EPIC
European Photonics Industry Consortium

Laser Market Report 2015

▸▸ *"Laser technology is one of the fields where Europe exerts a strong leadership. With a high level research community, a strong network of companies and end-users, many of today's new industrial and medical applications start in Europe."* *Eric Mottay, President and CEO, Amplitude Systemes*

Content

Laser Market Report 2015

A European Perspective...

1. Executive Summary

Laser materials processing systems are the dominant market sector for laser applications world-wide. The companies that form this sector are for the most part European countries, and the industry itself is the latest evolutionary development in a long European history of excellence in optics and fine mechanics. Yet, the development of laser systems requires competencies and experience in a range of disciplines such as optics, electronics, user interface design, material handling, IT interfacing up to machine vision for in-line quality inspection.

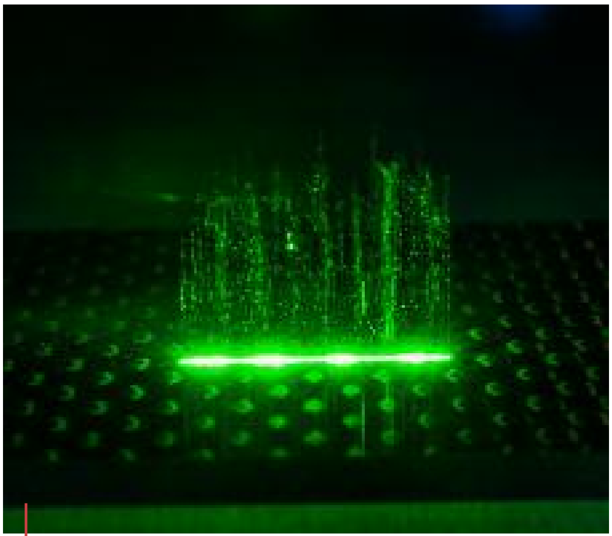
A key to healthy economic development in all laser sectors is progress from component manufacture to added-value systems development. Companies that do not or can not move up the value chain are faced on one hand with the challenge of declining unit selling prices and on the other hand the simultaneous requirement for capital investment to increase product volumes. This situation has been presented with eloquence by the semiconductor memory sector.

Development to capture added value is rather natural for sectors such as Medical-Cosmetic, while in other sectors, like communications, this development is hindered by the presence of large systems manufacturers, already in place, who work hard to maintain a stable of low-cost components that meet their needs.

The strong European presence in laser materials processing is reflected in a broad value chain with many participating companies, from fundamental materials development (like IQE in Wales, UK) through all aspects of laser-beam generation, to processing protocols and workpiece handling (like Prima Industrie in Italy). This value chain is supported by R&D funding that tends to support development of process systems based on lasers, rather than laser development per-se. In addition, there are a number of open-access laser process development laboratories where potential customers can try out new equipment and processes.

Laser materials processing has consisted traditionally of 4 basic manufacturing operations: surface treatment, marking, removal and welding. Most of these are subtractive: that is, materials are being removed from the workpiece. Laser additive processing, otherwise known as 3-D printing is a complement to these operations. For a number of years, laser additive processing was regarded as an artistic curiosity. However, it is now an important contributor to the laser systems market, generating 13% of total revenues in 2014. Furthermore, laser additive processing is growing at 20% per year for several years. We estimate that it will contribute 30% of laser system revenues by 2020.

Finally, there is a strong network of industry associations that work to build communications between laser companies and new technologies on one hand, and between laser companies and new customers on the other. This report from EPIC is a good example of this kind of contribution.



Thin film ablation with an ultrashort pulse laser
Picture: Fraunhofer ILT, Aachen / Volker Lannert

Laser processing setup with integrated machine vision for process monitoring
Picture: RAYLASE

2. Methodology

The market figures and other data in this report are taken primarily from current company financial reports, while market developments have been determined through questionnaires and interviews with laser specialists all over the world. We have also benefitted from data published by Optech Consulting and Laser Focus World.

In this report we focus on the value of laser systems. Laser systems are a significant indicator of impact on sector development, because systems are what most companies sell or are trying to develop for sale. This is in particular the case for laser materials processing, which is the largest market segment for lasers.

On an annual basis, the Laser Focus Wold magazine report a summary of market analysis for laser components carried out by Strategies Unlimited. The present report complements these data by focussing on systems value of these components. Fortunately, we know independently the systems value of the main sectors that compose over 70% of the market. This has allowed us to complete the systems market for the entire sector.

Finally, we are pleased to acknowledge the contribution of Roland-Berger Strategy Consultants for essential information regarding the development of the laser additive processing sector.

3. Laser Market

Laser Components vs Laser Systems

In 2014, according to data presented by Strategies Unlimited, (www.strategies-unlimited.com) sales of laser components were $9.8 billion. The two major sectors, materials processing and communications were of approximately equal size and accounted for about 70% of the basic components market. The communications sector is composed of diode laser applications: quaternary-alloy InGaAsP for transmitter and SOA devices, and GaAs-based diode lasers for pumping optical fibre amplifiers.

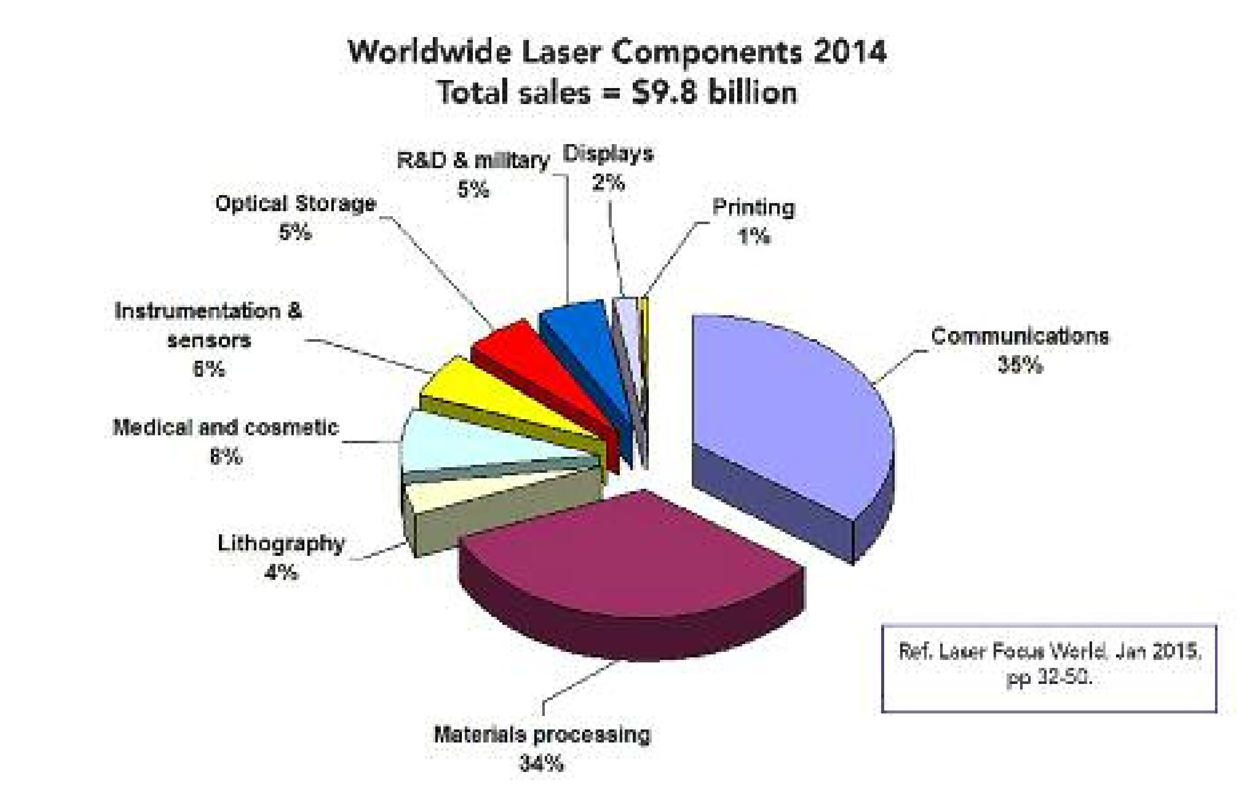


Figure 1. Strategies Unlimited 2014 Laser Survey puts the value of the laser components business at $9.8 billion.

This survey shows that the main application sectors for components are Communications, Materials Processing, Medical and Cosmetic, Sensors and Military-Security.

At the present time, the sizes of the medical and instrumentation sectors are comparatively small, although rapidly growing. The materials processing and manufacturing market is considerable. The value of laser systems for manufacturing is more than 3 times larger than that of the components alone. When we look at the sector analysis of the laser systems business, we see a different picture from that of *Figure 1*. Laser-powered manufacturing accounts for almost half the value of added-value system sales in 2014.

As accurate as these data might be, the strategic development of the laser industry worldwide is not focussed primarily on the value of laser components. It is based on the development and integration of lasers into value-added systems. Almost all major laser providers are working in this direction, acquiring companies that constitute the value-chain, and providing customer solutions rather than lasers alone.

The leading laser companies like Trumpf and Rofin are good examples of this trend. These companies design and manufacture lasers as part of systems, which is what they sell. The laser systems business is of course larger and a better way to view the industry from the points of view of customers and laser manufacturers.

Some examples: Optech Consulting who follow *laser systems markets* put the value of the materials processing market at $11.6 billion in 2014 (www.optech-consulting.com). This can be compared with $3.4 billion for the value *of laser components* in materials processing given in the Strategies Unlimited survey. The added-value is more than 3 times the component value alone. Finisar, the sector leader in communications components and systems has determined that the sector had revenues of $7.4 billion in 2014, of which $5.4 billion can be attributed to *laser systems*. This can be compared to the value of $3.6 billion determined by the Strategies Unlimited survey for *components alone*. In these examples we can see that the potential for capturing added-value is significantly larger in the Materials Processing sector than for the case of the Communications sector.

