Progress Report – 48 - Summary

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Leadership in Fibre Laser Technology

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1. Executive summary

The outcome of the LIFT project will establish international leadership for Europe in the science, application and production technologies for material processing by fibre lasers through the development of innovative laser sources. Major advances beyond the state of the art are at hand: The cold-ablation fibre laser, based on ultra-short pulses, will open an entirely new market (100 mill.€ p.a.) e.g. for laser processing of ceramics. The visible RGB fibre laser offers novel treatments in eye surgery and can be the first high-brilliance source for laser projection displays (15 mill.€ p.a.). New future-oriented manufacturing tools based on higher-power pulsed fibre lasers (80 mill.€ p.a.). The high-reliability laser for large-scale manufacturing with High Speed Laser Remote Processing - means a new level of performance for 2kWatt materials-processing lasers with raised MTBF to 50.000 hours (accessible market 1 bill.€ p.a.). The Horizontal integration and networking in Europe's high brilliance laser industry in this project enables a greater market share for existing applications, creates new areas of exploitation for manufacturing, and builds a European network of component suppliers, laser manufacturers, universities and research institutes.

Although Europe today is the leader in industrial laser processing, continuous innovation and adoption of novel technologies is required to defend this position. Fibre lasers represented only 10% of the market in 2007, but the growth rate of this sector is significantly greater, more than 25% per year. The market share of fibre lasers is expected to double by 2010 and double again by 2013, when fibre lasers will account for more than 30% of all industrial lasers sold each year. Much of this market growth will occur at the expense of CO_2 lasers. In order for Europe to defend its position as technology and manufacturing leader in industrial laser processing, it is imperative for European manufacturers to take the Leadership In Fibre laser Technologies.

Fibre lasers are a disruptive technology for materials processing. Originating from the low power world of information and communications technology (ICT), these lasers have been developed to meet the most challenging applications in the high power world of material processing. In industrial markets, the fibre laser has many advantages over the conventional CO_2 or solid-state laser. They are smaller, more efficient, have a high beam quality, a lower cost of ownership. Over the typical lifetime of a source, the total cost of ownership of a fibre laser is estimated to be approximately half the cost of a CO_2 laser and a third of the cost of a YAG or disc laser.

A main selling point for fibre lasers in this market is that they have a wall-plug efficiency of up to 30% compared with typically less than 5% for conventional solid-state lasers and 20% for diode-pumped solid-state lasers. This energy saving results in a significant cost reduction in the industrial environment and points the way to higher power lasers.

In result of the LIFT project the consortium developed 5 different types of fibre laser, from cw-multi kw system and cw-yellow to pulsed fibre lasers in the range from ns – fs pulse-duration. Together with the final fibre laser products many components for high brightness beam sources have been developed like fibres, isolators, pump diodes etc. For different kinds of application, it was also necessary to develop scanning heads for large area applications.

2. Summary description of project context and objectives

This large-scale collaborative project will establish an internationally leading position for Europe in this strategically important field, substantially advancing the position of Europe in the science, application and production technologies of fibre lasers. In this project the consortium has developed innovative laser sources with intelligent beam delivery systems and dynamic beam manipulation, in CW and pulsed kilowatt laser systems and ultra-short pulsed laser sources. LIFT enables a greater market share for existing applications, creates new areas of exploitation for manufacturing, and builds a European network of components' suppliers and laser system manufacturers.

Demonstrations have shown the potential of this technology in domains where there are large existing markets such as high-speed remote cutting and welding, medical diagnostics and treatment, battery manufacturing or where there are large potential markets like solar cell fabrication or cold ablation for ceramics manufacturing.

The study by the "Photonik Forschung Deutschland" organization presents an excellent review of the state-of-the-art in photonic industry and calls the growing sector a "job engine":

- The German photonics sector (as one example out of the European community) will employ 165,000 people in the country by the end of the decade
- photonics industry has created around 30,000 new jobs in Germany since 2005, with a similar number set to be added through 2020 as the industry grows at a compound average rate of 6.5% per year. Comparable perspective is anticipated for the EU.
- The study also sizes the global photonics market for 2011 at some €350 billion, up from €228 billion in 2005. The analysts predict "solid growth" for the rest of the decade, and estimate that the 2020 market will be worth €615 billion.

The disruptive nature of the fibre laser technology has "changed the rules". This project has been strategic for responding to the paradigm shift for continued European leadership in industrial laser technologies. The challenge presented by fibre lasers is also an opportunity. Impacts of the transverse actions in this project will last far beyond the end of the program by building a distributed European infrastructure in fibre laser technologies that can be used to build future fibre laser systems in fields that have not been explored through this proposal. The grant enabled this consortium to play a pivotal role in the development and advancement of laser systems for industrial applications.

Key Applications

The research, development and innovation that constitute the LIFT project led to a new level of high-brilliance laser sources. The results of the consortium work will bring radical advances in three important application areas:

- Laser Materials Processing
- Health Care Delivery
- Cost-Effective Manufacturing of Solar Cells for Renewable Energy

A **fibre laser** is a laser in which the active gain medium is an optical fibre doped with rare-earth elements. The structure of a fibre laser has been shown in Figure 1.

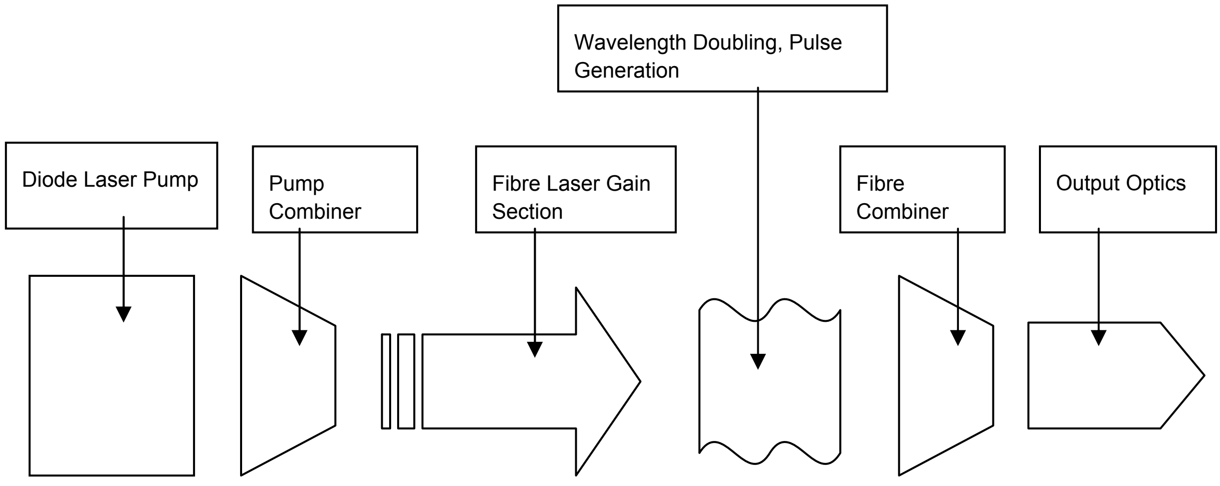

Figure 1: A fibre laser is a system based on components that energize the fibre laser by pumping photons into the fibre gain section, by components that modulate the laser so that pulsed operation can be achieved, by combiners that can efficiently transport optical energy into the laser amplifier as well as a different kind of combiner which extracts the optical laser output from the gain section.

Key Performance Challenges:

- CW power greater than 3 000 watts with a mean time between service longer than 50 000 hours
- CW fibre laser sources at visible wavelengths
- Pulsed femtosecond laser sources with peak power greater than 100 MWatt
- Pulsed nanosecond laser sources with pulse energy greater than 10 mJoules
- Pulsed laser source with continuously variable pulse-length and duty cycle or with average power greater than 200 watts
- Diode pump laser package delivering more that 200 watts at 980nm
- Reduction in photodarkening threshold energy by 50%

Holistic Strategy of the LIFT Project

Simply stated, the brilliance of a light source is the quantity of light emanating from a defined area of emission. The brilliance increases when the number of photons increases, and the brilliance increases when the photons appear to be originating from a smaller area, approaching a point. The challenge is to create a light source that appears to emanate from a point, leading to high beam quality, and at the same time increase the number of photons in the light beam, that is, the laser power.

