

How the Laser Came to Light

In the early days, lasers faced an uphill struggle. Now they enjoy a vast range of applications. This laser at France's Centre d'Essais des Landes measures the composition and turbulence of the atmosphere.

Fifty years have passed since a laser first shone. Now these intense light sources can be found everywhere, from the auto industry to CD players. In a joint project, researchers at the **Max Planck Institute for Economics** are helping to trace the laser's economic development – and in the process, they are challenging some common assumptions about how new technologies come to be established.

TEXT RALF GRÖTKER

The Martians are coming! And they are armed with invincible ray guns! As far back as 1898, American author Herbert G. Wells wove such a tale of horror in his book *The War of the Worlds* – more than half a century before the marvel of Light Amplification by Stimulated Emission of Radiation – that is, the laser – had even been invented.

"Certainly by the time Einstein formulated the theory of stimulated emission in 1916, it was scientifically proven that such a light source would come into existence," confirms Helmuth Albrecht, an expert in the history of technology at the TU Bergakademie Freiberg. "Its principal properties were also known: extremely tight bundling and high energy density. Long before the laser was actually invented, it was even a known fact that it could be used to measure distances and transmit data."

Albrecht is one of the partners in the LASSIE project: "Lasers: A Spatial-Sectoral System of Innovation and its Evolution." It explores the evolution of the laser innovation system, also including the regional dimension and as seen from a scientific, economic and political perspective. In addition to the Bergakademie Freiberg, the project, financed by the Volkswagen Founda-

tion, also includes researchers from the Max Planck Institute for Economics and Friedrich Schiller University, both in Jena.

MEANINGFUL TECHNOLOGY POLICY

Using the development of the laser as their example, they are jointly seeking to identify general patterns of technology transfer and economic development. The laser is the ideal candidate. Advances in laser technology would be inconceivable without a steady stream of new research findings. In addition, there is a well developed commercial sector that exploits a wide variety of laser products and applications. And last but not least, its development can be studied within the framework of international comparisons.

At the forefront of the project is the issue of the systemic nature of laser development. "In the 1950s, the naive belief still persisted that technology and enterprise developed along the lines laid down by the relevant institutions: first comes basic research, then applied research, and finally, the technology is taken over by industry," explains Jena-based regional economist Michael Fritsch, who is also doing entrepreneur-

ship research. "Today, however, we recognize the existence of what are called innovation systems – actors who are dependent on one another and interact with one another, but are spatially separated and spread across the fields of enterprise, politics and research."

This concept also plays a role in economic policy. "It reflects the widespread assumption that coordinated interaction between politics, public research sponsorship and the corporate sector is more beneficial to the national economy than completely unfettered competition," says Fritsch. One instance frequently cited as proof of this concept is the success of Japanese industry in the 1980s, which was closely managed by the then Ministry of Commerce and Industry (now the Ministry of International Trade and Industry, MITI).

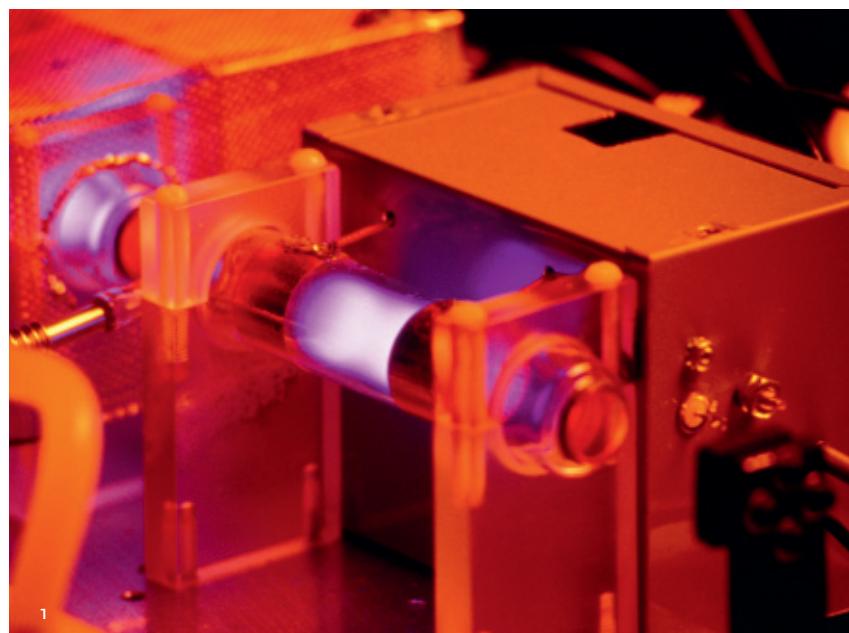
However, the fact is that little is known about what happens on a micro-level. This is unfortunate, to put it mildly, as an understanding of the context would be a valuable aid in formulating a meaningful technology policy. The partners in the LASSIE project thus hope to find out to what extent laser technology development in Germany took the form of "coordinated interaction" – or some other form. >

