History of Laser Materials Processing

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In the 100 years of OSA, laser technology has played a part for more than 50 years and industrial laser materials processing has played a part for more than 40 years. This capsule view presents the highlights of these years.

Prior to 1970, a handful of commercial laser suppliers, located mostly in the United States, attempted to satisfy requests from a number of industrial manufacturers that showed an interest in the possibility of a laser materials processing solution to a unique production problem. A 1966 publication stated, “This year will mark the beginning of an accelerated growth for lasers. Many of the early problems involved in their use are nearing solution. In the commercial markets, the applications will center on welding and other high-power CO_2 and neodymium YAG (yttrium aluminum garnet) lasers . . . ” [1]. Interestingly, this otherwise optimistic report ended with the statement, “The markets for lasers will gradually develop over the next few years, but they are not nearly as imminent or as large as is frequently quoted.”

One reason behind this disparity may be found in the premise that the laser was “born fully grown,” a view held by many who read about the amazing possibilities for this powerful energy source, as evidenced by the commonly quoted line that “lasers are a solution looking for a problem” [2]. Industrial manufacturers that approached these scientific laser companies were from many different industries: glass, with interest in cutting flat plate glass [3]; mining, with interest in rock drilling [4]; packaging, with interest in cutting steel rule dies [5]; aircraft engines, with interest in processing turbine engine components [6]; sheet metal cutting [7]; paper, for cutting and slitting paper [8]; and microelectronics, with accelerating interest in trimming resistors and printed circuits [9] and cutting/scribing ceramic substrates [10]. Of these, only the latter two advanced to widespread industrial utilization stages in the late 1960s, pushed by soaring growth in the microelectronics industry. The others, all technically good applications, languished for a few years, fulfilling the prophecy cited above, as the laser suppliers struggled to develop devices with more power or better beam quality with improved reliability and maintenance procedures.

The most economically successful applications drawing attention from a wide segment of the world’s media were the use of a CO_2 laser beam to cut woven fabric for made-to-order men’s suits [11] and the use of a pulsed ruby laser beam to drill holes in diamond dies used as wire drawing dies [12]. The latter was the first industrial laser processing machine to be exhibited in the Smithsonian Museum in Washington, D.C.

While technical and economic cases can be built to explain the slow commercial success of the laser as a manufacturing process tool, widespread implementation of laser processes was inhibited to a degree by published articles. These articles were headlined, for example, “Death rays benefit mankind,” a phrase that can be attributed to a number of journalists searching for attention-grabbing headlines in the early 1970s. Implementation was also stalled because of the unfortunate labeling, by engineering societies and the U.S. government, of laser processing systems as a nonconventional materials processing technology.

One anecdote that illustrates the former is this author’s personal experience. While negotiating the purchase of a high-power CO_2 laser welding machine by a Fortune 500 company, he was startled to hear a company official sanction the purchase because he was impressed by successful laser cataract surgery performed on his brother-in-law.

Thus, the industrial laser suppliers of the early 1970s were faced with an additional selling burden, easing the concerns of uninformed, risk-wary buyers, and reassuring potential buyers that their lasers were reliable and safe. A common selling tactic was to identify a laser "champion" as the potential customer and to educate this person to be an inside sales advocate. Many of these champions became laser industry advocates through their willingness to publish complimentary articles.

Overcoming the nonconventional tag took many years [13], and it was not until the late 1980s that this sobriquet was dropped by those charged with producing industry statistics. The 1970s, a period that saw the blooming of several industrial laser suppliers, is considered by most analysts to be the beginning of the industrial laser market, with annual revenues for laser sales ramping from $2 million to $20 million in the first decade of the market, an almost 26% compound annual growth rate (CAGR). Several applications drove this growth: thin gauge sheet metal cutting [14], microelectronic package sealing [15], cooling hole drilling in aircraft turbine engine blades and vanes [16], steel-rule die board cutting [17], and semiconductor wafer dicing [18]—all applications that continue successfully today.

An interesting footnote to the early beginnings of the industrial laser material processing era is that these applications, and many that rose to prominence later, were accomplished using lasers that can best be called "industrialized scientific lasers," which were controlled by analog programmable controllers or tape reader numerical control (NC) devices. MIT scientists developed numerical control for machining in the 1970s, and it became commonly used in the 1980s. This technology was a major contributor to the growth of lasers for industrial material processing applications. The evolution to computer numerical control (CNC) [19] and the industrial development of minicomputers in the 1980s and the microprocessor in the 1990s vaulted the industrial use of lasers to annual growth rates in the mid-teens.

Through the 1980s and 1990s, solid-state lasers led by Nd:YAG devices and ultra-reliable low-power, sealed-off CO_2 units remained the backbone of the industrial laser materials processing industry. On a smaller scale, excimer lasers were used mostly in semiconductor processing [20] and metal [21] and non-metal applications in the manufacture of medical devices. These lasers had evolved from the scientific designs of the 1970s into ruggedized, reliable, low-maintenance products that were being integrated by system manufacturers into material processing products acceptable to a broad range of global consumer product manufacturing companies.