Impact Area 1 – High Brilliance in the Visible and Infra Read

Concept and strategy
Fibre lasers, originating from the low power world of information and communications technology (ICT), have found their way into the two most challenging applications: the high power world of material processing and the medical area (Ophthalmology and Dermatology). The concept of this development work was to increase the brightness of high power, continuous wave fibre lasers in the infrared and in the visible and to develop the right tools for new industrial and medical applications.

Impact Area 2 – High brilliance pulsed sources

Concept and Strategy
Development of common pulsed fibre module capable of both high peak power and high average output power. The pulsed lasers developed here have peak powers of up to hundreds of MW. However the levels of peak power correspond to high intensities that can cause degradation through photodarkening and non-linear optical effects, leading to catastrophic damage.

Impact Area 3 – Components Reliability and Performance

Concept and Strategy
LIFT has emphasized throughout that the pathway to higher brilliance is to design components that can handle higher levels of optical power. However managing the total optical power so that individual components and systems do not suffer damage required R&D to improve reliability.

- Thermal management
- Degradation reactions provoked by photon energy
- Degradation provoked by the intensity of the optical beam

This Impact Area has improved the understanding of both long-term (*e.g.* photo-darkening) and instantaneous system degradation (*e.g.* laser diode or fibre component failure due to high optical power levels). It gathered real system reliability data and attempts to quantify the improvement to system reliability obtained through the developments made in the LIFT project.

Impact Area 4 – Beam-shaping and delivery

Concept and Strategy
The first objective of this work package has been to increase the useful optical power at the workpiece by at least 150% compared to the state of the art. This has been achieved by innovative beam handling inside the laser so that higher levels of power can be generated, and by innovation in the beam delivery that combines the laser output so that much higher power is delivered to the workpiece.

The second objective was to dramatically decrease processing time by harnessing the higher beam brilliance and using this to implement remote high speed laser processing. Remote processing means a much higher laser spot velocity at the work piece by the use of scanning mirrors in combination with long focal lengths. This technology can enable the increase of processing speeds by a factor of 10 – 100 compared to conventional laser processing systems using robotic arms.

3. Scientific and Technological success

3.1 High Brilliance cw IR multi kW fibre lasers

Laser cutting plays an important role in the field of laser materials processing. High beam quality, high laser power and high absorption rate are the most important specifications in order to reach higher cutting rates in combination with high cutting edge qualities. The ideal beam quality of the fibre laser means its beam can be focused to a diffraction-limited spot. Because of the available tight focused spot of the high-power fibre laser beam, it is possible to realize extremely thin welding seams with high aspect ratio at high processing speeds. To optimize the welding time for components with various different stitch weldings, a larger working space of the beam deflection is necessary, however, without a loss of beam dynamics and beam quality. Only a high brilliance fibre laser, which is the overall objective of this program, can achieve this combination.

Objectives

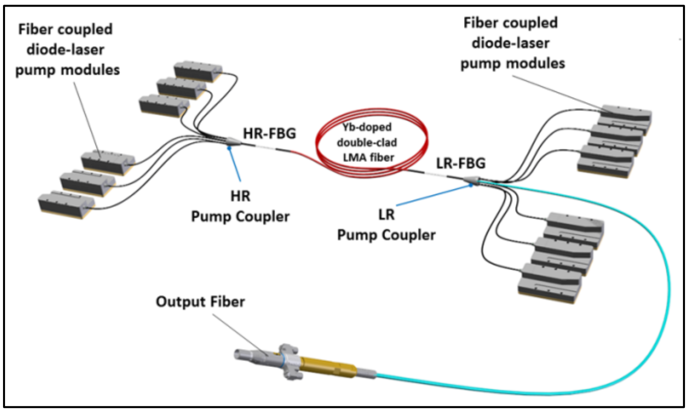

Figure 2: fibre laser oscillator architecture

A low loss technology for high power pump coupling for a combined pump power in the range 2-3kW was to develop. Power scaling of fibre lasers into the multi-kW range was achieved by combining the output of multiple fibre lasers. A signal combiner (developed in WP4) was utilized to setup a multi-kW fibre laser. Furthermore within this project Fibre Bragg Gratings (FBG) as “in-fibre-mirrors” for high power fibre laser oscillators have been accomplished. Developing existing pump module technology has permitted a 200W pump module with 200µm NA 0.22 fibre delivery. This technology has been further developed in a second iteration to 600W pump modules. Furthermore a new fibre for high power pump beam delivery including a SMA-type connector has been realized. A polarized fundamental mode 1kW fibre laser has been build, based on the developed components. The pump modules provided sufficient pump power to utilize a single side pump concept. The completion of the development of pump modules and pump beam delivery fibre connectors, as well as the low loss pump couplers enabled finally the build of a 2 kW fundamental mode fibre laser oscillator.

Components and laser sources

Fibre Bragg Grating (FBG) technology, iXFiber:

iXFiber was in charge of the development of High Power Reflectors. It consists of a pair of Fibre Bragg Grating-based mirrors (High/Low Reflection) written in a large mode area double-clad fibre for singlemode kilowatt cw laser. This work was divided into 5 parts: design of gratings, design of passive fibre, optimization of the processing steps, development of characterization setups and manufacturing of the deliverables. The gratings have been designed to reach the mirrors specifications taking into account the passive fibre photosensitivity and the necessity to preserve the fibre core integrity. Chirped and apodized gratings were imprinted into the Ge-doped 20µm core (NA=0.06) having an outer clad of 400µm (NA=0.46). iXFiber used the phase mask technology with a doubled Argon ion laser source. The HR gratings had a reflectivity up to 99% (FWHM of 0.8nm) while the output coupler (LR) exhibited a typical reflectivity of 10% (FWHM of 0.5nm) with a central laser wavelength of 1070 nm. Parameters of several processing steps (hydrogen-loading, degassing, window-stripping and recoating) have been optimized to prevent contamination, delamination or degradation of the optical characteristics of the multimode guide. A characterization setup has been designed to check the integrity of the pump guide based on a scanning thermography method. These process improvements resulted in an outstanding pump transparency with a residual thermal slope of less than 0.05°C per each injected pump power Watt.

Pump Coupler, Corelase:

In all laser types a supply of energy, often termed as a pump, is required in order to create laser emission. In fibre lasers the pump energy is generally supplied by fibre-coupled diode lasers as pump radiation. This pump radiation needs to be coupled into the active optical fibre of a fibre laser. For fibre lasers generating kW or more of laser power, very robust and low loss coupling is required due to the very high power levels involved. In the LIFT program, Corelase Oy (Tampere, Finland) has developed a high quality pump coupler component for coupling pump radiation into the active fibre of a fibre laser. Some key features of Corelase's pump coupler technology include very low losses, robust all-glass fused construction, high quality signal feed-through and insensitivity to high amounts of backward light. These key features have allowed to demonstrate more than 2 kW of single mode power from a fibre laser. A number of commercial fibre laser products utilizing Corelase's pump couplers are meanwhile on the markets. As an example, Corelase can offer customers the O-lase product, which is a single mode fibre laser module emitting up to 1.5 kW of laser power in a very compact package of 1U height mountable to a 19" rack.

Advanced High Power Diode Laser Modules, DILAS:

Several types of advanced high power diode laser modules for cw kW fibre laser pumping were developed and tested by Dilas. All are based on the tailored diode laser bar (“T-Bar”) concept, employing 5mm wide mini-bars and using a rather simple optical beam shaping scheme to couple the emitted power directly into 200µm passive fibres. A single T-Bar includes five individual 100µm wide emitters with a pitch of 1mm. The emitted radiation is then collimated with one fast-axis lens and one slow-axis lens array. Key feature for all realized modules is the usage of a standardized diode laser platform for a wide range of different output power levels. This opens up the subsequent potential for a high volume production of the unified sub-modules which makes it reasonable to introduce widely automated mounting and packaging techniques. This, at least partly, automated production is one necessary pre-condition to be able to reduce manufacturing costs and to maintain competitiveness compared to other concepts.

Basic 200W module IS21:
The first module realized was the basic 7-bar platform IS21, equipped with seven T-bars which are optically stacked and coupled into the 200µm NA0.22 Optoskand SMA0.5Q fibre, with an output power up to 200W. These modules may be used as single module or e.g. together with 7:1 fibre combiner to scale up pump power for kW class cw fibre lasers.