Guido Bünstorf, head of a research group in the Evolutionary Economics Group at the Max Planck Institute in Jena and co-initiator of LASSIE, has, in recent years, studied the development of a whole series of industries, mostly in close collaboration with Steven Klepper, an economist at Carnegie Mellon University. In the course of their work, the two researchers discovered that development in the industrial sector generally does not follow the pattern set in Japan in the 1980s, but is more akin to Darwin's theory of evolution. It is not so much a question of a "system" as one of momentous exceptions.

Klepper showed that the entire Detroit-based US auto industry emerged from the nucleus of a single company: Olds Motor Works. General Motors, Cadillac, Ford, Dodge and Chevrolet are all descended from Olds. Semiconductor manufacturing in Silicon Valley and the "rubber capital of the world," Akron, have similar origins. Located on the Ohio and Erie Canal, Akron, at the end of the 19th century, was growing fast and prospering from the transshipment of coal and cereal products. A postcard in Bünstorf's office depicts a cartoon image of 1930s euphoria with imposing skyscrapers, broad streets and a blimp in the sky: "Greetings from Akron Ohio."

The New York-based rubber manufacturer Goodrich found willing investors and settled in Akron. In 1888, his sons took over the business and were soon producing the first pneumatic automobile tires. Initially in cooperation with Goodrich, a maker of carriage tires named Harvey S. Firestone also set up shop. And finally, the sons of the investor who had backed Goodrich senior went on to found a tire firm of their own, called Goodyear. These three firms were the progenitors of almost the entire American tire industry.

- 1 Please blow into the light: A carbon dioxide laser helps diagnose gastric ulcers by identifying the bacteria responsible based on their metabolites. Lasers are now a standard feature of medicine, serving as scalpels, as optical drills to treat tooth enamel, and to remove kidney stones and correct defective vision.
- 2 When astronomers see stars, they just might be homemade. Using a laser, they can simulate a star in the heavens as a model in order to eliminate the ever-present atmospheric turbulence in the telescopic view.



