

Crystal Fire: The Birth of the Information Age

Theme: Sources

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“Silicon” is a compound that defines much of the modern technological era. The term connotes high-technology, exponential progress in Moore’s law, Silicon Valley, solar panels, even plastic surgery. The source of this transformation in large part arises from a single invention, the transistor, a sandwich of different types of silicon crystals. “Crystal Fire,” by Lillian Hoddeson and Michael Riordan, describes the invention of this device and its development up to the beginning of the microelectronic age of the 1960s. This is an unusually compelling story, both because of the invention’s huge impact and because of its straightforward progression of events involving a small number of people. The authors do an excellent job of telling the story as well as setting the institutional, scientific, and personal context.

The history of computing occupies a unique position in the history of technology. Because of its rapid changes and near-instant impact on society, there are complete stories to tell now. Intriguingly, many of the people involved in the critical events are still alive, permitting the genesis of new ideas and products to be followed in great detail. There is also a wealth of documentation, easily accessible. At the same time, it is more difficult to get a perspective of objective distance. People and companies have reputations to sustain, and they will work to steer the narrative in their direction. Historians must be savvy journalists.

Hoddeson and Riordan do a good job with their sources. Hoddeson herself had been working on solid-state physics history for 25 years. The pair of authors interviewed 41 people, including John Bardeen and William Shockley. Both authors have PhDs in physics. Thus, their grasp of the technical details is complete and they can appreciate important technical breakthroughs that could go unnoticed by an untrained eye.

They have consulted many records, producing a book of wide breadth while maintaining a single voice. They devote significant time to the critical contributions of dozens of people from different backgrounds, not just the three credited inventors. Among these three, the authors highlight each one's contributions. Finally, Hoddeson and Riordan look beyond Bell Labs and the United States, emphasizing the impact of other companies and nations on the transistor's success.

At its core, "Crystal Fire" is a history of the invention of the transistor. However, this story is only three of the twelve chapters. The rest of the book provides the context for the invention. This develops a richer history and gives a more satisfying sense of where the invention came from and what its impact was.

Part of the book is a biography of the three core inventors, Walter Brattain, John Bardeen, and William Shockley: where their families came from, where they went to school, how they came to Bell. All of the men came from independent, well-educated families in the West.

Another chapter is a history of science of solid-state physics. The authors describe the major paradigm shifts of the early 20th century: the discovery of the electron, the Bohr theory of the atom, the wave-particle duality of electrons, and quantum mechanics. These breakthroughs led to the band theory of solids, explaining the temperature-

dependent conduction of semiconductors. Bardeen and Shockley devoted their graduate school to solid-state physics.

A third important bit of context was the institution of AT&T Bell Labs. Already a major force in industrial engineering by the 1920s, the labs was committed to doing fundamental research in all areas of communications. Because of its patents, AT&T held a monopoly on telecommunications in the US. Thus, it had the resources to spend lavishly for the best researchers and equipment. It did so in order to get more patents and sustain its monopoly. Lab director Mervin Kelly was particularly interested in solid-state physics to solve some of the phone company's switching problems. Semiconductor crystal diodes were known to make good rectifiers, but their performance was erratic and poorly understood. In this setting, electrochemist Russell Ohl made a breakthrough in 1940 with the discovery of the P-N junction in experiments with highly pure silicon.

When World War 2 arrived, the labs threw itself behind the war effort. As a key part of the massive radar project, the labs developed novel semiconductor diodes to rectify incoming, shortwave radar signals. So, after the war, the lab was committed to further intensive research in solid-state physics. Shockley came up with the idea for a field-effect transistor in 1945, and the stage was set for the intricate materials and physics experiments that ultimately led to the transistor in December 1947.

From 1947 to 1951, the small group of researchers made several major breakthroughs, the core events of the book. First, Bardeen and Brattain made a point-contact transistor from germanium and two closely spaced sheets of gold foil. The first development was very exciting for physicists but was initially unappreciated by the wider society and economy. Gordon Teal then developed a method for growing single crystals

of germanium. Next, Teal and Morgan Sparks, two physical chemists, found a method to produce junction transistors under the direction of Shockley. William Pfann, another chemist, discovered a technique to make almost perfectly pure germanium. In 1958, Bell Labs successfully produced the first field-effect transistor.

After the publication of these results, AT&T and other companies began commercial exploitation of the transistor, and this is where the book supplies the business context. Texas Instruments bought a license to produce transistors. Having hired Gordon Teal, they discovered a process to produce silicon transistors, which proved significantly more robust than germanium. Sony then got its start mass-producing silicon-based transistor radios for the US market. In the mid 1950s, Shockley left Bell Labs to try to make money on his invention. While his own company floundered, a large group of his employees left and formed Fairchild Semiconductor. TI and Fairchild independently invented the integrated circuit in 1958-59, and both became wildly productive microchip companies.

Each of these five historical views requires a different approach and a different set of sources. The authors prove themselves to be effective with all of them. For the biographical section, they consult the collected papers of the three inventors. Brattain, Bardeen, and Shockley have archives at Whitman College, UIUC, and Stanford, respectively. Besides Bardeen and Shockley themselves, Hoddeson and Riordan also interview Robert Brattain, Walter's brother, Jane Bardeen, and Emily Shockley. While they couldn't interview Walter, many earlier interviews existed. He comes across as the most personable of the three inventors, and his reminiscences are used most extensively. When he won the Nobel Prize, he described his choked up feeling when applauded by his

peers: “knowing full well that one could not have accomplished the work he had done without them and that it was really only a stroke of luck that it was he and not one of them.” As another example, “The only regret I have about the transistor is its use for rock and roll music.” For the shy, but brilliant Bardeen, Hoddeson gathered enough material about him to write a whole separate biography, published in 2002. Shockley wrote many letters, and he also kept a diary in later life.