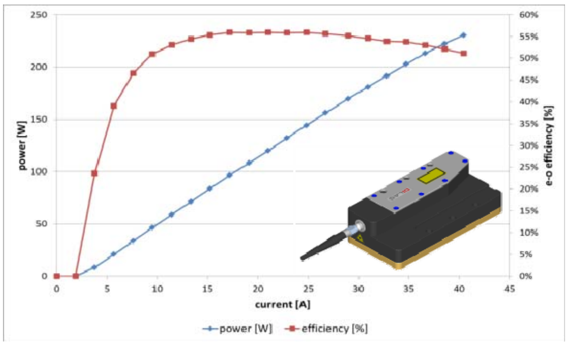

Figure 3: IS21 type standard 200W cw diode pump module

Figure 4: 300W pump module, equipped with 200µm QBH connector, available also with SMAQ fibre

Intermediate power level, 300W IS43 module:
Based on the single platform module, a second version delivers more than 300W output power. Two baseplates are polarisation coupled for power scaling and transmitted via a 200µm NA0.22 (or 400µm NA0.11) SMAQ fibre. Typical diode current for 300W is 30A, electro-optical efficiency reaches 48%. Cooling is possible with tap water from the bottom of the housing. Several of these modules are delivered to Lift partners for further pumping experiments.

High power 600W IS35 (new: IS45) module:
A third demonstrator was realized as a >600W version, applying four base-plates. This module was used for high-power duration tests with the 200µm SMAQ fibre provided by Optoskand. At 40A the module delivers up to 770W out of the 200µm NA0.22 fibre with an efficiency of 46%.

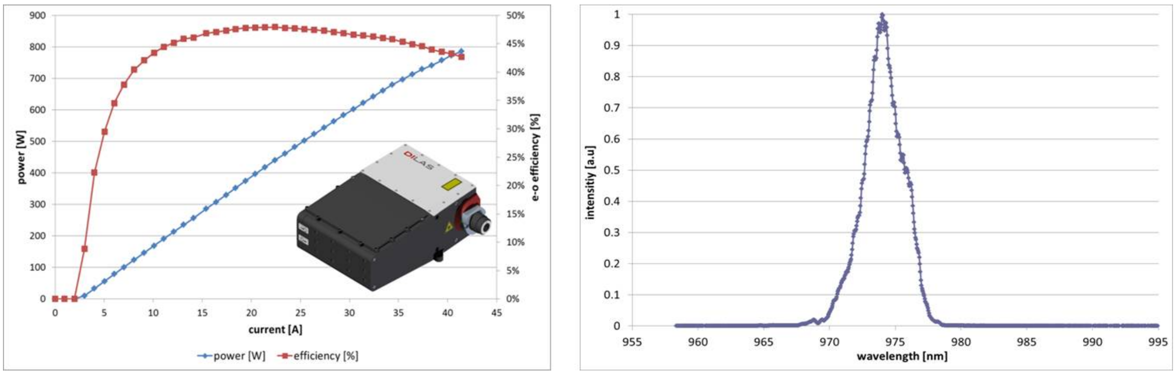

Figure5: Characteristics and spectral profile of four base-plate module IS35 using a QBH connector

SMAQ Fibre Optic Cable, Optoskand

By applying a technology of end-capping passive high-power transport fibres to a smaller fibre connector (SMA-type) and working with quartz components (patented technology) a new connector type that can withstand larger connector losses and has higher transmission has been developed. The new SMAQ fibre connector withstands higher powers (>500 W) with lower losses (typically below 1 % of the connected laser light) and can handle significant powers outside the fibre core (>100 W) compared to competing connectors.

The results of the SMAQ fibre development was presented in Photonics West 2013; in summary:

- In a 200-µm-core fibre with NA0.22, 730 W of transmitted power using a Dilas IS45 diode laser module was achieved. In this configuration the NA is overfilled, thus at this power level (970 W raw power) the connector handled 240 W outside the fibre core with a maximum temperature of 80 °C without any degradation (short-term).
- In a 400-µm-core fibre, 775 W transmission using the IS45 (max NA0.13) was achieved. At this power level the connector handled 45 W outside the fibre core with a maximum temperature of 35 °C without any degradation.
- SMAQs with 200 µm core have been tested at 290 W successfully for >3800 h.

Figure 6: SMAQ fibre connector

High Brilliance CW IR fibre laser sources, Rofin:

Origin for this development was an oscillator setup based on a cavity pumped in co- and counter direction by help of 12 fibre coupled pumps. This setup is meanwhile well proven at output power levels of 1 kW. Scaling the output power means not only to scale the pump power, to improve the cooling and to adapt the joining techniques, but also to minimize the power losses by targeting well matched components.

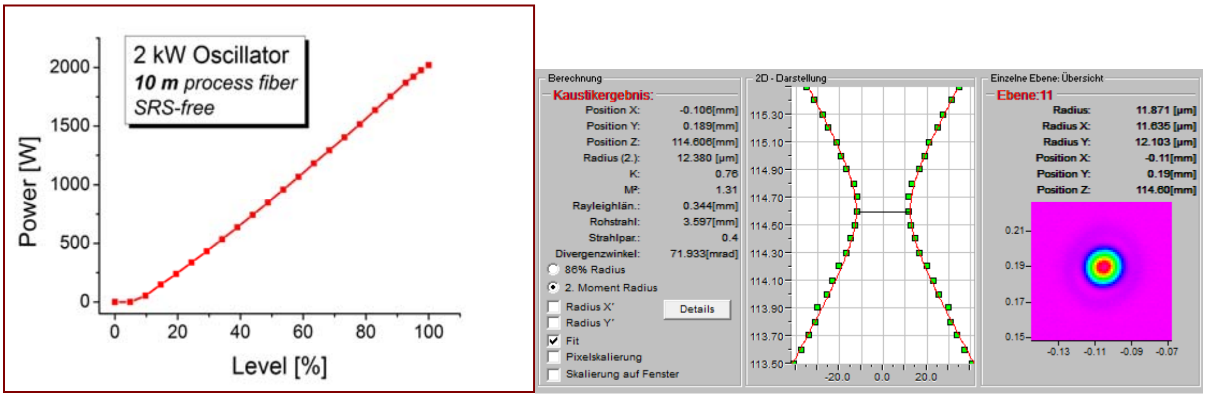

Figure 7: Characteristics of Rofin´s 2kW fibre oscillator

A maximum output power of 2020 W has been achieved, no thermal or other cavity performance limiting issues have been found. The oscillator output was terminated by help of a 10 m long QBH connector fibre cable. No performance limiting sign of stimulated Raman scattering was observed.

A 19”, 3RU module has been designed. The module includes the cooling water supply for pumps and oscillator, the oscillator itself and additional electronics to monitor the devices.

A similar all fibre design, despite the utilization of so called polarization maintaining fibres (PM) has been chosen by Rofin to additionally develop and build a 1kW polarized fundamental mode laser unit. PM fibres are special fibres preferring one polarization state to travel along the fibre. This laser unit is only single side pumped and fits into the same 19” module. 950W of output power and a maximum polarization extinction ratio of 98% at 550W have already been demonstrated. The R&D work is ongoing beyond the project span.

Figure 8: Rofin´s dual side pumped laser module (left) and new fibre laser product design presented at World of Photonics 2013

Rofin has used the increased output power of the fibre laser oscillator to create multi kW fibre laser systems by incoherent beam combination. The technology of a 6kW fibre laser product based on the combination of four fibre laser oscillators has been presented during the World of Photonics exhibition in Munich in May 2013. Furthermore it was possible to create a more compact design for the already existing product range. Of course the increased oscillator output power can be used directly for fundamental mode applications as well.

Application results:

Fibre laser systems with more than 1,5 kW of single mode output power can address high speed cutting applications, like remote cutting. By help of the LIFT laser source several application tests have been undertaken. As an example one can mention remote cutting of a 300 µm thick stainless steel sheet. At 1,5 kW a maximum beam speed of 8 m/s (10 repetitions) has been demonstrated.