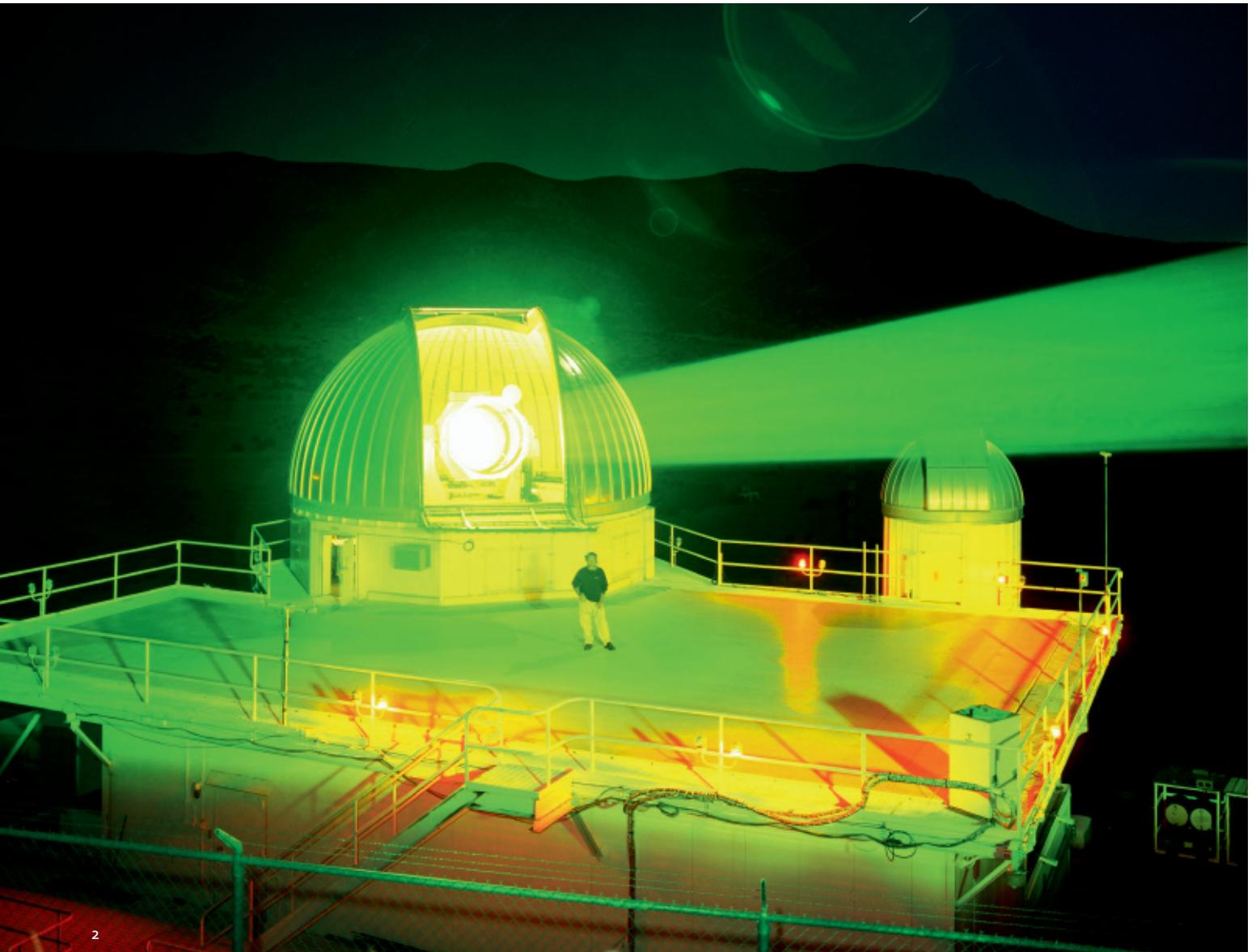
Bünstorf and Klepper gathered and statistically evaluated vast quantities of detailed information and data on the cases they studied. They analyzed behavior patterns and used their findings to test mathematical models of industrial development. Lasers, too, are among their research interests.

NO SYSTEM CHARACTER

LASSIE began with something akin to a bet. "It all started when we were sitting around the Klepper family's kitchen table in Pittsburgh," Guido Bünstorf recalls. "I told Steve about my plans for the laser project. He said, 'I don't believe in innovation systems.'" Who actually won the bet depends on the timescale applied; however, it was Steve Klepper who ultimately emerged the loser. For more than ten years, the laser industry

in Germany had no system character. According to LASSIE, this feature eventually emerged in the 1980s.

The research project traces the development process in detail. The initial investigations are already complete. When the project partners met in November in the wood-paneled conference room at the Max Planck Institute in Jena, a stack of freshly completed master's theses lay on the table. Helmut Albrecht was there from Freiberg, Guido Bünstorf traveled from Kassel, where he holds a professorship, and Michael Fritsch came from the university in Jena where he holds the chair of business dynamics, innovation and economic change. Also in attendance was Wolfgang Ziegler, head of the patent information office at the University of Jena, who became aware of the project when he, too, applied to the



Volkswagen Foundation. "It was a stroke of luck for us: Ziegler himself has a background in laser research and knows all about what happened in East Germany," says Bünstorf.

The meeting began with a student presentation of a study on team building. In his thesis, the student had analyzed "patents classified under IPC H01s that deal with laser sources. German applicants only." Between 1961 and 2005, there were 3,369 laser-related patent applications that fit the bill. The student had studied the size and stability of each team of inventors: were patents registered more frequently by inventors working together in the same team combination? In comparison, how often were patents registered by inventors working alone? The answers to these questions provide insight into the system character of the industry.

The extensively analyzed data show some clear trends. There is a distinct and continuous increase in team size – which presumably reflects the increasing complexity of the subject matter. At the same time, there are indications that scientists are switching from one team to another with increasing frequency – a sign of increasing networking. The meeting prompts questions, ideas and suggestions. Would it be possible to analyze the data by field of application? Could the same principle be applied to publications rather than patents? What would be the result for other industries?