EPIC research shows that the value of the laser systems sector was $27.3 billion in 2014, versus $9.2 billion for components alone. The breakdown by sector is shown in Figure 2 below:

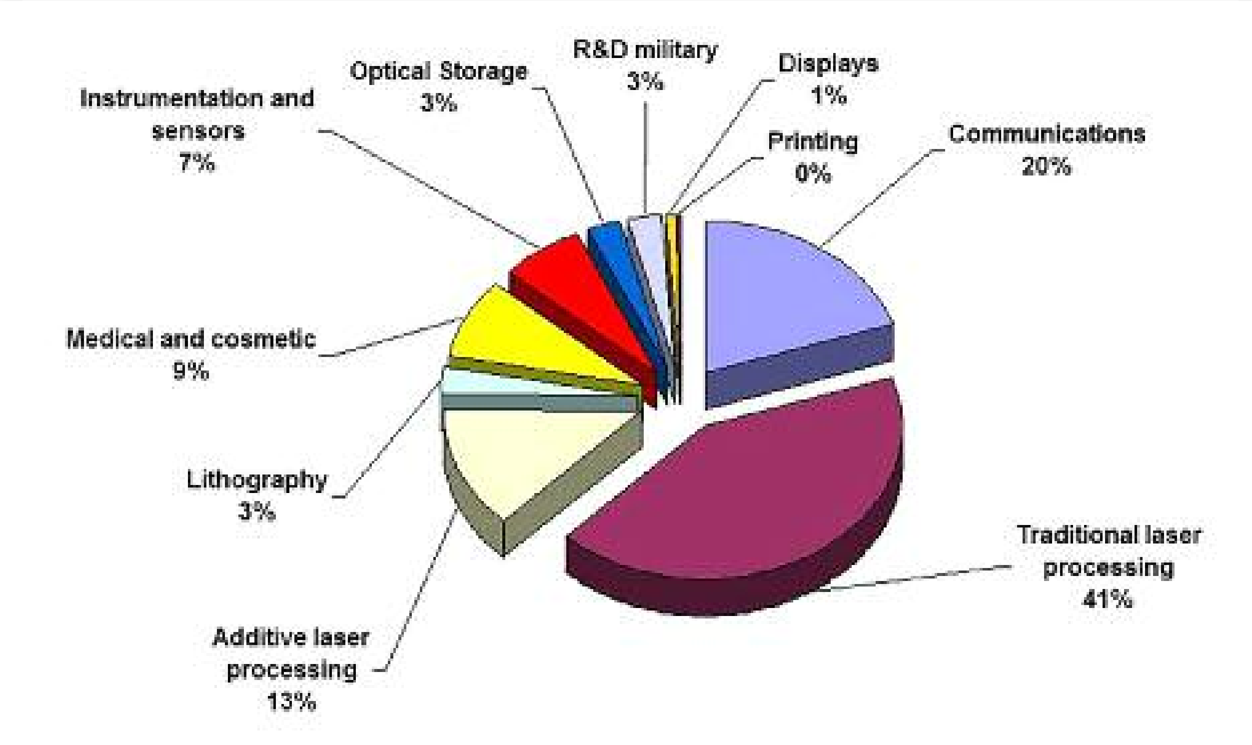


Figure 2. EPIC research values laser systems market at $27.3 billion, about 3 times larger than the laser components market. The value of the laser systems market is significantly higher than the components alone. System integration offers different opportunities for each sector. Three sectors in particular offer a large potential for added value:

- *Lasers for medical and cosmetic operations.*
- *Lasers for instrumentation and sensors.*
- *Lasers for materials processing and manufacturing, including both traditional and additive laser processing.*

In these cases, added-value is captured by providing customer solutions in addition to technology. Laser materials processing accounts from more than 50% of the total industrial laser systems market.

To determine the value of the laser systems market, EPIC has consulted audited financial reporting of a large number of companies who are principal actors in the laser industry. This analysis shows that the principal sector is Materials Processing, followed by Communications, Medical-Cosmetic, and Instrumentation-Sensors.

In the next sections of this report, we will examine these sectors, discuss the most important companies by size as well as identifying dynamic and innovative companies that are introducing innovative and even disruptive technologies. Since materials processing is the most important sector, and a sector dominated by European companies across the entire value chain, we will focus on this activity.

2D fiber laser cutting machine for high productivity

3.1 Laser-based Materials Processing

The laser systems market for materials processing and manufacturing, both additive and subtractive reached $14.2 billion in 2014, according to a studies by Optech Consulting and Roland-Berger. The 4 largest parts of this sector are in order of decreasing size:

1. Fibre lasers
2. CO_2 lasers
3. Solid-state lasers, including Diode-Pumped Solid-State Lasers
4. Direct diode lasers

Fibre lasers have been consistently a growing part of this market for several years. In 2014, Fibre lasers overtook CO_2 as the leading revenue producer for industrial laser systems. The major component in the fibre laser is the diode laser pump package. The diode pump can also be used as a stand-alone system for a number of industrial applications, like marking. The direct diode market also shows strong growth. In figure 3 we show that more than 60% of the market for laser-powered materials processing is based on high-power GaAs diode laser technologies. This trend is expected to continue with diode-based systems progressively replacing solid-state and CO_2 lasers.

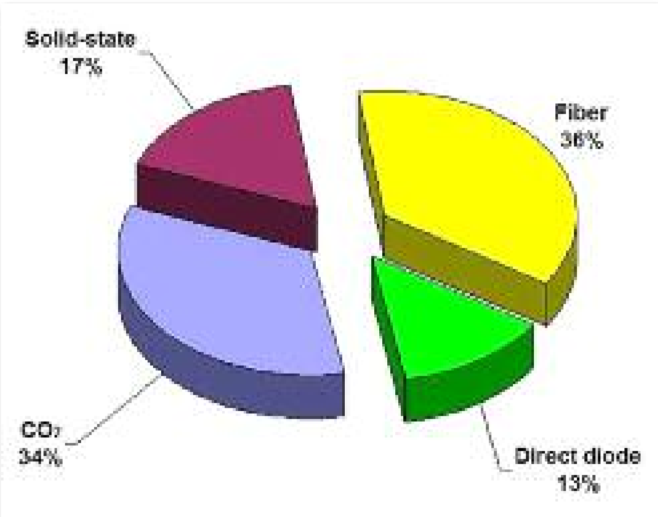


Figure 3. More than 60% of laser systems for materials processing are based on GaAs diode technologies.

The major companies, having more than $200 million in revenues and engaged in laser-powered materials processing are :

Traditional	Additive	Company Name	Revenues
X	X	Trumpf	$3 420
X		Bystronic	$350
X		Han's Laser	$941
X		IPG	$745
X		Rofin	$530
X		Prima Industrie	$500
X		Coherent	$794
X		Jenoptik	$720
X		Cymer	$810
	X	Stratasys	$750
	X	3D Systems	$653
	X	Proto labs	$209

Table 3.1 Laser System revenues of major (Revenue > $200 million) laser companies.

With the exception of Han's Laser and Cymer, these companies have a strong design and manufacturing presence in Europe. However Cymer Laser, based in San Diego, California, has recently been acquired by ASML, a Dutch company.

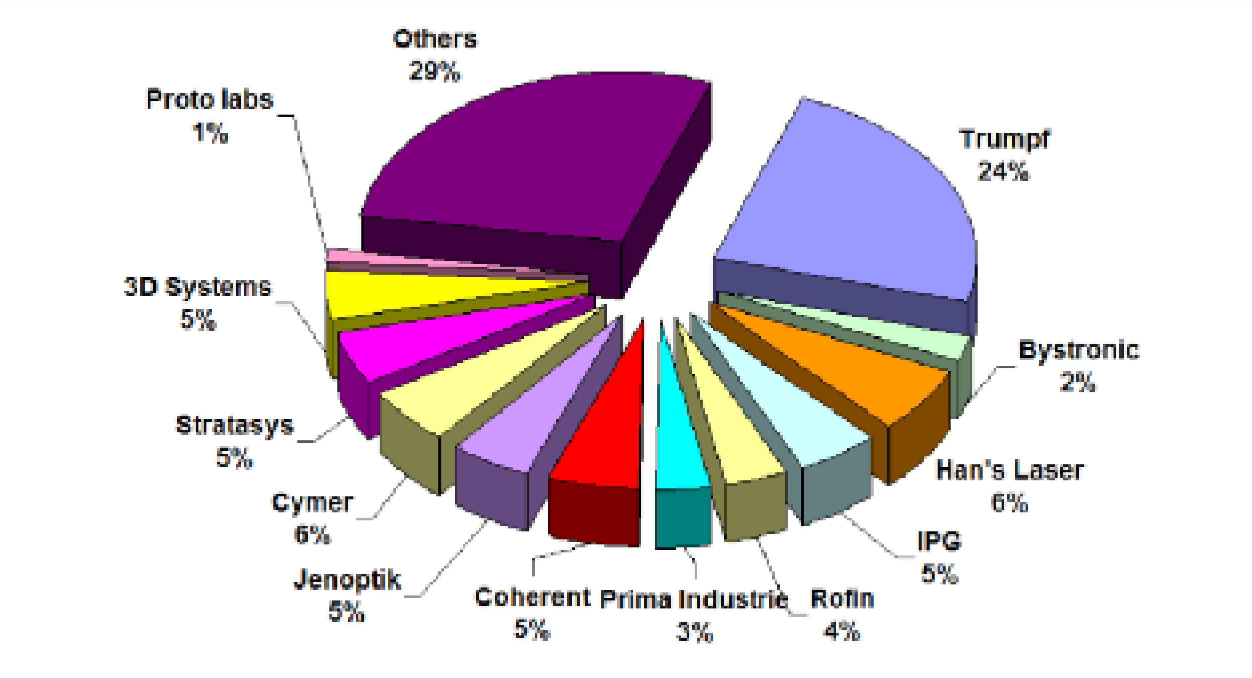


Figure 4. Trumpf is the market leader accounting for about 25% of laser systems revenues for materials processing. They are present in both traditional and additive laser processing systems.

The value chain for materials processing systems depends on the technology. In general there are four basic elements: Laser-beam generation, beam delivery, process environment, and workpiece handling. In addition, European institutions provide supplementary support through R&D and also through user facilities that perform personnel training and process development using advanced laser sources.

Significant value is added by adapting the laser engine to the specific process of the customer. The basic application could be marking, cutting or welding. Such operations require process gases, waste material evacuation, optimization of laser power and pulse duration, as well as efficient handling of the workpiece to achieve both the desired pattern and optimized throughput. In Figure 5 we show a schematic diagram of the value chain for fibre lasers. Examples of some of the companies that specialise at each level are also indicated. Companies like Rofin and Trumpf, integrate components made by other suppliers. In some cases, these companies have been acquired as subsidiaries. For example: Dilas and Optoskand are owned by Rofin, while SPI is owned by Trumpf.

- a light weight 300W/200μm fiber laser pump module for aviation application
- a red module at 40W/400μm, for cinema projection
- and a series of fiber coupled pump modules from 250W, up to 2kW

1kW OEM laser module by Coractive

3.2 Applications: Traditional Laser Processing and Additive Materials Processing

Traditionally the laser-based manufacturing has been divided into 4 operations:

- Welding
- Cutting
- Drilling
- Marking

For reference further on, we will call this the laser machining sector.

Cutting process of fiber reinforced plastics
Picture: Fraunhofer ILT, Aachen, Germany / Volker Lannert

Beginning about 15 years ago, a 5th operation; *Additive Materials Deposition*; or 3-D printing has been developing. This technology uses a computer-driven laser beam to solidify a spray containing metals or plastics, to build up a 3-D structure layer-by-layer. Additive materials deposition has been growing at a rate of 20% or more per year for the last 10 years. It now accounts for 13% of all industrial laser system sales. Roland-Berger estimates that in 2020 (5 years from now) the laser additive manufacturing sector will be similar in size to the traditional laser machining sector.