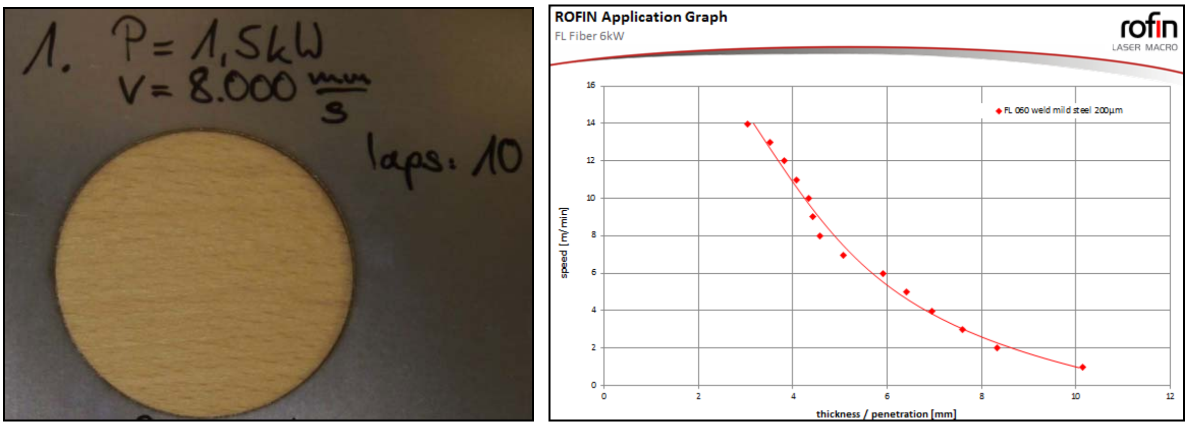

Figure 9: Remote cutting of stainless steel (left) and welding graph of mild steel with Rofin´s 6 kW fibre laser (right)

Furthermore the high power multi kW laser systems with a beam parameter product of 1,7mmxmrad (50µm process fibre) or 3,5 mmxmrad (100µm process fibre) enable applications for the automotive industry like welding on the fly with remote welding systems. With 6 kW of output power penetration depths vs. application speed of mild steel has been investigated.

The results achieved within LIFT have enabled all partners to introduce new products during the project span. Furthermore additional research results have been worked out, which will stimulate and quicken the product development for the next years.

3.2 *High brilliance cw yellow fibre lasers*

Introduction: Why visible laser systems?

In the framework of the European LIFT project, part of the work was devoted to the development of Continuous-Wave (CW) visible fibre lasers of high brilliance for medical and scientific applications. Such markets and fields of applications are demanding of CW visible laser systems with high brilliance (high power and singlemode beam quality) at various wavelengths. However, other visible laser technologies, such as frequency-doubled diode-pumped solid-state lasers (DPSSL), frequency-doubled optically-pumped semiconductor lasers (OPSL) or visible laser diodes cannot combine high power, diffraction-limited beam quality and wavelength versatility. For example, accessible wavelengths by solid-state lasers are limited to a few discrete emission transitions of rare-earth doped crystals, while semiconductor-based lasers struggle to offer high power (multi-Watts level) with good spatial beam performances. On the contrary, laser systems based on fibre technology can easily offer high CW power with perfect beam quality, while being able to emit in a wide range of wavelengths because of the non-crystalline nature of doped-fibres. Moreover, fibre laser systems are robust, efficient, versatile, and maintenance-free, as already proven in the material processing industry. All advantages of the fibre technology were exploited to demonstrate a 10W level singlemode yellow fibre laser system, leading to the development of a yellow laser demonstrator for retina surgery applications. The fibre technology developments, adapted to CW visible laser systems, supported by the LIFT project also benefit Quantel to develop and launch on the scientific market a single-frequency 780 nm all-fibre laser (EYLSA 780) for atom cooling applications.

Technical breakthroughs and high brilliance yellow fibre laser demonstration:

Three main technical challenges, depending on the precise targeted visible wavelength, were overcome during the LIFT project for the development of such visible lasers:

- the first is the efficient emission of Yb-doped fibres at long near-infrared wavelengths with a high CW power level, a linear polarization state and a small linewidth,
- the second is the improvement of the Second Harmonic Generation (SHG) process used to convert the near-infrared light into a visible light beam, with efficiencies ranging from 25 to 40% in a robust and simple optical architecture,
- the third one is the packaging of the SHG stage, with all requested functionalities for medical or scientific devices and to make it as a compact, robust and efficient component.

A high brilliance yellow fibre-based laser source has been demonstrated with as high as 11W of output power generated at 577 nm and with a diffraction-limited beam quality. The general principle of such a visible fibre-based laser is depicted on the figure below. A CW laser emitting a linearly polarized beam in the near-infrared is frequency-doubled down to the visible by SHG into a non linear crystal.

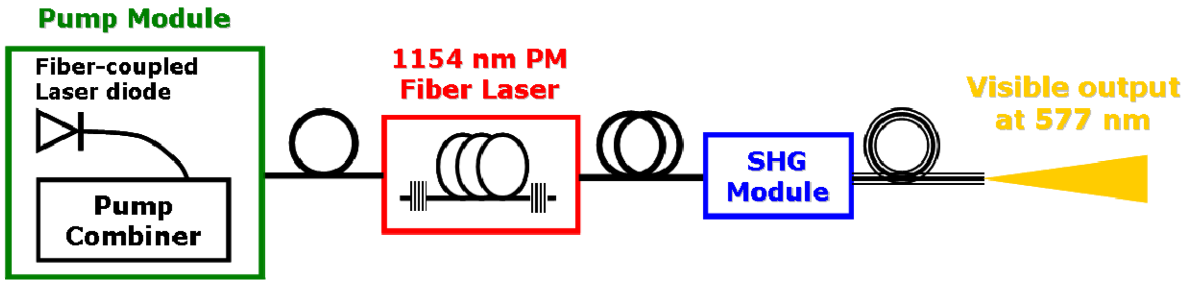

Figure 10: Yellow fibre laser architecture scheme

A pump module, composed of fibre-coupled laser diodes combined into the same output fibre with an all-fibered pump combiner, is used as an energy source to pump a fibre laser oscillator. The near-infrared fibre laser is based on an Ytterbium doped fibre (active media) and emits at a wavelength of 1154 nm with a linear polarization and a narrow linewidth. This linearly polarized beam is then focused into a periodically-poled non linear crystal that converts near-infrared photons into visible ones with a maximum efficiency of 40%.

The extraction of high CW powers at long wavelengths (>1120 nm) is challenging with Yb-doped fibres because of gain competition with conventional wavelengths of the Ytterbium emission spectrum (1030-1100 nm). A hard work has been achieved during the project on the laser cavity design, as well as on the active fibre, leading to the extraction of more than 25 W at 1154 nm with a narrow linewidth (<0.1 nm) and a linearly polarized beam (PER>16 dB). It represents an x3 increase for the 1154 nm output power laser beam compared to the Quantel knowhow at the beginning of the LIFT project.

While before the LIFT project, the maximum reported single-pass SHG efficiencies in CW operation was in the range of 20%, we were able to reach 40% at the end of the project by adapting the non linear crystal geometry. Raicol was able, thanks to the LIFT project, to increase both length and thickness of the crystals, as well as the optical quality and homogeneity of the periodic poling applied on such crystals. Combined with the developed narrow linewidth fibre laser sources of very good beam quality we demonstrated a large increase in the efficiency of the SHG process.

The result of these 2 main technological breakthroughs is the first demonstration of a high brilliance CW yellow fibre laser source providing more than 10 W with a perfect Gaussian beam quality, as shown on the figures below. It represents an x5 increase of the yellow output power compared to the Quantel know-how at the beginning of the LIFT project.