"An important part of the LASSIE project lies in gathering data," says Guido Bünstorf. Company registers, patent applications, publication statistics, dissertations, trade fair catalogs and trade journals are all grist to the mill. And

then there are also interviews with the principal participants in industry and research. "We are compiling a database of events sorted by year – at a level of detail that, over the almost fifty-year period we are looking at, does not, to my knowledge, exist anywhere in the world for any other technology." The researchers aim to be able to track individual persons over time as they progress through the innovation system – from their dissertation to publications and patent applications to the possible founding of a business.

Michael Fritsch sums up the picture painted by the data as follows: "In the 1960s and 1970s, there was hardly any cooperation. There were few spinoffs from universities or existing companies, and spatial mobility between companies was minimal. Exchanges between academic and industrial re-

searchers were limited to conferences." There was no systemic aspect to the development process at the time. It was not until the 1980s that networking began in various forms on the laser scene. Research sponsorship (a dissertation topic in its own right) took on greater importance and the establishment of application-oriented research facilities, such as the Fraunhofer Institute for Laser Technology (ILT) in Aachen and the Institut für Strahlwerkzeuge (IFSW) in Stuttgart, received political support.

These observations prompt a fascinating question: How do we explain the fact that Germany was able to acquire a leading international position in some important areas of laser technology even though a system as such – and thus also broad public support – did not exist until the 1980s? Is the link between economic success and

targeted support for key technologies perhaps less cohesive than is commonly assumed in economic and research policy? A look back at history offers some useful clues.

AN OUTSIDER SCORES A BIG HIT

The laser was invented by Theodore H. Maiman – a scientific outsider working in a research laboratory at Hughes Aircraft Corporation in California. "Maiman must have made his breakthrough some time early in the summer of 1960," explains Albrecht. "He succeeded in generating a laser effect with a ruby crystal." At the same time, but without being aware of Maiman, a working group headed by the future winner of the Nobel Prize for Physics, Arthur Schawlow, was also working on a laser. Schawlow's group also managed

to generate a laser beam just a few months later, in October 1960, and, unlike their rival Maiman, they published the results in the journal *PHYSICAL REVIEW LETTERS*. "And that was where it started," says Albrecht. "Everyone immediately began trying to reproduce the experiments, and by the turn of the year 1961, most had managed it."

Before the Second World War, Siemens in Munich had been conducting research with a view to using microwaves for communications purposes. After the restrictions on research were lifted by the Allies in 1955, they picked up where they left off. In 1961, the company had two teams working in competition with one another on this new technology. They actually succeeded in replicating the laser even before the Schawlow team had published its results. This was to have a lasting effect on

"An answer in need of a question" is how Theodore Maiman described the first laser – a ruby laser, shown here disassembled into its component parts. Maiman built it with his assistant Charles Asawa at the Hughes Research Laboratories and activated it for the first time on May 16, 1960.