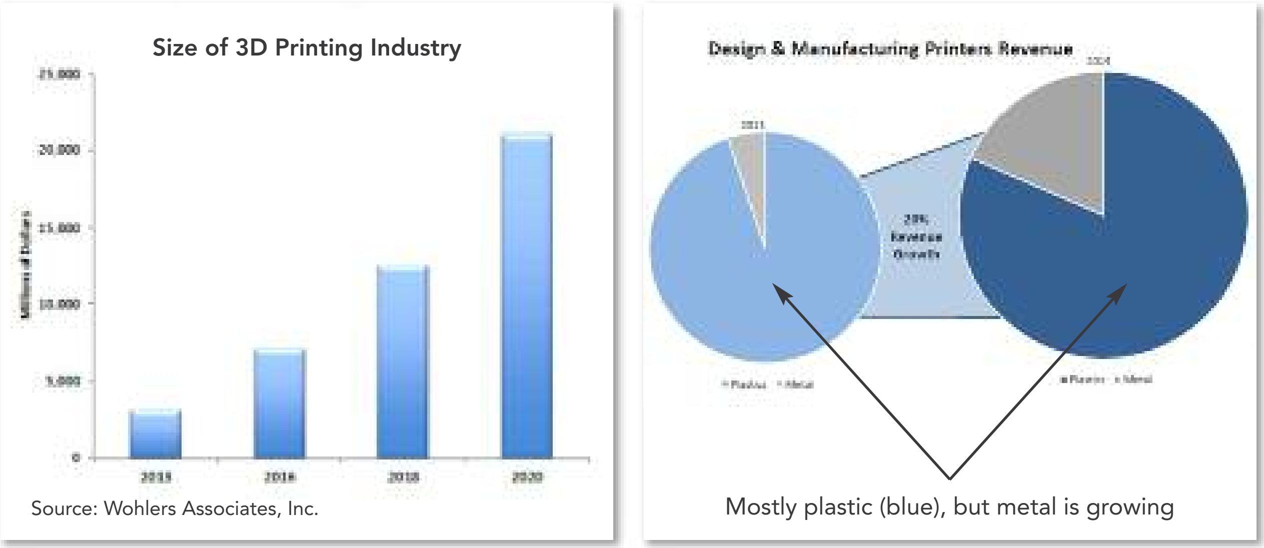


Figure 5. The 3-D printing sector has been growing at 20% per year. Projections claim that this sector will quadruple in size by 2020.

There are two main manufacturers of laser additive depositions systems world-wide: Stratasys, based in Israel and 3-D Systems based in the United States. In Europe, Trumpf is responding to this opportunity by offering its first laser deposition system in 2014.

At the present time, the vast majority of 3-D printing is producing product based on plastic. However, the technologies for 3-D printing of solid metal parts has been developed and is being rapidly deployed. Data from Wohlers Associates show that between 2013 and 2014, the production of metal parts has quadrupled in volume.

Additive laser deposition of metal results in material that has a density less than that of the bulk. Thus the weight of a finished part made by 3-D laser deposition is less than that made by laser machining or by cast metals. The key question is how to maintain required strength and resistance to fatigue, while reducing the weight at the same time. There appears to be good progress in this area, assuring the capacity to treat both metals and plastics by additive deposition. The weight savings has been a big selling point for 3-D laser manufacturing in the aviation and automobile product sectors.

Using commercially available equipment, 3-D manufacturing is a time-consuming process, requiring hours to days to make a single part. These systems are typically used at the present time to make prototype parts for testing and evaluation. In order for the sector to fulfil the very optimistic growth projections, technology development will need to make progress in the deposition rate.

3.3 Materials Processing Value-chain Analysis

3.3.1 CO_2

The four basic technologies used in materials processing systems are shown in Fig. 3. Of these, CO_2, although it has significant market share, is manufactured by only a few highly vertically integrated companies. It is the only one of the 4 technologies that does not make use of diode lasers. Laser action occurs in a CO_2 gas environment, either a sealed tube or flowing variety. As with all gas lasers, there are issues of tube lifetime and maintenance Emission occurs at 10.6µm. The beam quality is good, but it cannot be delivered efficiently to the workpiece except by near direct contact between the laser emission head and the workpiece. In addition, process gases like oxygen are required to optimize the laser action on the workpiece. However, these lasers put out a lot of processing power. They are affordable and highly competitive with fibre lasers for marking, cutting and welding. Customers who use these lasers can benefit from an extensive library of processing experience, making this a low-risk choice. On the other hand, there is a limited amount of investment to enhance CO_2 technology, while fibre laser designers are working hard to surpass CO_2 performance. In Figure 6 we show the value chain for this technology. Companies are listed as examples only. There is no attempt to be all-inclusive.

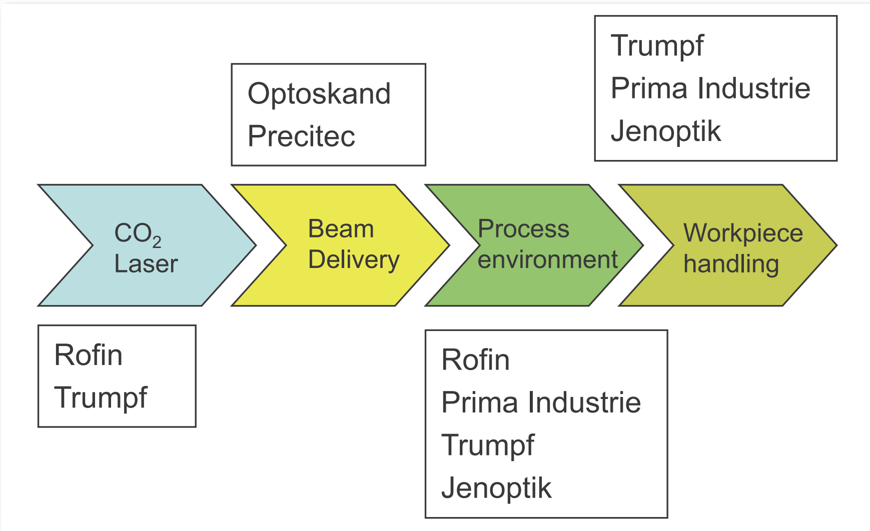


Figure 6. Schematic value-chain for CO_2 lasers.

3.3.2 Fibre Lasers

The fibre laser value chain captures a number of photonics activities in Europe. The fibre laser integrates three main technologies: semiconductor diode lasers, fiber lasers, and process development. The output of a fibre laser is a well-behaved single-mode optical beam. This means that it can be scanned and focussed on a remote spot, opening up a significant array of processing options. The diode pumped package can be designed to deliver optical pulses of exceedingly high peak power 10's of kilowatts in an ultra-short pulse (10's of femtoseconds) enabling cutting and drilling without melting the target materials. This opens up the processing of glass and ceramics by lasers. Because of its versatility on one hand and a rapidly innovating technology, fibre-lasers will continue to build market share, in part by replacing CO_2 in many applications.

There is diverse group of companies that participate in the value chain, and major processing system manufacturers like Trumpf and Rofin have been quick to acquire companies along the value chain to ensure both innovative development and access to emerging technologies.

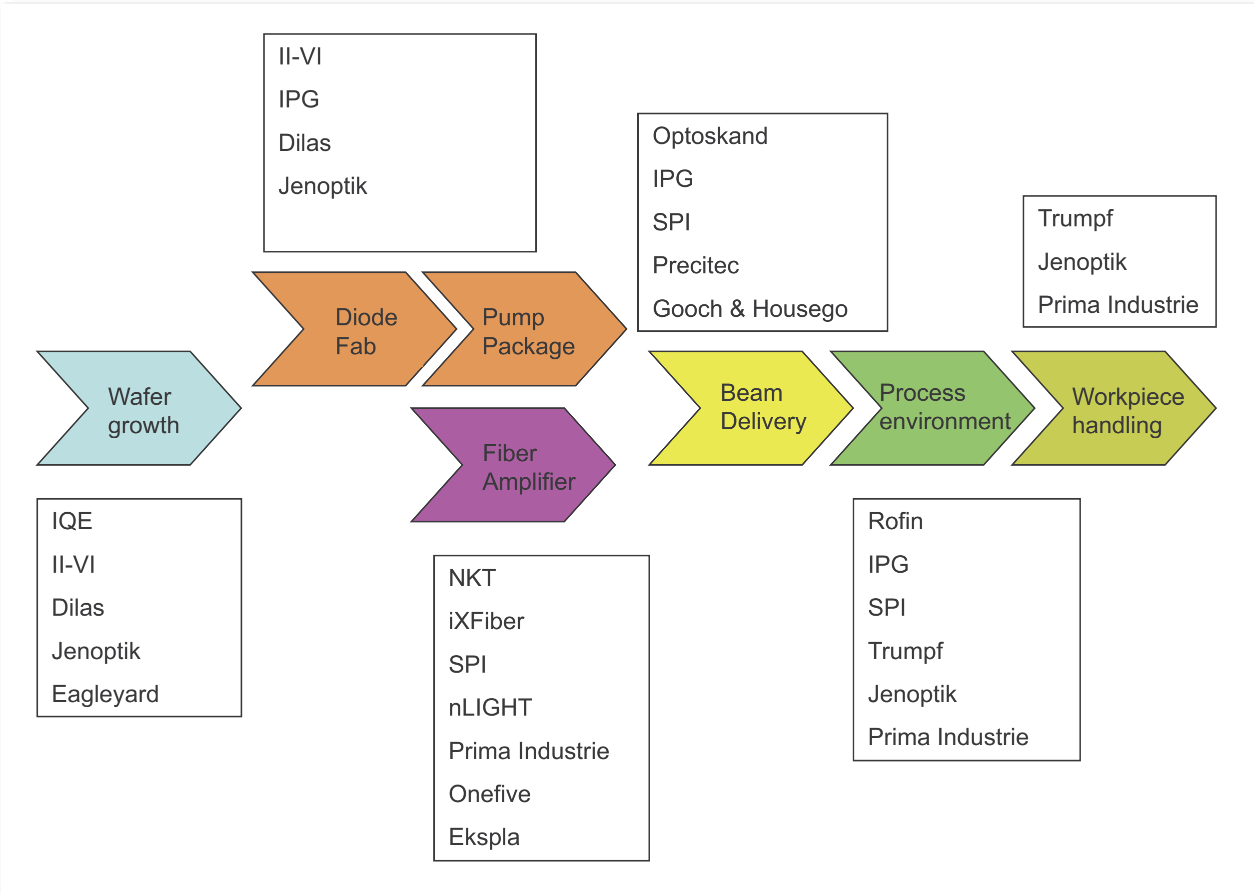


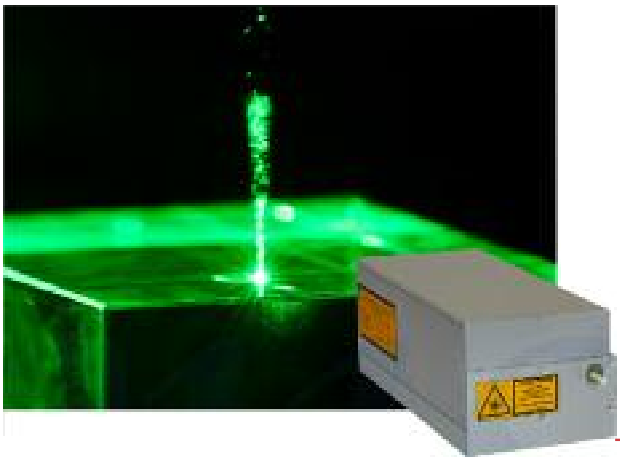
Figure 7. Schematic value chain for Fibre Laser materials processing system.

