silicon, then this glass will pull out these impurities.<sup>5</sup> This then really gave us the possibility to make good junctions.

For all of Shockley's intelligence, he could not run a business. He commercialized his four-layer diode, but with poor production yields that his staff could not improve significantly. In part, this stemmed from the difference

between government research and production engineering, and in part from the working conditions, which were markedly different from Siemens's facilities.

It was an old barn, a big hall with lots of empty spaces. On the floor there were diffusion furnaces, and measurement equipment, and everything. . . . It didn't look like a German laboratory at all! It had been improvised. There were a few offices built into this big hall. It was of course not very clean, which was the reason we had so many problem with our technology. Everybody knows this today, but at the time it was just not known.

## V. FROM SILICON AT SHOCKLEY TO MOS AT MURRAY HILL

Arnold Beckman sold the firm to Clevite Corporation in 1960, whose management replaced Shockley with Goetzberger as manager of research and development. Then Clevite installed a general manager, "a very picayune man who thought that if you watch how many sheets of paper are consumed and how many stamps, then you could turn around such a company." He also timed employees' arrival in the morning, and the creative staff, including Goetzberger, began to leave in 1963. He joined Bell Laboratories in Murray Hill, NJ, USA

at the beginning of a technical important development. It was the development of MOS [metal-oxide-semiconductor] devices and I started working on the physics of MOS. At that time MOS systems were unstable and uncontrollable but nobody knew why. With my previous experience . . . I was able to also come to some results rather fast there.<sup>6</sup>

Goetzberger spent five years at the labs working in the "relatively open research area" of MOSFET. Working with Edward Nicollian, he

decided to explore the properties of MOS capacitors and we could do a lot of physics with it. Our standard paper is this, how to understand surface states in interfaces and how to measure them. This is one which is being quoted many times.<sup>7</sup> It's a very long paper also.

<sup>6</sup>Adolf Goetzberger, "Ring-dot Impedance Measurement, a Simple Technique for Measuring Inversion-layer Conductance in Semiconductors," *IEEE Transactions on Electron Devices* 12, no. 3 (March 1965), p. 118–121; Edward H. Nicollian and Adolf Goetzberger, "Lateral AC Current Flow Model for Metal-Insulator Semiconductor Capacitors," *IEEE Transactions on Electron Devices* 12, no. 3 (March 1965), p. 108–117; idem, "MOS Conductance Technique for Measuring Surface State Parameters," *Applied Physics Letters* 7, no. 8 (October 1965), p. 216–219.

<sup>7</sup>Adolf Goetzberger and Edward Nicollian, "The Si-SiO<sub>2</sub> Interface - Electrical Properties as Determined by the Metal-Insulator-Silicon Conductance Technique," *The Bell System Technical Journal* XLVI, no. 6 (July–August 1967), p. 1055–1133, had 1287 references on Google Scholar as of 15 January 2015.

<sup>4</sup>Adolf Goetzberger and William Shockley, "Metal Precipitates in Silicon P-N Junctions," *Journal of Applied Physics* 31, no. 10 (October 1960), p. 1821–1824. The paper had 307 citations on Google as of 15 January 2015. We do not know the technician's name or if he proposed the potential map with the flat diode, which could be inferred from Goetzberger's wording. George Heilmeyer at RCA's David Sarnoff Research Center was perhaps unique in insisting that his technician, Louis Zanoni, be listed as co-author on articles in which he made similarly useful suggestions in experiments on the first liquid crystal displays; see, for example, George H. Heilmeyer, Louis A. Zanoni, and Lucian A. Barton, "Dynamic Scattering: A New Electro-Optic Effect in Certain Classes of Nematic Liquid Crystals," *Proceedings of the IEEE* 56 (1968) p. 1162–1171; and Heilmeyer's discussion of research contributions in "This Week's Citation Classic: 'Dynamic Scattering. . .,'" *Current Contents* 18 (May 3, 1982), p. 16. Unfortunately, few Ph.D. researchers have seen fit to follow his example in breaking class barriers where public credit is due.

<sup>5</sup>Ibid.