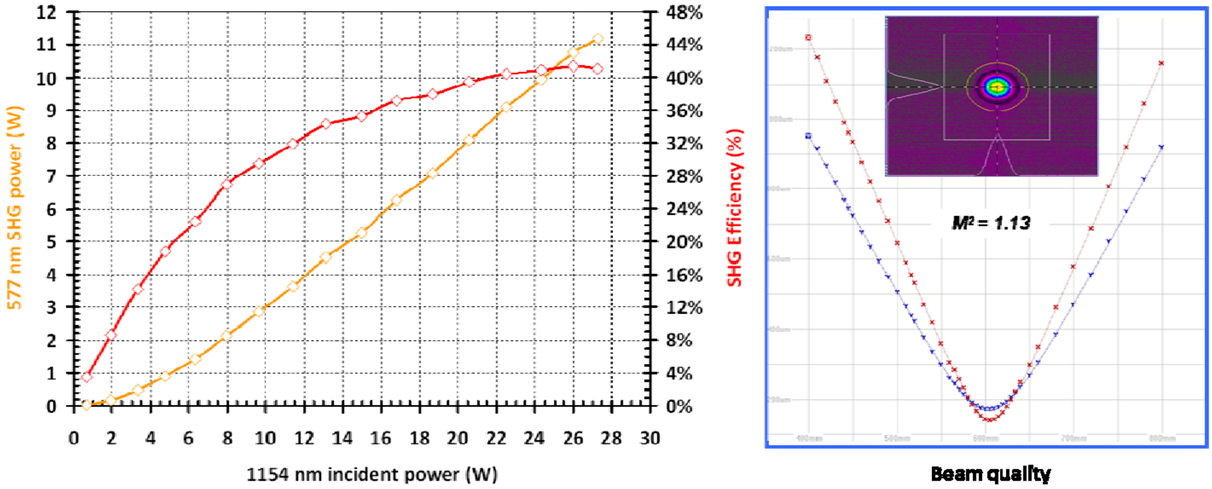

Figure 11: High Brilliance Yellow fiber laser performances.

Yellow laser medical system

Thanks to the previous results, Quantel, together with Raicol and Gooch & Housego, developed a yellow fibre laser demonstrator for retina surgery applications, using the photocoagulation process. Retinal photocoagulation uses the energy coming from a laser source to be turned into heat by absorption of visible photons by some pigments of the retina (oxyhemoglobin, melanin …). This localized heat deposition creates a coagulation necrosis by denaturation of cellular proteins of the retina when their temperature rises to more than 65°C. It is mainly used to treat patients suffering from retinal detachments, diabetic retinopathy, some types of AMD (Age-related Macular Degeneration), or macular edema. The result of this process is a kind of retina welding. Doctors and ophthalmologists have known for decades that yellow wavelengths (575-580 nm) offer a number of advantages for retina photocoagulation compared to the historical green wavelength at 532 nm.

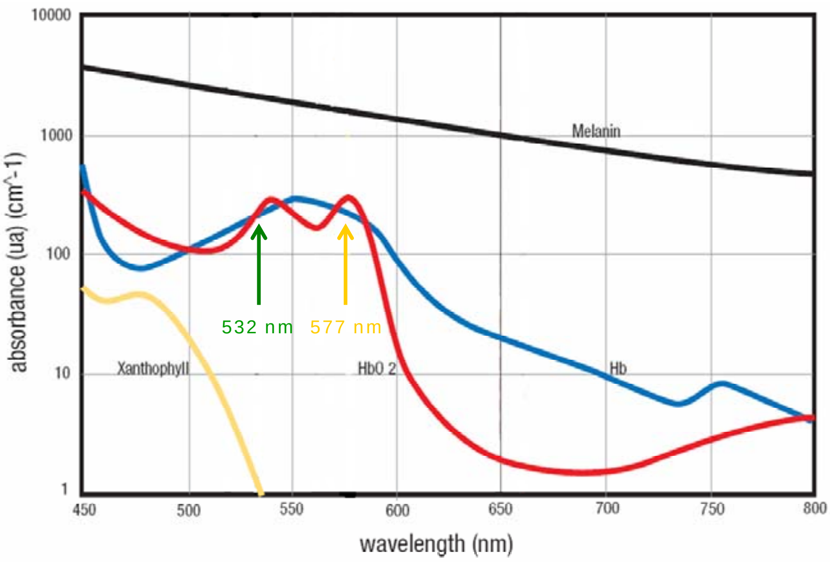

Figure 12: Absorbance spectra of some human retinal pigments.

The main advantages of yellow light compared to common 532 nm laser systems are:

- less scattering and better transmission by the cornea, leading to less needed power and smaller accessible spot sizes,
- better absorption by oxyhemoglobin (HbO2), leading to both less requested power, better selective treatments and less pain for the patient,
- negligible xanthophyll absorption, allowing treatments closer to fovea and macula area, less pain for the patient and less collateral damages.

However, because of technological and costs aspects, the use of yellow laser systems, based on dye or krypton lasers, remained at the stage of clinical studies in some laboratories.

For demonstration purpose, the yellow laser source, previously described, has been adapted to fulfil the requirements of the targeted ophthalmologic application.

The amount of energy that has to be deposited onto the retina in order to reach the desired effect is dependent on the power and duration of the optical pulses produced by the laser system (ranging from tens to hundreds of milliseconds). These medical pulses are obtained by modulating the pump power of the CW yellow laser demonstrator with an adapted electronic pulse control to avoid any optical overshoots.

For such medical applications (retina photocoagulation), the demonstrator is integrated onto an existing slit lamp (apparatus used by ophthalmologists to precisely see the retina of patients) with its optical zoom. In order to be adaptable onto the zoom of this medical apparatus, the output of the yellow laser demonstrator is fibre-coupled into a 3-meter long delivery fibre.

Furthermore, to be able to target the area of the eye to be treated, a red aiming beam, perfectly superposed to the main yellow laser beam, has been integrated into the yellow laser system.

Finally, Doctors need to control and trigger laser shots while targeting the area of the eye to be treated. For this, a foot pedal has been implemented in this yellow laser demonstrator, allowing the Doctor to trigger a single laser pulse onto the retina area, while looking into the eye of the patient.

To develop this yellow medical laser demonstrator, Gooch & Housego, helped by Quantel, worked on the packaging of the SHG stage with all the requested functionalities for medical or scientific devices. The objective was to build it as a compact, robust and efficient component. This fibre-in / fibre-out SHG yellow module integrates a non linear crystal from Raicol.

Figure 13: Fibre In / Fibre Out Yellow SHG module.

Finally, the whole yellow medical laser system has been integrated into a rack with all the electronics and optical parts, a touch screen and a foot pedal for medical laser pulses triggering. It generates a maximum output power of 3 W at the output of the delivery fibre.

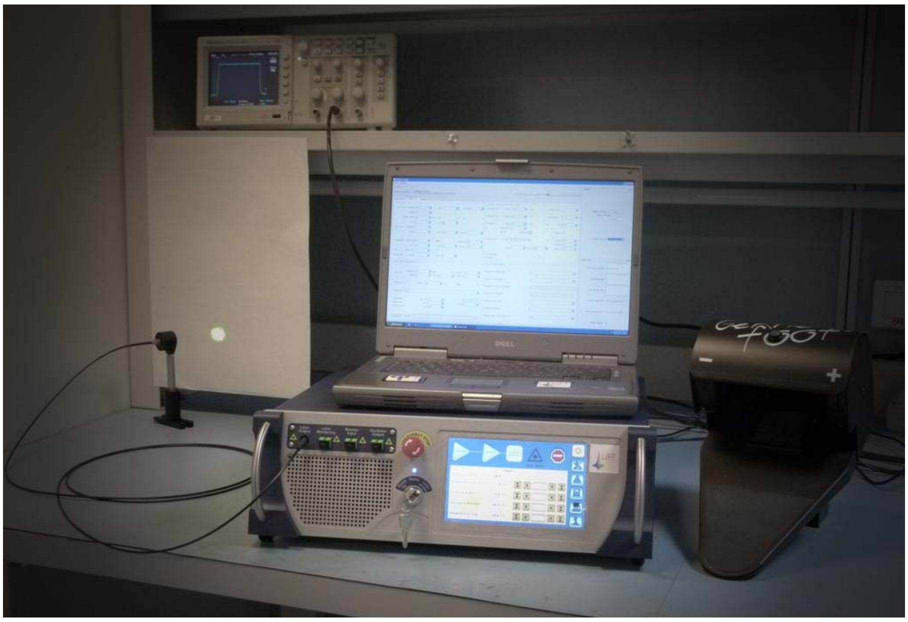

Figure 14: Yellow fibre laser medical demonstrator.

Medical tests with Professors of Ophthalmology from the University Hospital of Saint-Etienne (France) have been performed with this medical demonstrator, demonstrating the efficiency of this type of lasers for the photocoagulation process. Several months of developments are still needed before launching this new yellow fibre-based photocoagulator, mainly because such laser systems for medical applications require different security qualifications and medical homologations.