The short history of 20th century particle physics requires a much broader sweep. However, the authors, being physicists and historians of science, knew the territory well. Hoddeson had previously edited a book: “Out of the Crystal Maze: Chapters from the History of Solid State Physics.” Riordan had written the book “The Hunting of the Quark: A True Story of Modern Physics”.

For the institutional history of Bell Labs, AT&T itself provided numerous sources. Bell Labs maintains a historical archive, including the lab notebooks that the researchers used. Also, eager to demonstrate its patriotism and importance in the war, AT&T produced several internal histories. Lab director Mervin Kelly had written a report, “War Contributions of the Bell Telephone Laboratory”. Company historian M.D. Fagen wrote “A History of Engineering and Science in the Bell System: National Service in War and Peace.” Kelly also wrote an internal memo, kept in the archives: “A First Record of Thoughts Concerning an Important Postwar Problem of the Bell Telephone Laboratories and Western Electric Company”

For the invention history itself, the authors have an astonishing array of primary sources to call on. First, most of the researchers kept neat, detailed lab notebooks. This way, in any patent litigation, the researchers could demonstrate precisely when they had

come up with particular ideas. Bardeen, Brattain, and Shockley all had notebooks in the archives. The authors could see what each researcher was thinking at specific dates and at each major experiment. In addition, Lillian Hoddeson had interviews with a large majority of the participants, conducted in the mid-1970s: John Bardeen, William Shockley, Robert Gibney, Gerald Pearson, Russell Ohl, John Pierce, Jack Scaff, Morgan Sparks, and Gordon Teal. The invention history thus covers the full sweep of theoretical, experimental, and materials innovations that were necessary to get a working device. If anything, this section is too detailed. Readers with little knowledge of solid-state physics or semiconductor fabrication may get lost in the intricate experiments and processes.

Finally, for the business history, the authors introduce yet another group of sources. Fortune had an article in 1953, “The Year of the Transistor,” discussing applications for the military and for hearing aids. Other articles from Business Week and the Wall Street Journal discuss the prospects and profits for Fairchild Semiconductor and the Shockley Transistor Corporation. The authors interview Mark Shepherd, the founder of TI’s research lab. They also interview and cite extensively Gordon Moore, the founder of Fairchild Semiconductor and Intel, a legend of the computer industry, one of the wealthiest individuals in America. For the integrated circuit, they largely rely on secondary sources, since its invention story is as involved as the transistor itself. The early years of Sony come from secondary sources, an official company biography, and founder Akio Morita’s memoirs.

Overall, “Crystal Fire” is a very well-researched book with materials the authors gathered over 25 years. At the same time, it is entertaining and well-written. The authors keep their mountain of information well contained, and the book ends gracefully after

only 280 pages. In particular, there are several potential conflicts that the authors manage well. First, there is the issue of who invented the transistor. While Shockley had the ideas for how the transistor ought to work, Bardeen and Brattain were the ones who actually made it work. When the device was first publicized, Shockley tried to take all of the credit for its invention. Indeed, he subtly pushed Bardeen and Brattain out of the transistor group, one of the reasons Bardeen soon left for academia.

Reading the book, it is clear that all three men deserve credit. While Shockley was not present for the first transistor, he led the subsequent development of the junction transistor. His original idea for the field effect transistor, developed in 1945, also eventually became a reality in 1958.

The figure of Shockley himself is controversial. He had a cold relationship with his co-inventors, he kept getting passed over for promotion at Bell Labs, he divorced his first wife while she was dying of cancer, his employees deserted him at his California company, and he was loathed for his later white supremacist theories. However, the book is balanced, painting Shockley as a classical tragic hero. One of the major sources is Fred Seitz, a college and life-long friend of Shockley's who made major contributions to solid-state physics himself as a professor. Seitz called Shockley "The Moses of Silicon Valley." This evocative metaphor captures the authors' attitude toward Shockley. This quote is the last sentence of the book, and the authors credit it as helping "enormously in writing this book" in the notes. The book is dedicated to Fred Seitz.

Though it highlights the contributions of the three men, the book certainly does enforce the myth of the god-like inventor. Many people are recognized as major contributors. For example, Russell Ohl was a researcher without a PhD who did not work

at the main Bell Labs in Murray Hill. Yet he discovered the P-N junction and began the work of refining extremely pure semiconductors. Combining all the interviews, the authors paint a convincing narrative of many specialists working collaboratively to incrementally innovate in a way that none of them could have done on their own.

The book also does not take a purely adulatory attitude toward AT&T and Bell Labs. While the applied science there was extraordinary, there were problems. Namely, despite being the inventor of the transistor, other companies were the ones to achieve commercial success. TI figured out how to make silicon junction transistors, and this led to the mass production of them in electronics, particularly the transistor radio. More importantly, TI and Fairchild invented the integrated circuit. AT&T denied the importance of the IC for years. Therefore, it lost the opportunity to participate in the microchip boom that began in the 1960s and became the transistor's major economic legacy.

Finally, the book does not bias itself purely toward the United States. It acknowledges that the major theoretical contributions to quantum mechanics and solid-state physics were done in Europe. Also, at the beginning of World War 2, the British secret radar program was more advanced than the American one until the two countries began collaborating. While the point is not speculated explicitly, it seems clear that a major reason the U.S. invented the transistor in 1947 was because Europe had been decimated by the war, and the U.S. was stronger than ever. The book makes a special effort to highlight Sony's rapid mastery and exploitation of the transistor in spite of severely limited resources. In summary, "Crystal Fire"'s sources are exemplary. It

provides a wealth of detail for the critical events and a judicious, balanced overview for the broader context.