The group at Bell Labs competed and cooperated with “other groups, one that was at RCA and also one at Fairchild, but we all got together at meetings. We organized a new type of meeting, the interface specialist meeting which got together to discuss the new results.”<sup>8</sup> The cooperation was stimulated by the fact that “there was already some commercial interest in MOS transistors.” As a result, the

basic phenomenon was still rather freely discussed. . . . [W]e had, for instance, some instabilities in the oxide caused by alkali ions and that was first published by Fairchild and that clarified an important part of the technology. But then they had a different way of doing it, of producing their oxides, and we always got different results. We were arguing about all these steps and it turned out that they had done one thing differently, and they hadn’t even realized that it was a difference, so we never even discussed that.<sup>9</sup>

## VI. REFORMING ELECTRONICS RESEARCH IN WEST GERMANY

Goetzberger enjoyed his time at Bell Labs. The work was “fruitful” and he was promoted to lead a MOS research group with colleagues ranked among the best scientists in the world. In addition, he “had a house within walking distance from the laboratory and had very good circumstances there. I probably would have stayed there had I not received a very interesting offer from Germany.”

This was an invitation to take charge of the Fraunhofer-Gesellschaft’s Institute for Electrical Materials. After ten years in the United States, Goetzberger had an opportunity to return to his homeland and reshape research in his field based on what he had learned working on cutting-edge semiconductor technology in the nascent Silicon Valley and the world’s leading research laboratory. When he arrived in Freiburg in 1968, Goetzberger signaled the change by renaming it the Institute for Applied Solid State Physics and beginning the process of culling less productive members from the 100 staff members. He

put in an entirely new management of the departments. One of the department heads, who was an Austrian, also came from Bell Laboratories. Another one came also from the United States. So the whole thing became a lot more effective. It was actually

<sup>8</sup>Steven Hofstein, then at RCA’s David Sarnoff Research Center, also takes credit for starting the IEEE Silicon Interface Specialists Conference in 1965; see *Oral History of Steven Hofstein*, interviewed by David Laws (October 28, 2011), Computer History Museum ref. no. X6296.2012, p. 6–7. He was chairman of the Invitations Committee while serving on the Conference and Technical Program Committees, the only organizer to serve on all three.

<sup>9</sup>Ross Bassett provides the fullest account of the development of MOSFET technology in *To the Digital Age: Research Labs, Start-up Companies, and the Rise of MOS Technology* (Baltimore, MD, 2002).

considered a very good research institute and this is what I think was the final result of the work. It was more directed toward, let’s say, the needs of the operating agencies. We finally also managed to get it partly financed by the Ministry for Science and Technology. So it was open for civilian applications. We established good collaboration with industry. One thing I also enjoyed during that time was that I was an advisor to the government for the government contracts. So I could have, I hope, a positive influence on the type of R&D they had contracted.

## VII. BEGINNING SOLAR CELL RESEARCH AND DEVELOPMENT IN WEST GERMANY

After twelve years of successful reform, Goetzberger “decided I was getting stale in it. I had realized everything I had intended to do and there wasn’t much more I could do. I realized I needed something new. I found solar energy.” In part, the choice of field depended on the institute’s liquid crystal display group, which had created “a fluorescent enhancement of the display and it occurred to me that one could use that for the collection of solar energy.”<sup>10</sup> In part, it depended on the oil price shocks of the 1970s, which stimulated European investment in energy conservation and alternatives to oil. In the late 1970s, Goetzberger exploited a budget priority of the Federal Ministry for Research and Technology, organizing a group of 18 researchers within his institute to work on solar energy.<sup>11</sup>

By 1980–1981, however, solar energy was only one of several renewable energy technologies with the drawbacks of being expensive at \$25–30 per watt, up to six times as expensive as wind energy, and inefficient in yield at little more than ten percent conversion.<sup>12</sup> Armin Rauber, one of Goetzberger’s researchers at the time, remembered that “we had very bad times. . . . Nobody wanted this strong engagement with solar energy, especially not the people from the Ministry of Research and Technology.”<sup>13</sup> Its installation also implied an “off the grid” philosophy and economy antithetical to the business of the dominant electric utilities. When Goetzberger managed to spin off his group of 35 people into the new Institute for Solar Energy Systems (ISSE) in 1981, a ministry press release derided it as a boondoggle equivalent to the United States’

<sup>10</sup>Adolf Goetzberger and Volker Wittver, “Fluorescent Planar Collector-Concentrators for Solar Energy Conversion” in *Festkörperprobleme [Advances in Solid State Physics]* (1979), p. 427–451; idem, “Fluorescent Planar Collector-Concentrators: A Review,” *Solar Cells* 4, no. 1 (August 1981), p. 3–23.