Because of this diversity, the value chain for fibre-lasers includes a good number of the industrially-oriented laser companies in Europe. Examples of a number of these companies are noted in Figure 6, although there is not room to make an exhaustive list

3.3.3 Diode-Pumped Solid State Laser

Diode-pumped solid-state lasers DPSSL are very attractive for some applications, such as for very high peak power pulses. The DPSSLs are particularly effective for harmonic generation, especially at low output powers. This feature can be used to generate Red-Green-Blue sources for compact laser projection. This laser design is relatively easy to design and assemble from components that are widely available on the market. As a result the technology is a good point of entry for smaller companies that seek a place in the market. The resulting laser systems are often destined for research laboratory or prototype development and evaluation applications. There are many smaller companies (revenues < $50 million) that work in this space.

As an example, recent developments in fast q-switching technology allow Bright Solutions to manufacture short pulse lasers with pulse duration down to 200 ps in compact air cooled industrial packages. Such laser sources allow generation of peak power in the kW to MW range allowing efficient micromachining of many hard and transparent materials like glass and sapphire. The same kind of laser sources are being used in airborne LIDAR applications where high accuracy range measurements as well as environmental insensitivity are needed. The laser package is a “single block” where electronics and optics are tightly integrated so that no delicate connections and fiber cables are necessary, thus simplifying integration.



The Wedge-HF lasers from Bright Solutions allow sapphire micromachining with 100s ps pulses in an environmental insensitive compact aeronautical-type package

3.3.4 Ultrafast Lasers

Ultrafast lasers produces pulses with picosecond or femtosecond pulse duration. They are available either as fiber lasers or solid-state lasers (thin disk, slab, Titanium:Sapphire). Due to their very short pulse duration, they exhibit an extremely high peak power. They are used in basic research, in medical and micro-processing applications. Because of their very short pulse duration, they enable very precise material processing with virtually no heat generation. The ultrafast laser market is estimated today at more than 500 M$ (source: Strategies Unlimited), and is experiencing significant growth due to the requirement for ever smaller feature size and quality requirements. Industrial applications include micro-electronics (semiconductor dicing, glass cutting for displays, …), medical device manufacturing, drilling of injector nozzles, etc. From the research point of view, Europe benefits from the large scale ELI (Extreme Light Infrastructure) European program which aims to build three very large research facilities for high energy physics in Eastern Europe. Europe in general enjoys a strong position in ultrafast lasers, with key research centers (University of Jena, ETH Zürich, Institut d’Optique, …), and major industrial players (Amplitude, Trumpf, Rofin, …).

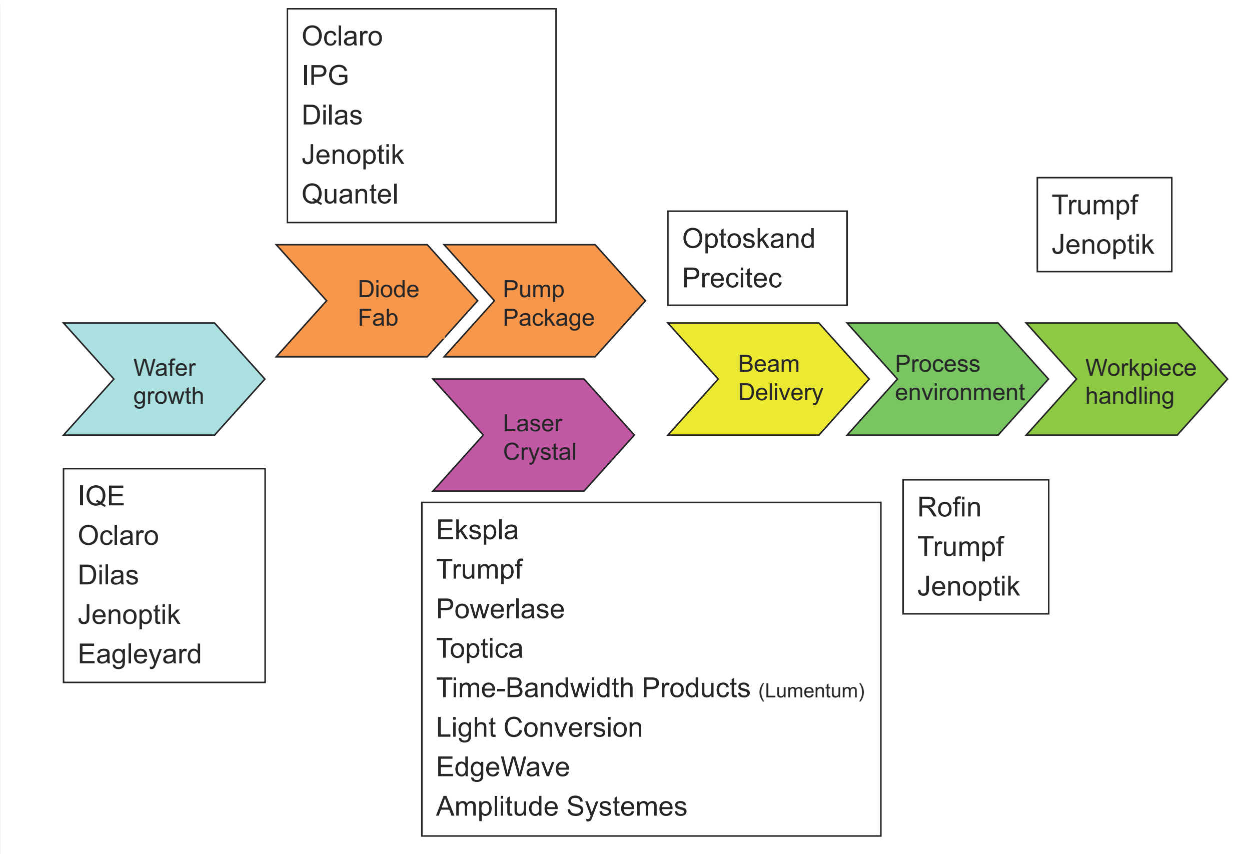


Figure 8. Schematic value chain for diode-pumped solid-state laser materials processing system.

Thin-disk lasers are a special class of DPSSL design. Although the principles are the same, the thin-disk laser has been optimized to deliver high-power, pulsed lasers for industrial scale materials processing. Trumpf has invested considerably to make the disk-laser one of its main light engines for laser processing systems. Europe, in particular, has supported R&D in thin-disk lasers through the European Union, and the German BMBF programs. As a result a lot of exploitable intellectual property in the technology resides in European companies. Disk lasers use Yb:YAG crystals as the gain material (with output at about 1030 nm) because this can be doped to achieve maximum gain. Yb:YAG crystals are excited by pump diode lasers emitting in the range of 930 to 945 nm.

Femtosecond DPSSL laser with integrated 3-wavelengh harmonics module from Light Conversion. This small footprint versatile system can deliver both: multi-GW peak power pulses for non-linear effect driven processing or MHz repetition rates for high speed machining.

InnoSlab lasers and InnoSlab amplifiers are considered as compact, efficient, reliable and scalable laser sources with short and ultra-short pulse length. InnoSlab lasers and amplifiers have slab shaped crystal. The slab crystal is partially pumped by diode laser beam. The oscillator is a hybrid resonator formed by a two cylindrical mirrors. In case of InnoSlab amplifier two cylindrical mirrors are used for generating multi passes through the slab crystal. Since 2001 EdgeWave provides InnoSlab lasers for industrial applications like precision processing of glass, ceramic, sapphire, cutting of PCB board, ablation of thin film in photovoltaic and display and for scientific applications like particle imaging velocimetry, laser induced fluorescence spectroscopy, pumping of dye laser and OPO, etc.

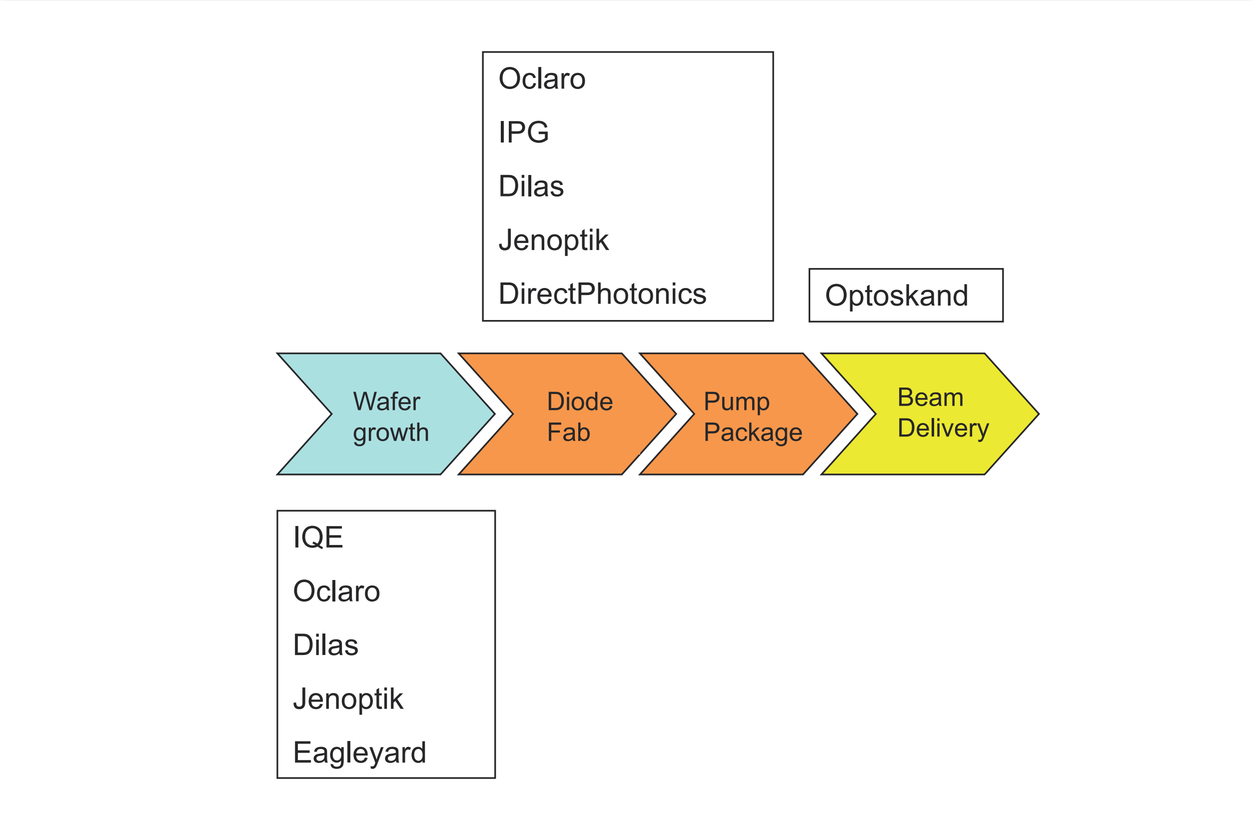


Figure 9. Schematic value chain for Direct Diode Laser materials processing system.