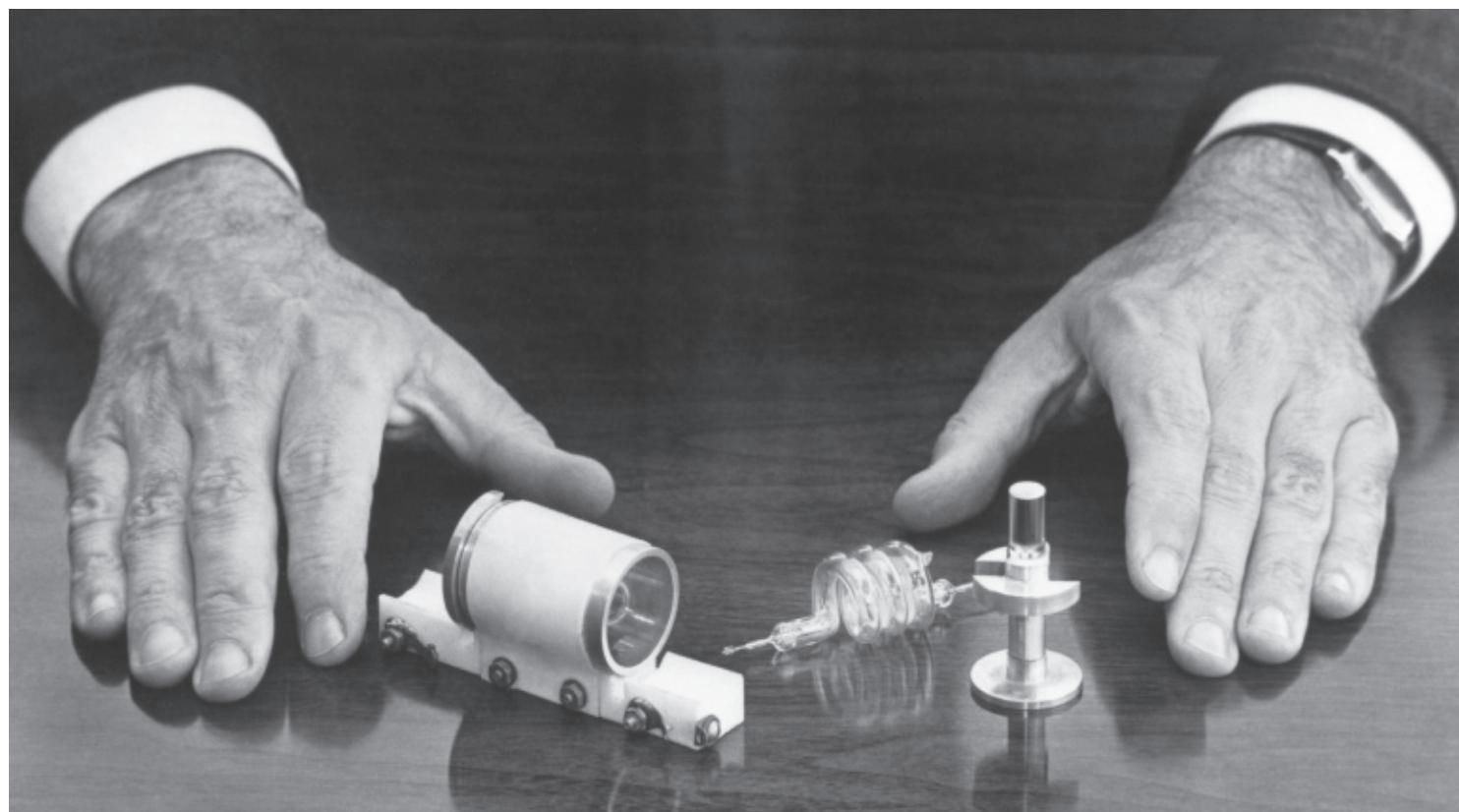


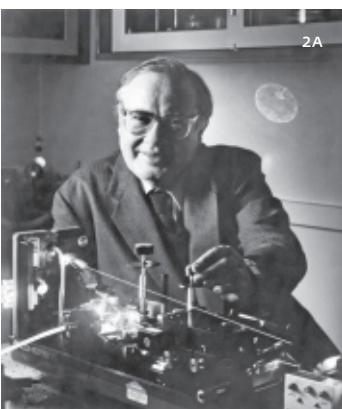
Photo: SPL-Agentur Focus

the German research landscape. Thanks to Siemens, Munich became the stronghold of laser research in Germany, competing with Jena and Berlin – a development to which the Institute for Plasma Physics in Garching, founded in 1960 and incorporated into the Max Planck Society in 1971, also contributed.

Having succeeded in replicating the laser, an initial series of experiments was launched predominantly in the fields of communications technology and materials processing. The properties of the new technology were systematically explored. New forms of lasers were discovered in rapid succession: within a few years, first the ruby and then helium-neon gas lasers were followed by glass lasers, cesium gas lasers and low-temperature semiconductor lasers, ion lasers, carbon dioxide lasers, chemical lasers and dye lasers.

1 Lasers were initially used mainly for research purposes, for example to generate interference patterns. These occur when a beam divided into two paths is recombined and one path is slightly altered.

2 Arthur Schawlow (A) developed the laser at the same time as Theodore Maiman (B). Neither of them knew that they were competing with one another.



Science itself initially provided a market for the new technology. "Laboratories scrambled to get their hands on a laser, not just in industry, but at universities and schools, as well," explains Helmut Albrecht. In 1971, two students from the Max Planck Institute for Biophysical Chemistry in Göttingen set up a company called Lambda Physik. Producing traveling-wave nitrogen lasers for the research market, it went on to become one of the most successful Max Planck Society spinoffs ever.