<sup>11</sup>Bob Johnstone, *Switching to Solar: What We Can Learn from Germany’s Success in Harnessing Clean Energy* (2011), p. 149; Armin Rauber, “On the History of PV Development: With a Focus on Germany,” in Gerhard P. Willeke and Erick Weber, *Advances in Photovoltaics: Volume I* (2012), p. 12.

<sup>12</sup>For the relative cost of solar versus wind energy in the late 1980s, see Johnstone, p. 144; for the price per watt of crystalline solar cells, see the chart at Wikipedia’s “Price per Watt,” [en.wikipedia.org/wiki/Price\\_per\\_watt](http://en.wikipedia.org/wiki/Price_per_watt), visited 17 January 2015.

<sup>13</sup>Quoted in Johnstone, p. 149.

Solar Energy Research Institute, good only to “collect university-educated solar energy researchers that cannot find a job in industry.”<sup>14</sup>

The Chernobyl nuclear reactor accident in 1986 helped change institutional thinking, as did steady progress in research and development around the world. Today, the Fraunhofer ISSE employs 1300 people and is the largest solar research organization in Europe.<sup>15</sup> Goetzberger took pride in his institute’s fabrication of

the world’s best flat plate collectors. For the solar cells, we most certainly make the best solar cells in Europe. Only [Martin] Green in Australia makes better ones. And we have a calibration group established here which is in exchange with six or seven others around the world, and they set the standards for solar cell measurements.

He also took satisfaction that

the basic material for solar cell is still silicon. Although numerous other materials have been tried, also introduced with great fanfare, silicon is still surviving. Of course this makes me happy because I had from the beginning already decided that we would work with silicon only. This means that we are still doing the right work. There may be some new materials sometime in the future, but I expect it will be more and more difficult as silicon develops further. . . . [W]e now have in the laboratory about three times the efficiency we had ten years ago. And something

very surprising with solar cells, the efficiency is now higher than it was considered theoretically possible ten years ago.

## VIII. “RETIREMENT IS NOT WHAT IT’S SUPPOSED TO BE”

After stepping down as director in 1994, Goetzberger continued as president of the German Solar Energy Society and took up a variety of related activities.

I’m doing project work at the institute. I’m still heading up the project of the self-sufficient solar house. . . . I’m giving lectures in many places. I’m doing a few consulting things, like for the Hahn-Meitner-Institut in Berlin. Then there is a research association of all the solar energy institutes in Germany, for them I am doing R&D coordination. I haven’t really started seriously with it because it seems to involve a lot of work. I’m also a partner in a small company that applies photovoltaics. . . . [Thomas] Nordmann has a company in Switzerland.<sup>16</sup> Since Switzerland is not a member of the European Common Market, he needed an outlet within the Common Market, so he approached me to found a German company together with him. This we started only about half a year ago in Freiburg. . . . He is a specialist in installing photovoltaics along motorways.

In other words, turning 65 was no excuse for becoming idle, but “at my age you do not have many plans. [I’m] just happy that I can continue with some of my work and contribute a few things.” ■

<sup>14</sup>Armin Räuber, “On the History of PV Development: With a Focus on Germany,” in Gerhard P. Willeke and Erick Weber, *Advances in Photovoltaics: Volume I* (2012), p. 12.

<sup>15</sup>For more information on the institute and its current activities, see [ise.fraunhofer.de/en](http://ise.fraunhofer.de/en).

<sup>16</sup>For more information on Thomas Nordmann and his company, see [tnc.ch/en/team/thomas-nordmann](http://tnc.ch/en/team/thomas-nordmann).