> ***"Ultra high brightness Direct Diode lasers will penetrate the market for lasers in industrial manufacturing. Continuously improving power and beam performance out of semiconductor lasers plus enabling combining techniques will make high power direct diode lasers an alternative source to fiber lasers in the near future."***
>
> *Wolfgang Gries, CEO, DirectPhotonics Industries*

Most femto- and picosecond lasers for micro-machining use compact and cost effective ultrafast fiber seeders

3.3.5 Direct Diode Lasers

Diode laser have not been used for material processing like cutting and welding as the beam performance was not good enough. The new generation of Direct diode lasers show now a high brightness in a kW level suitable for such material processing. The diode package is not based on geometrical stacking only anymore. Especially wavelength multiplexing is utilized for generating highest power launched into small multi mode fibers realizing kW output power with BPP < 10 mm mrad. Due to the fact that no resonator is needed the footprint is very small and the wall plug efficiency is very high, often > 45%. Still there are only few companies that provide such high brightness direct diode lasers but first results show similar performance like fiber lasers in metal cutting or welding. Although the lower wavelength of < 1 µm combined with broad band emission gives a benefit in absorption for some materials.

The 500 W Building Block from DirectPhotonics is based on wavelength multiplexing and directly integrated driver electronics and all common industrial interfaces generating 500 W in 7.5 mm mrad with the size of a shoe box

Where are materials processing lasers being purchased?

Using data provided by IPG, we can complete this discussion with an example showing where laser systems are sold. Since IPG has by far the largest market share in fibre lasers, this gives in particular a snapshot of world-wide fibre laser sales by region. Fig. 9 shows that sales are evenly distributed among the highly industrialized regions of the northern hemisphere.

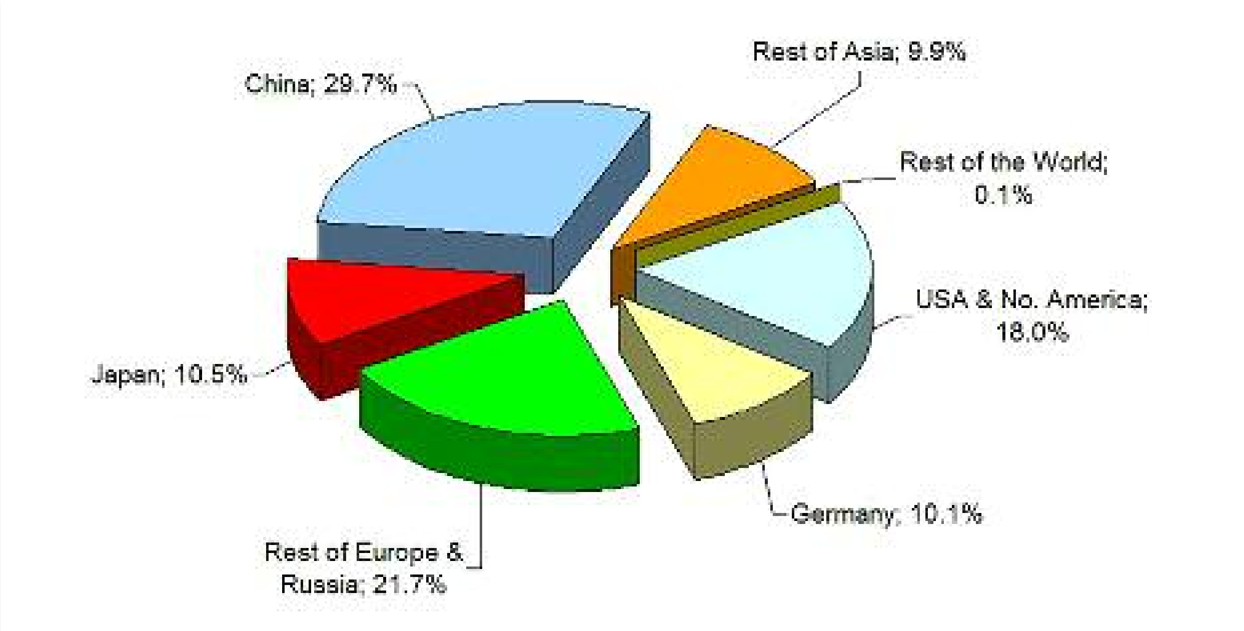


Figure 10. IPG, the world-wide leader in fibre-lasers, has major manufacturing sites in the US and in Germany. However, it sells its systems globally, with China being the principal sales region.

Although the largest sales volume occurs in China, the concentration of sales in Germany is much higher than any other region.

3.4 Communications Lasers Value-Chain Analysis

Lasers for telecommunications applications can be divided neatly into two groups: (1) low-power, single-mode lasers with gigabit modulation bandwidth based on InP and InGaAsP heterostructures, and (2) high-power CW lasers based on GaAs/AlGaAs which are used to pump fibre amplifiers. This latter group consists of devices that are very similar if not identical to those used to generate laser action in materials processing lasers, and they are made by the same companies. The profits in the telecommunications sector come primarily from lasers based on InGaAsP/InP devices. Integration of these lasers with switches, amplifiers, modulators, etc, also based on InGaAsP/InP heterostructures is a route toward building and capturing added-value, and is being led by Oclaro in its UK facility.

Lasers for telecommunications signal generation are designed to meet specifications determined by major network operators. There are only a handful of these companies in the world, and they work to harmonize requirements where possible, so that networks can be connected in a compatible and transparent way. At the component end of the value chain, all specifications are precisely defined and well-known: performance, device footprint, reliability, etc. The customers are a small group of systems manufacturers: Alcatel-Lucent, Huawei, etc who use these components to design highly-functional communications systems with significant added-value that meet network requirements. In this environment, an innovation must sometimes wait until all the customers agree to use it. On the other hand components manufacturers can freely work to lower their own costs. Thus, management of outsourcing is a key to maintaining profit margin. On the other hand, it is more difficult to grow margins by introduction of value-added products. This leads to an evolution of market value that is similar to that for LEDs or semiconductor memory: manufacturing volume rises, accompanied by declines in unit price and margins.

This is a very different market environment from that of materials processing, where many fewer systems are manufactured, and where individual manufacturers, like IPG or Rofin, can introduce specific innovations into a system in order to give the customer a competitive advantage.

The communications laser sector is led by Finisar, based in California, who recorded 16% of sector revenues in 2014. Ten years ago there were a number of competing European companies manufacturing communications lasers: Alcatel, Infineon, JDSU, 3S-Photonics, Oclaro (Bookham). Today, most of these companies have been consolidated or sold. The beginning of this change was announced in 1999 by Serge Tchuruk, then CEO of Alcatel, who decided that Alcatel would close its telecommunica-tions components factories and buy its components from qualified suppliers. Basically this was the announcement that Alcatel would move up the value chain in order to capture added-value in systems and improve its margins. The diode laser industry is now dominated by American and Asian companies.

Oclaro stands out as a contributor with strong European roots. Although the company is head-quartered in California, the key design and fabrication of its communications lasers is carried out in the UK. Oclaro has recently sold its Eu-located GaAs division which designs and manufactures GaAs pump lasers, and GaAs VCSELs to the US Company II-VI in order to focus on InP-quaternary-based low-power high-speed communications lasers, modulators and detectors. Oclaro owes its success to its ability to manufacture in large volumes very high bandwidth lasers with excellent control of emission wavelength and reliability that exceed systems requirements.

There are a handful of smaller, European-based telecoms diode laser companies. These produce innovative devices in small lots for customers developing prototypes that might be suitable for large scale manufacture. In every case that we have studied, these companies are diversifying their products to meet demand in other sectors. Innolume is addressing telemetry in oil and gas exploration. VI-Systems is focussed on datacomm for short-distance very-high capacity data exchange, but also selling test boards incorporating its lasers. Modulight is positioned as a medical laser company. In each of these cases, diversification has opened the path to capture of added-value by integrating their laser as an enabling device in a larger system.