However, it took another ten years for the laser to establish itself as an industrial production tool. The key problem lay in designing a technology that would function reliably under industrial conditions as a component part of a material processing plant. The beam guidance, in particular, proved to be critical. "To start with, a mirror

system was tried out. But it was very difficult because, with even the slightest maladjustment, the beam was out of line," Albrecht continues. It was not until the arrival of fiber-optic cables, which could be used as optical waveguides, that it became possible to build the modern, highly flexible production systems that now handle cutting, drilling and welding tasks in many branches of industry.

Although the laser was invented in the US, it was German engineers and equipment manufacturers who made it a commercial success in industrial production. One of the first applications of the laser was in drilling watch springs and jewels for the precision engineering company Haas in the tiny Black Forest town of Schramberg. In 1970, Haas purchased the first Nd:glass laser for spot-welding coil springs before setting up the subsidiary HAAS-Laser in 1972 to build its own equipment. Another prominent example was Berthold Leibinger, general manager of the Trumpf machine tool company, who in 1979 introduced the first *Trumatic* punching and laser cutting machine, which became a great commercial success.

GERMANY BECOMES THE MARKET LEADER

German industry became the world market leader in the use of lasers for materials processing. And it did so, at least in the early years, entirely without political support. What's more, for economic researchers, the success of German laser technology may possibly indicate that the European paradox is misjudged. In economic research, the term European paradox is used to describe the theory that the industrial nations of Europe are not lacking in the ability to innovate, but rather in the will and the talent to exploit their innovations commercially – which is why they supposedly lag behind the US in terms of enterprise. However, when proven German expertise in precision manufacturing came head to head with a new technology, the Germans clearly appreciated the commercial potential of the laser and set about exploiting it.

The presence or absence of a system and the European paradox were not the only aspects in which the laser man-



Cutting with light: A carbon dioxide laser slices through a tube. Industry today also makes ready use of the heat of this intensely bundled light for welding, for example in automotive production.

aged to surprise economic researchers. The course of events in the laser market also confounded another previously observed law of industrial evolution. After just a few years, most industries undergo a shakeout in which the majority of suppliers find themselves forced out of the market, leaving just a handful of large and strong survivors. The reason for this is that product innovations are overtaken in significance by standardization and increasingly efficient manufacturing processes. Newcomers and smaller companies are unable to compete, and the overall number of companies operating in the field declines.

In the case of the laser, the situation was quite different. "Although the laser industry as a whole grew in size over a period of more than 30 years, we were unable to find any proof of smaller companies being pushed out of the market,"

reports Steven Klepper. "That was a complete mystery to us." Their surprise was even greater when Klepper established that the absence of any shakeout was limited to the period from 1961 to 1994 – after which the number of firms was reduced by almost half. Why should this happen at such a late stage?

LITTLE EVIDENCE OF THE EFFECTS OF MASS PRODUCTION

Klepper and his colleagues looked at the various segments of the market and were able to establish that, just because a company produced a laser with one particular wavelength, it did not necessarily enjoy a competitive advantage in manufacturing and marketing other types of lasers. For this reason, there was little evidence of the effects of mass production and thus no shakeout in the early years. But why did the situation change? "A new invention! The diode-pumped solid state laser. This changed the economics of the industry," Klepper argues. "Suddenly it was possible to generate many different wavelengths using the same fundamental technique."

If this reasoning is correct, then something similar should be evident in Germany. In fact, as Bünstorf explains, "Compared with the US, the development in Germany was a little delayed. But the pattern is the same: rather late in the day, the usual processes of industrial development were set in motion."

Laser diodes have since done their part to ensure that lasers are ubiquitous – in CD players, traffic control systems, medical equipment, supermarket checkouts, and they are even responsible for printing the sell-by date on plastic water bottles. Yet, despite the success with which the technology is being applied in more and more fields, the heady days of the laser may already be over. "We haven't been able to discern any further increase in the number of publications in recent years," reports Bünstorf. The initial phase of technical development and the associated increase in research activity seems to have already reached an end. "With the whole world describing the 21st century as the age of optical technology, that's not what we would have expected." ▲