The utilization of industrial lasers, very much advanced in the U.S. in the first two decades of the technology, was due in great part to the marketing prowess of domestic equipment suppliers. This is counter to some international views, mainly in Europe, that the U.S. government, through the Department of Defense (DOD), funded the development of the laser products that were being used in commercial industrial applications. In reality, the industrial laser and systems suppliers of the 1970s and 1980s were essentially a part of a bootstrap industry, self-funded in terms of equipment and applications development. What little funding flowed from the U.S. government through its DOD Manufacturing Technology programs was focused on laser applications that could improve or repair defense products. In part, this lack of a national initiative to support progress in manufacturing stultified the growth of the industrial laser economy.

Stepping into the void left by this modest industrial laser program, the government of Japan in the 1980s and Germany (supported in part by the European Union) undertook university-based efforts to understand and improve the laser beam/material interaction on a broad range of materials. In Japan, most of the effort focused on defining and improving the process of laser cutting sheet metals [22], specifically stainless steel, at that time a major industry in that country. As a result, increased output power from new types of CO_2 lasers, improved gas-assist nozzle signs, and purpose-built cutting systems entered the market from a number of suppliers, first in Japan to a large number of custom cutting job shops and then exported to the international markets. In addition to this effort, the Japanese government funded a major program for flexible manufacturing, which had as a part the development of a very-high-power CO_2 laser that vaulted the selected supplier to the top of the CO_2 power chain.

In the late 1980s, almost concurrent with the laser cutting development in Japan, European CO_2 laser suppliers [23] made efforts to expand their markets by improving their product lines. This spawned the development of RF excited high-power CO_2 lasers and the consequent alliances with system integrators while educating the market about laser technology. In several countries, a “make it with lasers” program found eager interest among manufacturers. In Germany, the federal and state governments funded programs to improve the process of laser cutting, and one effort was designed to improve the manufacturing capability of small- to medium-sized manufacturers so they could become global competitors. As a consequence, the technology of laser material processing became familiar to manufacturers [24], paving the way for future employment of these processes in their manufacturing operations. European industry became “laser aware,” a situation that prompted the government to heavily sponsor laser and applications development, which has led Europe to become the major center of industrial laser and material processing and development today.

The late 1980s and the 1990s have been judged as the “golden” years of industrial laser materials processing. Abundant, pertinent, and beneficial development of laser applications, and the lasers and systems to achieve the processes, occurred during this period, led by institutions such as the various Fraunhofers [25] that built upon the basic understandings necessary to expand the use of these processes throughout the manufacturing world. As a consequence, industrial laser sales grew by more than a factor of eight in the period from 1985 to 1999. Driving market growth were global industries such as automotive, aerospace, agriculture, and shipbuilding for high-power lasers, and semiconductor, microelectronics, and medical devices for low-power units. The lasers being used remained those that had been introduced in the 1970s: Nd:YAG lamp and diode pumped at both the fundamental and the frequency-shifted wavelengths, CO_2 with output power up to 8 kW, and excimer that had a major redesign into more reliable products.

The turn of the century marked the thirtieth year for industrial laser materials processing, and the total industrial laser system market was then approaching $3 billion and laser sales were almost $1 billion, both experiencing a 23% CAGR [26]. The technology of laser applications was centered in Europe as was much of high-power laser development, while the U.S. retained leadership in the solid-state laser and microprocessing sectors and Japan, as a consequence of national economic conditions, slipped from a leadership role in the industrial laser market.

At this point, laser materials processing had become accepted by mainstream global manufacturing industries and the technology no longer was classified as unconventional machining, perhaps due in part to the fact that in 2000, laser machines represented about 10% of the total machine tools sold globally.

In the first decade of the new century, industrial laser growth showed a dramatic increase until the great recession of 2008/2009. After this major setback, the industry rebounded to prerecession levels, rapidly led by surging sales of high-power fiber lasers that were replacing high-power CO_2 lasers in sheet metal cutting applications. The rise of fiber lasers in this decade as replacements for other lasers used in established applications was the first major shift in the types of industrial lasers selected to satisfy industrial market demands. Low-power fiber lasers replaced solid-state lasers for marking and engraving applications, substituting for diode-pumped rod type devices in this market that installs more than 20,000 units per year. In 2012, fiber lasers represented 27% of the laser materials processing systems installed [26].

Also appearing in this period were high-power direct diode lasers with improved beam quality that increased the market for this efficient compact laser. Although output power for these focused beam devices had yet to reach the multikilowatt level, these lasers created interest among the many cutting system suppliers that had already converted to high-power fiber lasers.

As this is being written, the market for industrial lasers for material processing is well on the way to breaking the $10 billion/year mark. In 2012, 50% of the world market for industrial lasers was in Asia. Major markets have been established in China and Southeast Asia, and looming on the horizon are markets in South America, Russia, and India, which are expected to add to growth opportunities for industrial lasers.

Further, a new generation of laser and system suppliers is appearing in Asia with companies first serving domestic needs but eventually entering the global markets, establishing competition for the old line sellers that have dominated the market for decades.

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