EYLSA 780 fibre laser product

On the scientific side for visible lasers applications, Quantel also worked on the development of a new product platform based on the fibre technology. The first laser system (EYLSA 780) of this platform is a single-frequency 780 nm fibre laser producing an output power of 1 W from a polarization maintaining single-mode output fibre and with a spectral linewidth down to 100 kHz. It is dedicated to Rubidium atom cooling, an exciting field of fundamental research studied in more than 100 laboratories around the world and with some recent Physics Nobel prize laureates in Europe. The aim of this field of research is to slow down and manipulate atoms, as it is already possible with photons or electrons, with a wide range of future applications (Atomic clocks for new generation of GPS, gravity sensors, frequency standards, tests of fundamental physics …). For this, it is necessary to concentrate atoms in a very tiny volume of the space by cooling their temperature (lowering their speed) with an optical trap. Basically, as schematized on the figure below, the cooling process is obtained by concentrating 6 lasers beams to create an optical trap in a defined volume of space.

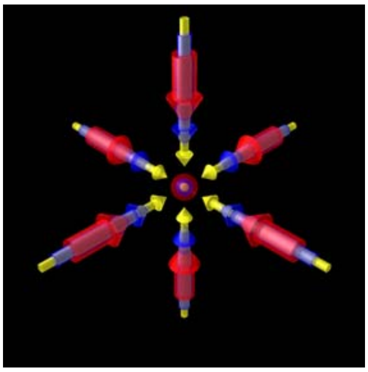

Figure 15: Principle of a 3D optical trap.

This single-frequency 780 nm fibre laser product has already been tested on real experiments to trap and cool Rubidium atoms down to a temperature of 30 µk. Both pictures below show the EYLSA 780 (left picture), and the fluorescence of cooled and trapped Rubidium atoms (right picture).

Figure 16: (left) EYLSA 780 fiber laser from Quantel, (right) Picture of real fluorescence of trapped Rubidium atoms with EYLSA 780 laser source.

Conclusions

In conclusion, the LIFT project led Quantel to demonstrate the first high power and high brilliance Yellow laser system based on fibre technology. It opens the way toward the development of a real product for ophthalmology applications. Quantel also launched a new single-frequency laser for scientific applications. All these achievements were possible because of strong interactions between Quantel, Gooch & Housego and Raicol

3.3 High power Green Q-switched laser

Objective:

The initial goal of this program was to develop a very high average power laser source producing short nanosecond pulses with diffraction limited beam quality. The market for this source was the production of Extreme UV radiation for EUV lithography. Over 200W of 13.5 nm radiation at intermediate focus could be produced by focusing a very high power (> 20 kW) pulsed CO_2 laser on a tin droplet target. A few years ago, a Japanese group demonstrated that a pre-pulse at a shorter wavelength can create a pre-plasma. The plasma will expand reducing the density of the tin droplet up to a point where the 10.6 µm from the CO_2 laser radiation can couple to the droplet much more efficiently. This method calls for a 1 kW average power around 1 µm, 10 ns source running at 100 kHz with a beam quality as closed as possible to the diffraction limit.

Unfortunately, the EUV lithography market kept moving away in time and 4 years after the start of the project, only a few prototypes of EUV steppers have been constructed and they still do not use pre-plasma. We decided to re-adjust our program toward more realistic markets using the same high power laser technology. We decided to develop a very high power nanosecond green laser.

Architecture

EOLITE choose to build a high power green source based on the experience we accumulated on the high power IR source for EUV lithography. The original architecture is given in Figure 17. This set-up shows the different components needed to build a high power Q-switched fibre laser. LIFT partners developed three strategic elements (shown in red on the figure):

- Very large mode area rod-type fibres
- High brightness, high power diodes at 976 nm
- High power Q-switch

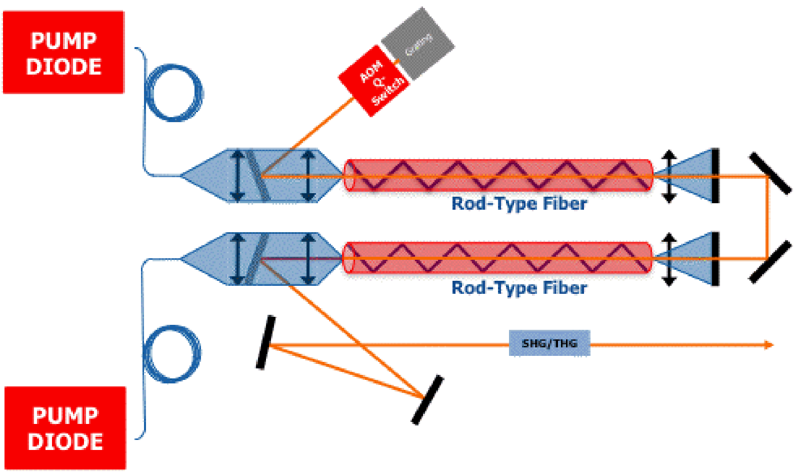

Figure 17: Experimental set-up of a high power green laser module

Components:

One of the crucial components in a high-power fibre laser is the fibre itself. Our architecture calls for very large mode area (> 50 µm in diameter) and perfect beam quality. When the project started, large mode area fibres were available but the beam quality was far from being perfect. During the program multiple partners collaborated to improve the quality, lifetime and performances of the large mode area rod-type fibres. The main contributor was NKT Photonics that developed a new family of fibres called Distributed Mode Filtering (DMF) fibres (see chapter 3.4 for more details). By the time new geometries were invented, new sources of problems were also discovered. Photodarkening remains an important issue that was mitigated during the LIFT project. More complicated was the discovery of thermally induced spatial beam instabilities that occur in any single mode fibre at very high average power. The threshold for these instabilities goes down when larger diameter fibres are used. This issue is still under study and remains the strongest limitation for high power Q-switch laser development. The DMF fibres were shown to push the threshold to almost 200 W in an amplifier configuration and to about 60W in oscillators. Even better stability was obtained using a geometry developed by the University of Jena. NKT Photonics drew Large Pitch Fibres with core diameters up to 80 µm and very high beam quality. These LPF fibres were integrated in all the high power lasers built by EOLITE.

The goal being to obtain short nanosecond pulses, the laser cavity has to remain below 1 m in length. This calls for short piece of fibre with a very high absorption. In order to keep the Yb concentration in the fibre below the threshold for photodarkening the fibre has a special geometry with a small pumping clad that needs very high brightness fibre to provide an efficient coupling to the fibre. DILAS was able to develop 300 W diodes fibre coupled on a 200 µm fibre. Compared to what was available at the start of the project, this is an improvement by at least a factor of 5 of the brightness, while keeping or even increasing the reliability of the diodes.

Figure 18: High brightness diode modules from DILAS

The gain of rod-type fibre can be very large and switching on and off the laser emission is a difficult point with an average power that can reach 300 W. Gooch and Hosego developed high quality, large aperture acousto-optic Q-switch modules that handle over 250 W while keeping excellent diffraction efficiency.

High power IR system

These components were used in a first module producing a maximum of 300W Q-switched power with a fresh fibre and up to 220 W in a steady state mode. Multiple high power sources were built through the LIFT project and wavelength multiplexing was demonstrated by spectrally combining two high power Q-switch lasers into a single diffraction limited beam with 400W average power.

In order to get these performances EOLITE has developed end caps that protect the tips of the fibres and make it possible to obtain energies above the damage threshold of the fibre itself. The thermo-mechanical stability of these large sources has been theoretically and experimentally studied to insure a perfect long-term beam pointing stability. This is of particular importance when it comes to combining several lasers in a single diffraction limited beam. Fast synchronization electronics have been developed by EOLITE to insure that the multiple lasers will produce perfectly synchronized pulses within 2 ns jitter. Finally EOLITE worked with OPTIGRATE (USA) to develop narrow linewidth, high efficiency volume Bragg gratings that can reduce the linewidth of the lasers and combined several lasers running at different wavelengths.