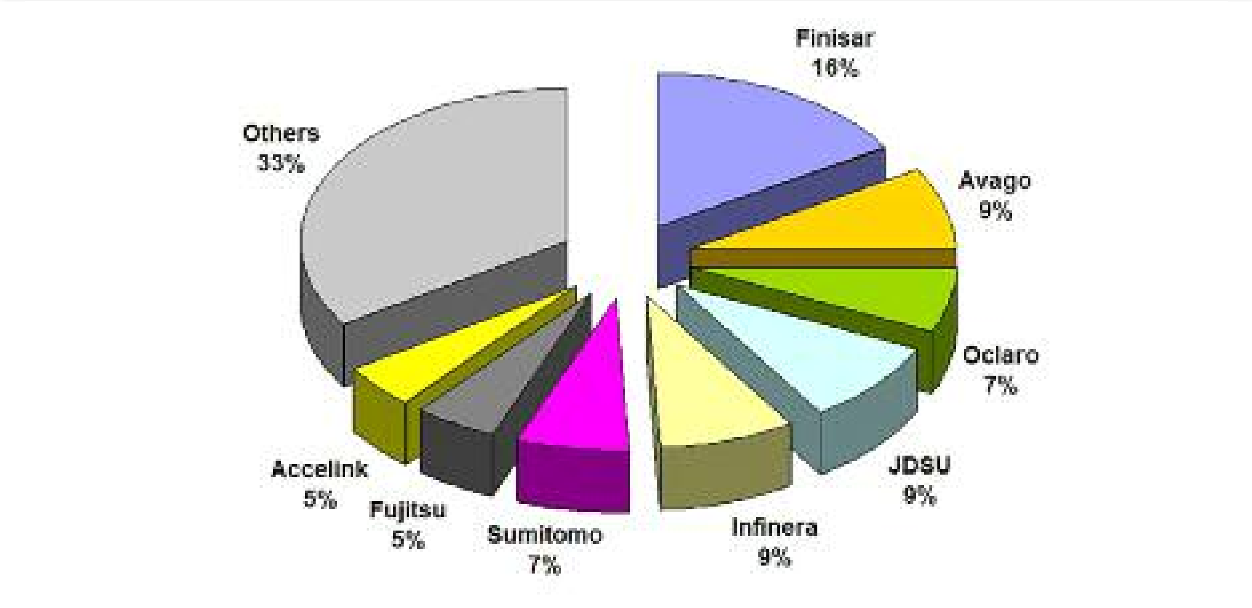
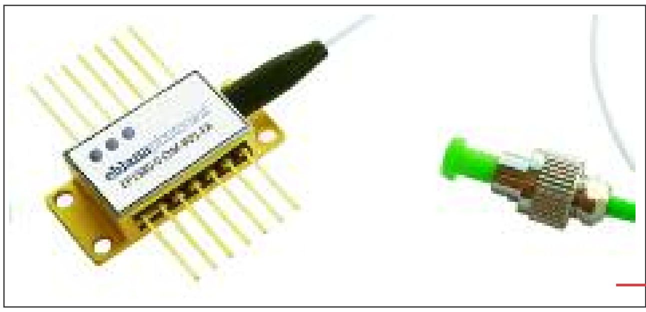


Figure 11. The market for lasers in telecommunications is dominated by companies located in Asia and the United States. Oclaro is the principal European company with a strong position in this market sector.



Eblana Photonics EP1580-DM laser, emitting at a range of wavelengths around 1580nm, is specifically designed for sensitive detection of hydrogen sulphide, carbon dioxide and carbon monoxide in TDLAS systems. The laser can be packaged in 14-pin butterfly and free space TO-39 can with TEC.

The communications lasers have the largest growth rate of any of the major market sectors (see figure 2). Growth is powered by consumer demand for higher capacity networks that can deliver rapidly evolving internet-based communications. In 2014 the communications laser components business was worth $3.6 billion, while the value of these components in transmitter systems industry-wide was $5.4 billion. At the current time, there is an exceptional demand for components as telephone operators, such at BT or Deutsche Telekom are working to raise network capacity.

A typical supplier is positioned at the bottom of the value chain with basic design of the laser epitaxial structure as the basis for intellectual property and competitive advantage. Lasers can then be made in-house, such as the case with Oclaro or subcontracted to a custom semiconductor epitaxial wafer fab. In almost every case, wafers containing laser structures are packaged under subcontract in Asia. Some companies then sell packaged chips, while others will go further by integrating the laser on a circuit board with photonics components for wavelength multiplexing and demultiplexing, amplification, switching and detection.

3.5 Medical and Cosmetic Value-Chain Analysis

This is a sector where, unlike either the materials processing sector or the communications sector, there is a wide variety of laser technologies that are used.

- Superluminescent LEDS (SLEDS) are key for optical coherence tomography (Exalos).
- Diode pumped lasers for cutting and etching in ophthalmic operations (Quantel, Onefive).
- Photodynamic therapy, specific wavelengths required) for cancer treatment (Modulight).
- Ultrafast lasers for vision correction and cataract surgery (Amplitude Systemes).

Lasers for medical and cosmetics are designed using criteria that are significantly different from other application areas. The laser emission wavelength is determined by the biological system of interest and often falls in the visible or ultraviolet. Beam power should be kept as low as possible, and pulsed lasers are preferred to minimize heating of collateral material. Hand-held portability is often required with the surgeon holding the laser beam delivery unit at the operating table.

The femtosecond laser Origami XP from Onefive is largely integrated into ophthalmic operating stations. It offers the highest portability and the easiest possible system integration thanks to its innovative air-cooling system, reduced footprint and removable handle bars.

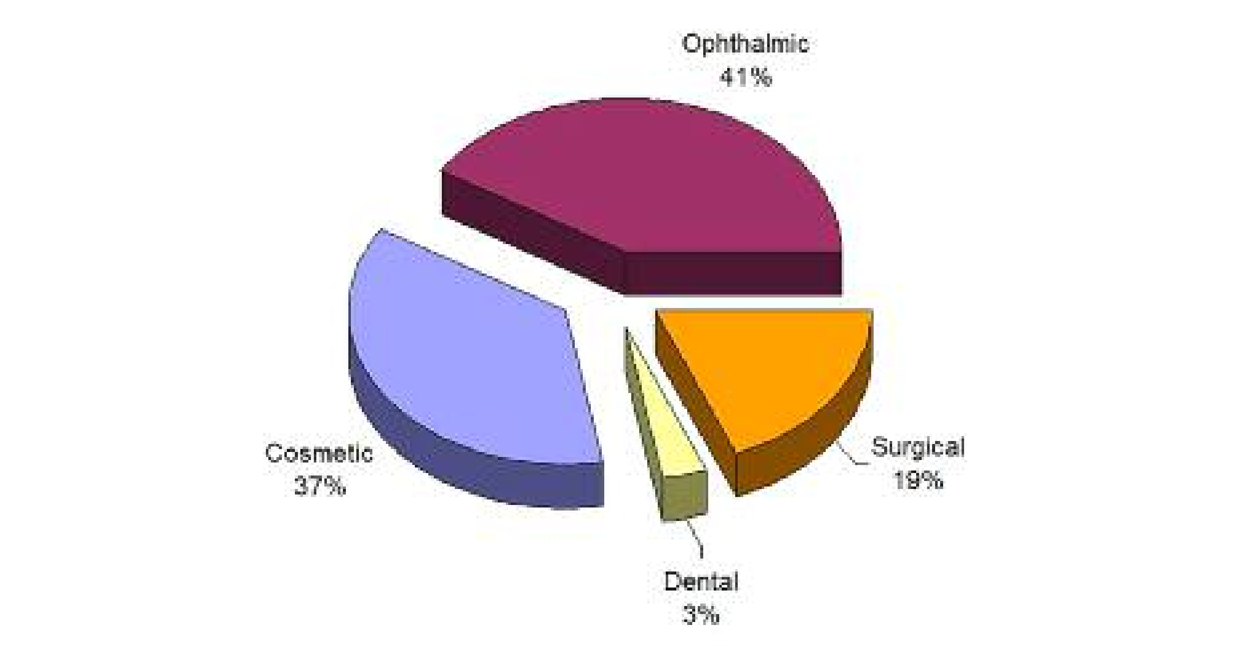


Figure 12. The Medical and Cosmetic sector contains 2 market areas of approximately equal size: Ophthalmic and Cosmetic treatments.

The medical and cosmetic sector currently represents 10% of the overall laser systems market. It should be noted that systems in this sector and particularly the cosmetic systems have a tremendous potential for capture of added-value through the integration of up-stream features and capabilities. There are two reasons for this situation.

This sector is not controlled by a few large medical equipment manufacturers. Thus a company that manufactures an appropriate laser can continue to develop its equipment into a sophisticated laser surgery station without being blocked by a well-established potential customer higher up in the value chain. Lumenis (Israel) and Cynosure (USA) are two laser systems developers who are making strides to move upstream.

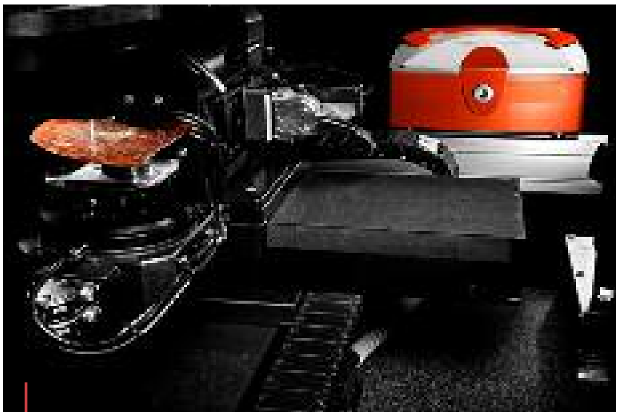
Cosmetic treatment uses small and relatively inexpensive diode pumped laser systems. Strategies Unlimited estimates that more than 300,000 lasers for this application were sold in 2014 with an average selling price of less than $1000 per unit. This indicates that there are many care-givers working in this space. The average selling price of a laser tool is declining year-on-year, while the annual increase in sales volume is more than enough to offset this decrease. The majority of sales take place in Asia.

Diode pumped solid state laser developed by Monocrom are used to treat macular degeneration of the eye. This Q-Switched green solid state laser is capable of providing microseconds pulses and is considered one of the most important developments in eye surgery in the last years.

The ophthalmic application space is quite different. Strategies Unlimited reports about 13,000 units sold in 2014, with an average selling price of $24,000.

The European leader in the area of optics applied to medicine is Zeiss Meditec, with many years of experience. Meditec reported revenues of more than $1.2 billion in 2014. As much as $200 million may be attributable to laser systems for ophthalmic treatments. In Figure 13, we show an ophthalmic operating station from Zeiss, an excellent example of added-value design incorporating a laser as the processing engine in sophisticated surgical station.

Figure 13. The Zeiss MEL-80 laser system consists of an ArF excimer laser. This is a good example of a value-added system. Used for ophthalmic surgery, the laser itself is not readily visible.



Satsuma ultrafast fiber laser used in the semiconductor and display industries

›› 3.6 Security, Military Value-Chain Analysis

The military / security sector is in terms of laser types a vast market space, part of which is shrouded in secrecy. At the high-power end, there are two European centres that design and build laser systems that create small thermo-nuclear explosions for nuclear weapons development. Next in size are systems for controlled nuclear fusion for electrical power. There is a military market for directed energy weapons that are capable of disabling missiles and satellites. Rheinmetall in Düsseldorf is designing and manufacturing such systems.

Rheinmetall showcased this weapon's capability at the company's own test center in Ochsenboden in Switzerland. This event saw the first-ever deployment of mobile laser weapons in Europe: With its 1 kW laser (Mobile HEL Effector), the M113 demonstrated its potential application in ordnance clearance. The crew inside the armoured vehicle searched for mines and unconventional explosive charges and lasered them from a safe distance, rendering them harmless at the high speed required for the scenario in question. The crew of the GTK Boxer wheeled tank used a 5 kW laser (Mobile HEL Effector) to neutralize an extra-heavy machine gun positioned on the bed of a traveling pickup without endangering the marksman. Proof that the laser was not hazardous was delivered by sensors mounted on the dummy, which recorded the scattered laser radiation levels during the entire process.

Together with the Skyguard radar, the HEL effector also demonstrated its effectiveness against a completely new kind of threat: small rotary-wing drones (octocopters).

At the other end of the spectrum there are fingerprint recognition systems that resemble a supermarket bar code scanner. In between these extremes there is a large array of applications. The market volume appears to be modest, about $1 billion is spent annually according to our analysis, and is stagnating because of world-wide budget austerity programs. Civilian deployment of security systems is an attractive supplementary customer base, but this is likely to focus mainly on lower cost systems, such as burglary protection, that can be manufactured large volumes (read: in lower labor-cost countries).

The major interest in maintaining activity in this sector is that military development pushes the design envelope regarding system performance and reliability. Lessons learned in building military laser systems ultimately filter into civilian systems. Some of the interesting applications with civilian market potential include LIDAR for automobiles, laser fiber gyroscopes for avionics, face recognition for industrial security.

In Europe, France and the UK are among the major producers of military hardware. The major companies that work in this area are typically system designers that buy components through procurement. Examples of some larger companies in this part of the sector are BAE, Sagem, EADS, Selex-Galileo, Thales, Alenia-Space, MBDA. Component manufacturers such as Alpes Lasers in Switzerland provide laser chips and subsystems to European and worldwide companies and agencies. Defense/security laboratories help to design and evaluate systems for these companies. They are present in every European country. In France the CEA-DAM and Onera are examples, while in the UK the analogous labs are the AERE at Harwell, and the Rutherford Laboratory at Appleton.

Watt-level high power laser component

The world-wide leader in military defense spending is the United States, and by a large margin. Spending on laser systems for military applications is dominated by the US and contracts covering the range from research to systems delivery are practically limited to US companies. For this reason, coverage of the value chain by European companies in this sector is sparse.

iXFiber Specialty Fibers & Fiber Bragg Gratings for High Power Fiber LASER

4. European Laser Value Chain

4.1 Lasers for Material Processing

In Europe, materials processing is the sector for laser applications where it makes sense to talk about value chain coverage. In the table below, we list a selection of European laser companies with their position along the value chain from basic materials to processing systems for material processing laser applications based on diode-pumped laser systems. This chart is intended to be a representative sample rather than an inclusive analysis. There is generally competitive coverage throughout the chain. However, there are two areas where a bottleneck could occur: speciality fibres for amplifiers and beam delivery components. There are at least four companies that cover all the components in the value chain.

Value chain analysis

COMPANY / PARENT	DIODE WAFER GROWTH	DIODE FABRICATION	PUMP PACKAGE	FIBER AMPLIFIER	BEAM DELIVERY	PROCESS ENVIRONMENT	WORKPIECE HANDLING
IQE	■						
Eagleyard	■	■					
Dilas / Rofin	■	■	■				
II-VI	■	■	■				
Jenoptik Laser Diode	■	■	■				
Eagleyard	■	■					
EdgeWave			■				
VI Systems		■	■				
Modulight		■			■		
Innolume		■	■				
Toptica				■	■		
Ekspla			■	■	■		
Powerlase / EO-Technics			■	■	■		
Novae				■	■		
PicoQuant			■		■	■	
Corelase			■	■	■		
JK Laser			■	■	■		
Optoskand					■	■	
Precitec					■	■	
Fianium				■	■	■	
Amplitude Systemes				■	■	■	
Eolite / Electro Scientific Industries				■	■	■	
Time-Bandwidth / JDSU				■	■	■	
Laserline			■	■	■	■	
SPI / Trumpf			■	■	■	■	
Onefive			■	■	■	■	
NKT Photonics		■	■	■	■	■	
Coherent		■	■	■	■	■	
Bystronic			■	■	■	■	■
Prima Industrie			■	■	■	■	■
Quantel		■	■	■	■	■	
IPG		■	■	■	■	■	■
Rofin Sinar		■	■	■	■	■	■
Jenoptik		■	■	■	■	■	■
Trumpf		■	■	■	■	■	■

Table 4.1 Presence in the value chain for some European laser systems and components manufacturers.

High-power fiber laser series by Rofin

4.2 Other Key Components to the Value Chain

Customer evaluation laboratories

In Europe it is possible for a customer to evaluate a laser manufacturing process using state of the art laser systems with the help and guidance of top-level laser scientists and engineers. The Fraunhofer Institutes were set up with this idea in mind.

AlphaNov	France
Fraunhofer ILT: Institute for Laser Technology	Aachen, Germany
Fraunhofer IWS: Material and Beam Technology	Dresden, Germany
Fraunhofer IPT: Institute for Process Technology	Aachen, Germany
IREPA	Strasbourg, Germany
Laser Zentrum Hannover	Hannover, Germany
Tampere University of Technology	Tampere, Finland
TWI (The Welding Institute)	United Kingdom
Center for Physical Sciences and Technology	Vilnius, Lithuania
Laser Center University Politecnica Madrid	Madrid, Spain
AIMEN	Spain
Lappeenranta University of Technology	Finland
BLZ (Bavarian Laser Zentrum)	Erlangen, Germany
Manchester	United Kingdom

Access to these facilities is fee-based, but open to organisations world-wide.

Technology industry associations

Photonics industry associations play an important coordination role between companies and sources of financing for laser systems development. In addition, workshops organised by associations promote up-to-date knowledge of laser system capabilities both up and down the value chain.

AILU	UK
European Laser Institute	Eu
EPIC - European Photonics Industry Consortium	Eu
EFFRA	Belgium
Eureka Laser	Eu
Laser Lab	Germany
Photonics21	Eu
Route des Lasers	France
Swissphotonics	Switzerland
WLT	Germany

5. European Strength in Laser Systems

The primary competitive advantage of the European laser industry is its world-wide leadership in the design, development and deployment of lasers for industrial applications. As we have shown, European laser companies are prominently represented in other important sectors like communications, security, and medical, but these are often singular examples, like Zeiss Meditec, Quantel or Oclaro.

5.1 Laser Technologies and Competitive Manufacturing in Europe

High power lasers are a key element of agile, lean and green manufacturing, and have been widely adopted in Europe for automotive manufacturing, contributing in a significant way to the world-wide competitiveness of this industry. Typically these lasers deliver 10s of kilowatts and pulse energies of a few Joules.

The research and development behind these tools for welding, cutting, drilling and marking have also shown the possibilities for lasers to be applied to a much wider array of applications, treating plastics, medical interventions, cutting and sewing of clothes, printing, packaging, and many other applications including the 4 major manufacturing operations, materials deposition, materials treatment, materials marking and materials removal.

Demonstration of redENERGY G4 ability to weld various combinations of bright metals

Example of bright metal cutting with an SPI redPOWER CW Fiber Laser - Brass, Aluminium, Copper & Stainless Steel

Additive laser deposition is a new dimension. In Europe, there are a number of companies making prototypes by additive deposition, but almost all of them are doing this by conventional injection molding. At present, there are few suppliers of additive laser deposition systems : EOS, Stratasys and 3-D Systems. These are already big companies by laser standards, approximately the size of Coherent or Rofin. Stratasys is based in Israel and 3-D Systems is based in the US. Other competitors entering this field will have a challenge to catch up. A major near-term objective for additive laser deposition is the mastery of additive metal deposition where desired weight of the finished piece can be minimised while maintaining the necessary mechanical properties like hardness and strength.

The introduction of laser technologies in manufacturing is highly disruptive, creating competitive opportunities for manufacturing, because laser processing implements flexible, fast and reactive manufacturing sites that are highly beneficial to both large companies and SMEs. European manufacturers design, manufacture and sell more than one-half of world-wide industrial laser systems.

"It is not an exaggeration to propose that lasers will soon be regarded as the tool of choice in nearly all areas of industrial manufacturing."

Jose Pozo, Director of Technology and Innovation, EPIC

The reasons that support the dominant position of Europe's laser technology for materials processing are easy to enumerate:

- Educational excellence: An emphasis on rigorous mathematical and scientific curricula.
- A job market, particularly in Germany, that is rich with opportunities for young graduates.
- Recognized economic importance: Strong and sustained government support for research and development at both the European and national levels.
- Significant customer base: Congruent with a long regional history of machine tool design and manufacturing industries from watches and instruments to automobiles.
- Customer outreach: Numerous facilities for process development and user training so that laser technologies can be adapted to industrial needs.
- End-to-End: Presence of European companies across the entire value chain.
- Synergy: The most advanced research lasers are based on the same structure and principles as entry-level commercial lasers, facilitating product innovation.

We summarize this in a flow chart:

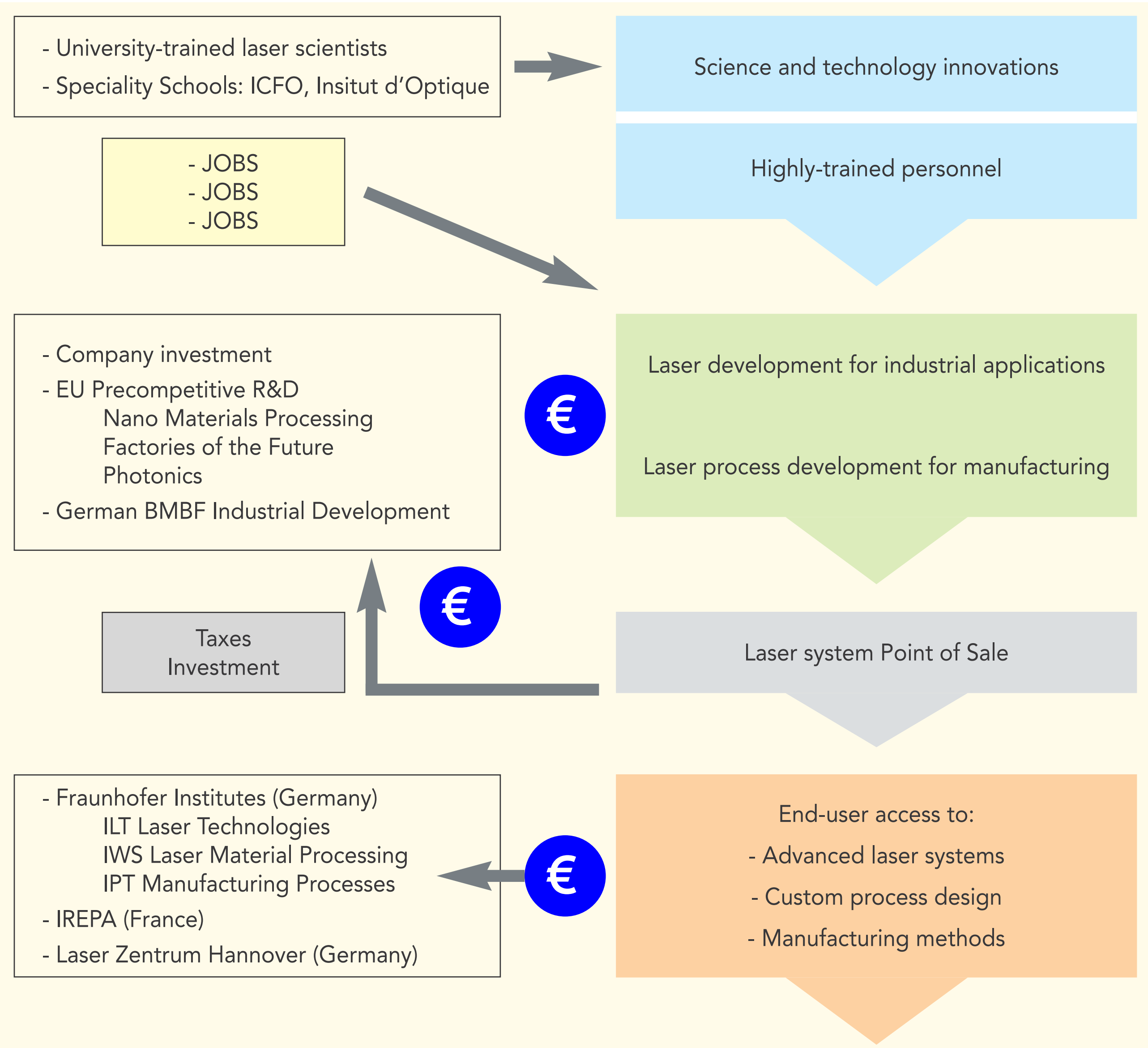


Figure 14. Flow chart for laser economic development.