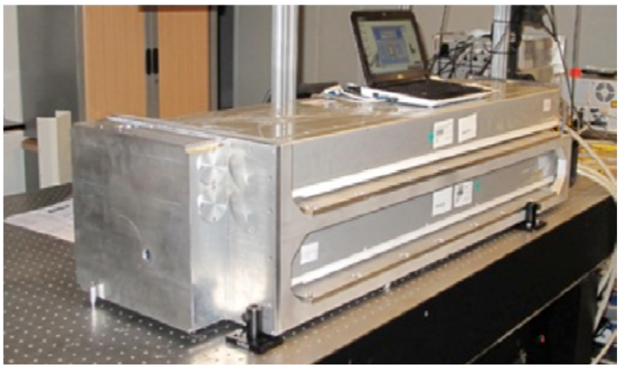

Figure 19: 300W system delivered to GIGAPHOTON for EUV lithography

Similar results were presented to GIGAPHOTON (Tokyo, Japan), one of the two companies involved in EUV generation using high power lasers. GIGAPHOTON purchased 4 systems to create a pre-plasma on a tin droplet. Two of the lasers were combined together using polarization coupling to produce over 300 W on a single diffraction limited beam in a 10 ns pulse at 100 kHz. A picture of the system is given in Figure 19.

Unfortunately the laser market for EUV generation did not take off as expected and EOLITE decided to stay at the power demonstrated using two lasers and switch to new opportunities utilizing the same technology. A summary of the results obtained at 1030 nm is given in Table 1.

Parameter	**Single laser Goal**	**LIFT results**	**Goal with 3 lasers**	**LIFT results with 2 lasers**
Average Power	>200 W	310 W	>600 W	400 W
Pulsewidth	<10 ns	15 ns	<10 ns	<15 ns
Pulse Energy / Rep Rate	>2 mJ @ 100 kHz	>1.6 mJ @ 250 kHz	>6 mJ @ 100 kHz	>2 mJ @ 200 kHz
Output Polarization	Polarized, >100:1	Polarized > 100:1	Polarized, >100:1	Polarized, >100:1
Beam Quality (M^2)	<1.3	< 1.2	< 1.3	< 1.2
bandwidth	< 0.3 nm	< 0.3 nm	3 x 0.3 nm	2 x 0.3 nm

Table 1: Forseen and actual performances of the IR lasers built in LIFT

High Power Green and UV lasers

LIFT gave the opportunity to EOLITE to develop high power Q-switched lasers with a narrow linewidth and a diffraction-limited beam. Starting from this IR engine, EOLITE has developed record high power green and UV nanosecond and picosecond lasers. The first demonstration was done by developing a high power second harmonic generator based on a LBO non-critically phase matched crystal. A maximum of 120 W of green radiation at 515 nm was obtained with a perfect beam quality (M2< 1.1). A similar source was built in the UV and produced up to 50 W at 315 nm. A typical performances curve is given in the figure below together with the spatial beam profile.

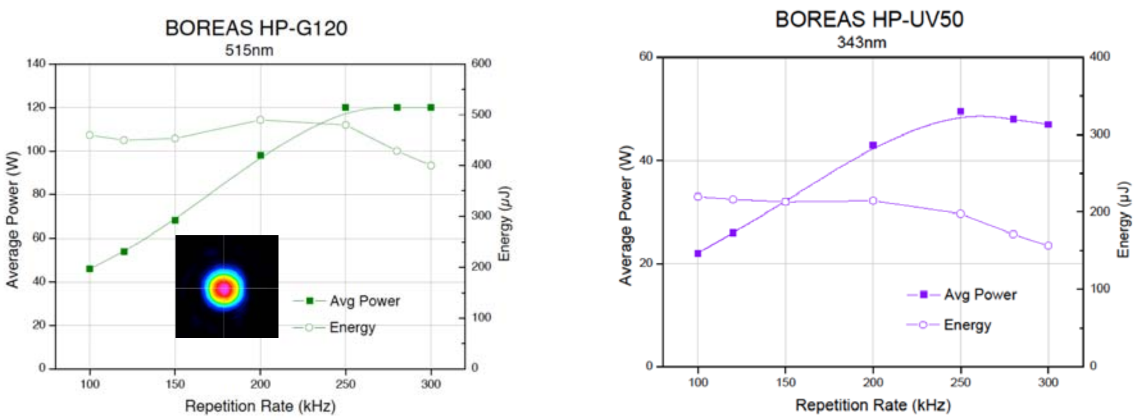

Figure 20: High Power green and UV lasers performances

The same double fibre architecture has been used to develop the highest average power picosecond laser on the market. Seeding the system with a mode-locked fibre laser producing 60 mW , 30 ps pulses we obtained over 200 W of IR picosecond pulses , 115 W at 515 nm and 65 W at 343 nm.

Improving technical performances

Figure 21 gives an idea of the improvement of high power Q-switch laser performances over the LIFT project duration at EOLITE. The IR power has been multiplied by 3 and the green power by 5. The plateau that can be seen in the figure is due to the limitation in average power coming from spatial instabilities in the rod-type fibres. This issue is being studied by several groups in the world and is expected to be solved or mitigate in the coming years. The other limitation in the race toward higher power is the ability of customers to handle very high average power short pulses lasers and to find applications for these sources.

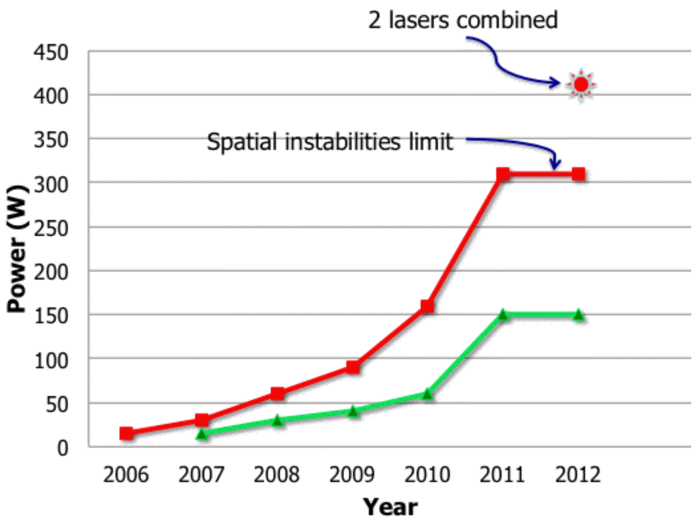

Figure 21: Evolution of the EOLITE lasers average power versus time (red: 1030 nm; green : 515 nm)

Turning LIFT results into products

Eolite Systems used the results from the LIFT project to develop several families of new products. EOLITE has sold multiple high-power IR systems to a Japanese customer working on EUV generation for lithography. This market is not alive anymore for EOLITE and the >200 W IR system is waiting for new market opportunities.

Nevertheless, several other markets appeared during that time in totally different fields. EOLITE has introduced a 60W green laser on the market that found applications firstly in the photovoltaic market and then in micromachining. PV is on hold for the moment but very good results were obtained in high quality Metal Wrap Through wafer drilling and wafer dicing. New markets emerged with micromachining of different kind of materials like silicon or metals. Very good results were obtained on wafer dicing and for the watch industry. Five 60W green lasers have already been sold in Korea, Japan and Switzerland for these applications. Customers are in the qualification period and larger volumes are expected as soon as the lasers are designed in.

In a totally different field, EOLITE has delivered a 100 W picosecond laser working at 515 nm to an Asian customer. This source is the largest average power commercially available picosecond laser in the visible. The laser will be used for micro-machining applications and four more sources will be delivered to this customer in the next 12 months.

Figure 22 shows some of the products based on the high power amplification technology that EOLITE developed through the LIFT project.