These features help to build a sector with deep company representation over the entire value chain. There is room at the bottom for start-ups, because innovation in the simplest lasers may be relevant and attractive to larger companies. Since everyone is using the same building blocks: diode lasers, doped fibers or crystals for amplifiers, optical combiners, etc, there is a kind of economy of scale.

3D fiber laser cutting machine dedicated to the automotive industry

5.2 Synergy Across the Entire Value Chain

Overall the structure of an industrial laser consists of several subsystems: Optical pumping by laser diodes, laser-beam generation, optical pulse formation, amplification, output coupling, and beam management. The basic structure is the same whether the laser is a compact unit, such as those manufactured by Modulight, a high-power materials processing laser, such as those manufactured by SPI, or such as the same subsystems that will form the basis of the Mega-Joule laser and the lasers of the Extreme Light Initiative (ELI).

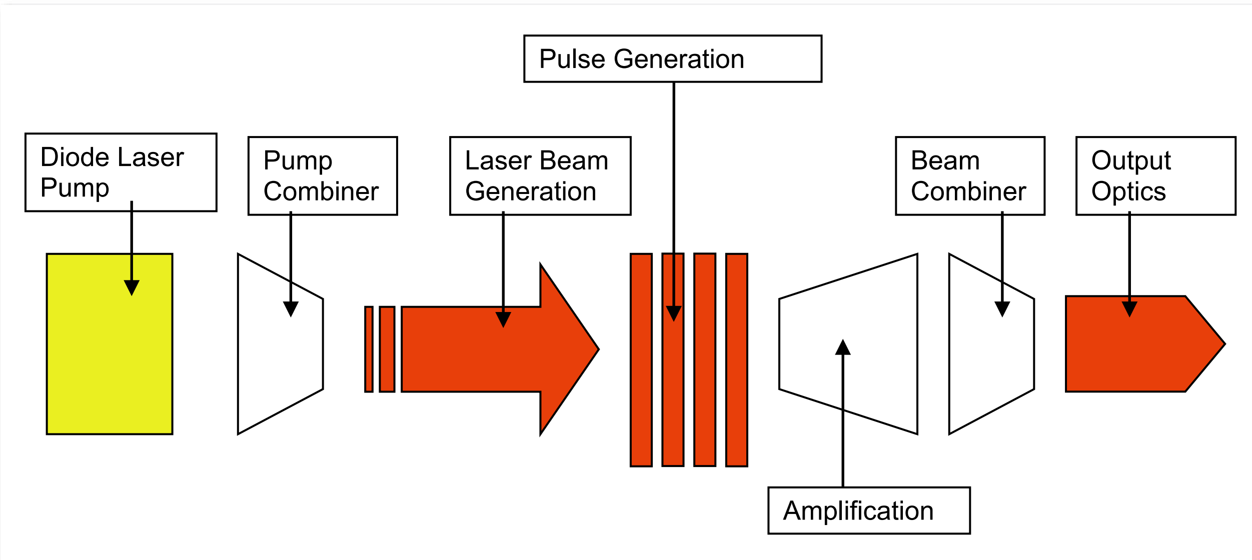


Figure 15. Schematic structure of a diode-pumped solid-state laser.

5.3 Large Laser Facilities

Large laser based scientific facilities integrate most of the technologies in the value chain. Laser technology now gives access to PetaWatt power, and multi-kiloJoules of pulse energy.

The HiPer project in the UK (www.hiper-laser.org) aims to create laser fusion for electrical power generation. The large MegaJoule laser in France is dedicated to the study of nuclear fusion. A similar laser, PETAL, runs alongside the MegaJoule laser for high power experiments.

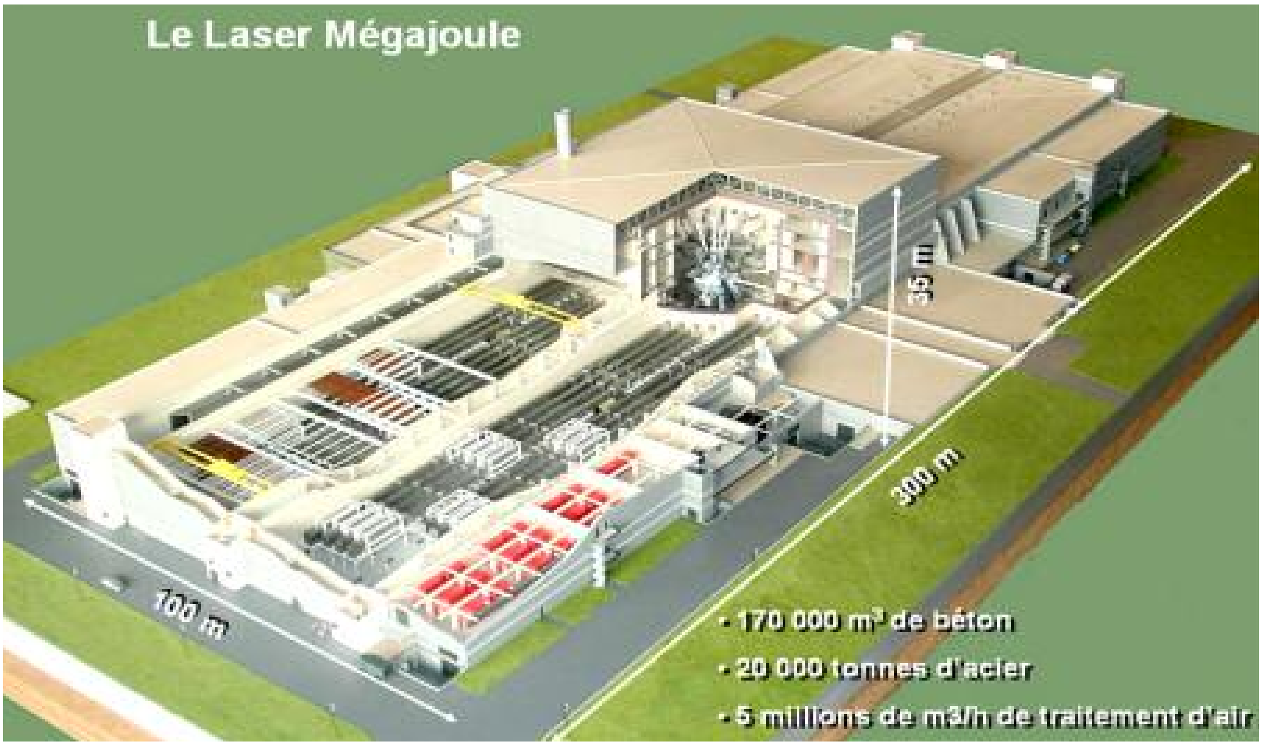


Figure 16. The Mega-Joule laser is housed in a building the size of several football fields.

These large infrastructures facilitate the development of various technologies alongside the value chain: From optical components to fiber based preamplifiers (Quantel), all the way to system design and large project management.

On a smaller scale but with the same peak power, femtosecond PetaWatt lasers are today available from European manufacturers (Amplitude Technologies), and enable research laboratories to conduct advance scientific research.

More recently, the Extreme Light Infrastructure (www.extreme-light-infrastructure.eu) is a European project to build three open-access laser laboratories in Eastern Europe to explore interactions between light and matter in 4 key areas: Attosecond (10^{-18} sec) science, high electric field science (creating matter from the vacuum). photo-nuclear chemistry, and generation of short pulses of coherent x-rays. ELI lasers is in the building phase with the first operating demonstrations still several years away.

These projects, which have secured long-term funding, will assure that the European laser industry will be continuously stimulated to improve laser designs and optical materials. We wish to emphasize here that the synergy and symbiosis that links the laser value chain from one end to the other makes an important contribution to the success of the laser sector in Europe.

"There is not a similar infrastructure in any of the other sectors in Europe, and no other region in the world can match the European infrastructure." *Carlos Lee, Director General, EPIC*

6. Conclusions

Laser materials processing is the largest part of the world-wide laser systems market sector. In 2014 laser materials processing systems generated more than $11 billion. European industry is the leader in this sector with a strong presence across the entire value chain.

Additive materials deposition by laser is emerging as a new sector for laser materials processing. Manufacturers, primarily European companies, are largely different from those providing solutions for traditional materials processing of etching, drilling, cutting and welding. The additive materials processing is currently growing at about 20% per year.

European laser companies are leaders in other sectors: Zeiss Meditec in Medical-Cosmetic; Oclaro in Communications, and EADS in Defense. However, coverage of the sector value chain by European companies is nowhere as complete as is the case for laser materials processing.

A significant part of market growth comes from adapting a laser to a specific application. There are many more applications than laser companies, and this situation naturally encourages system development and movement up the value chain.

There are some important features of the European laser environment that contribute to the particular prosperity of the laser systems sector.

- A strong and rigorous university level curriculum in optics and laser across Europe.
- A job market, particularly in Germany that is rich with opportunities for young graduates.
- Strong financial support from the European Commission for the development and deployment of lasers in industry.
- Strong financial support from the BMBF for the development and deployment of lasers in the German industry. The BMBF generally invests as much in its German companies as the EU invests in Europe research in this area.
- A common design structure based on the diode-pumped laser that is used for the simplest compact laser devices as well as the largest industrial and scientific systems.
- A significant network of user facilities that can be accessed by potential customers enabling evaluation of laser performance in specific applications.
- A strong network of industry associations that helps companies find new technologies and new customers.

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