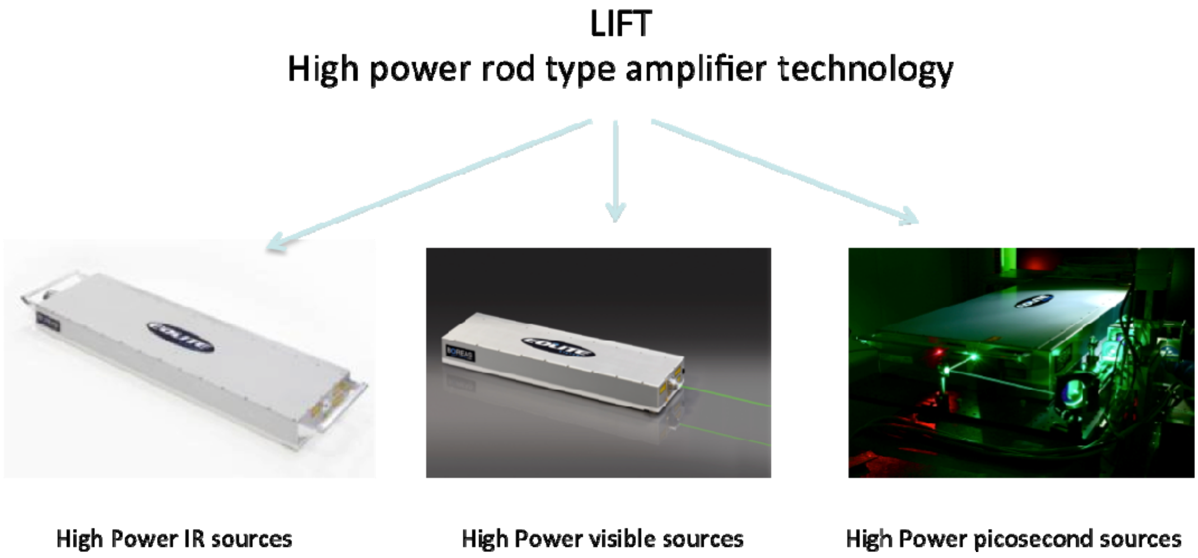

Figure 22 : example of products developed from LIFT results

High power amplification architecture, high brightness diodes, single mode LMA fibres and high power components developed in LIFT will have a significant impact on the business made by EOLITE and hopefully by other companies switching to this technology in the very near future.

3.4 High average power ultrashort-pulsed MOPA laser system

While nanosecond (ns)-micromachining has been established in industry for more than a decade, and picosecond (ps)-micromachining is quickly moving into established industrial applications, femtosecond (fs)-microprocessing is still in its infancy. However there is an expected future growing demand for high-power fs-laser systems for various reasons: one aspect is the potentially improved quality that can be achieved with fs-lasers compared to conventional pulsed laser systems. This is mainly due to the cold ablation process achieved with fs-processing which exhibits a minimum heat affected zone in the processed material and leaves little or no melt-debris at edges and surfaces. Furthermore, the high peak intensities achieved with fs-pulses enables unique processing of materials such as two-photon ablation in transparent materials, at qualities or throughput not achievable with current technologies.

Until now, achieving acceptable processing quality has been too expensive or too slow for industrial production. One key limitation for high throughput has been the low average power of available fs-lasers. The ultra-short pulsed system developed in the LIFT project is targeting this issue. It will offer a new, reliable high-power fs-laser source at a competitive price, which will enable processes not possible before in an industrial environment. Promising applications from advanced research in material science and health care are waiting for the right tools to bring them into production.

Objectives

The goal within the LIFT project was to develop an ultrashort-pulsed high-power laser system offering high peak power and a highly flexible pulse energy. The system was designed in a Master Oscillator Power Amplifier (MOPA) architecture with multiple amplification stages. Among the key system goals were: sub-picosecond pulse duration, 100-200 W average output power, available pulse energies of >100 µJ, a user-adjustable pulse repetition rate and diffraction limited beam quality. The system should be based on a common fibre-engine to be developed within the LIFT-project. Furthermore compact packaging including the realization of a compact pulse-stretcher- and compressor-architecture based on Volume Bragg Gratings (VBG) should be implemented. The tasks to realize the aforementioned goals included substantial new developments such as a stable high-power femtosecond laser oscillator to be used as the master-oscillator seed source, a pre-amplifier, based on flexible Photonic Crystal Fibre (PCF) and a power-amplifier using inflexible so called ROD-type PCF.

Subsystem fibre engine

In order to realize a sophisticated fibre engine, to be used in the final system as the power amplification stage, two fundamental building blocks are vital: one is a high-power, high-brightness pump module, the other one is a Large-Mode-Area (LMA) active fibre. For both building blocks completely new components with remarkable specifications have been developed within the LIFT project, which in the meantime have been transferred into commercial products.

<u>Pump-module:</u>
In the Lift project, several types of advanced high power diode laser modules for fibre laser pumping were developed and tested by Dilas Diodenlaser GmbH, as described in chapter 3.1. As a result of the LIFT project, a pump diode delivering more than 800 W out of a 200 µm fibre was built and used to pump the power-amplification stage of the ultrashort pulsed MOPA system.

<u>Large Mode Area Fibre:</u>
In the development of active LMA PCF, the main tasks which partners iXFiber and NKT Photonics had to address were effects of Photo Darkening (PD), clean single mode operation and potential damage due to extremely high optical intensities in pulsed laser operation. Prior-art fibres had neither sufficient power handling capabilities nor lifetime. Instead of refining an existing ROD-type PCF, a completely new design type was developed within LIFT, satisfying all of the before mentioned requirements. To obtain the specified amplification, a reasonably high ytterbium doping level of the active core was required while maintaining a limited refractive index increase of the material and also a melting point matched to that of silica. iXFiber has developed and produced a multi-component core material with excellent PD-properties. In multiple iteration-cycles the composition of the core elements Silicon, Aluminum, Ytterbium, Cerium and Oxygen have been optimized to obtain a PD-resistant material with good pump-absorption and signal amplification. This new core material is fully compatible with the complex manufacturing process used for ROD-type PCF and can be produced and delivered reproducible in large batches of homogeneous preforms.

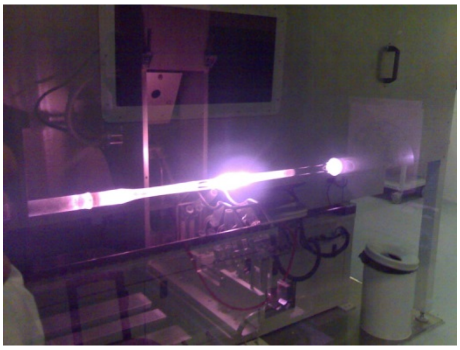

Figure 23: Production of low-PD preforms: picture shows MCVD collapse phase.

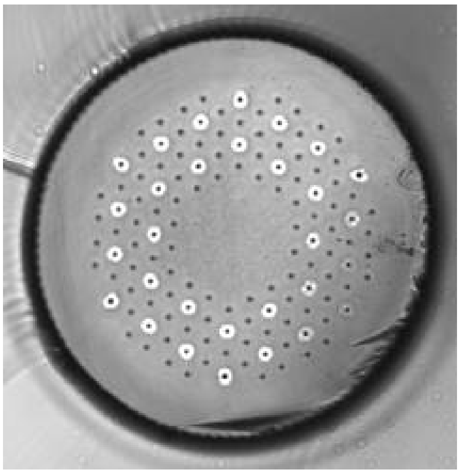

Figure 24: The microstructure of the PCF. Bright circles are DMF

A crucial geometric design parameter of an active fibre for high-power and high-energy applications is the effective mode-field diameter, which has to be maximized to avoid optical damage. To facilitate single mode operation in very large mode area fibres the fibre design is utilizing the Photonic Crystal Fibre platform where the fibre is micro-structured with holes in a periodic pattern around the central core. The key advantage is that it is easier controlling the hole-size than controlling the refractive indices of the fibre materials and thereby PCF can be scaled to larger mode areas than conventional fibre, while still maintaining the desired single mode operation. Within LIFT, NKT Photonics has developed a novel design using a spatial Distributed Modal Filter (DMF) in the cladding (visible as bright rings in Figure 24), efficiently suppressing higher order spatial modes for a 85 µm core ROD fibre. This new ROD fibre was matured and commercially launched by NKT Photonics in February 2013 under the name aero-GAIN-ROD. The PCF ROD development within the LIFT project has resulted in one patent application, four scientific papers in peer-reviewed journals and six conference contributions at peer-reviewed international conferences.

Both of the before mentioned components were finally combined into a fibre-engine, which was used in the ultrashort-pulse MOPA system as the power amplification stage.

Ultrashort-pulsed MOPA system performance

The ultrashort-pulsed high power laser system is designed in a MOPA architecture, where pulses from a seed laser are amplified in multiple stages. As a master-oscillator, Time-Bandwidth Products has developed a seed laser with excellent properties such as sub 200 femtosecond pulse duration, high average power and good long-term stability

Figure 25: Time-Bandwidth

The properties of this laser oscillator were identified to be very attractive for other applications outside LIFT as well, such as multi-photon microscopy, nanosurgery or time-resolved spectroscopy to mention a few. As a consequence, the laser was refined and packaged in an industrial-grade OEM-housing and is now available as a commercial product under the name “YBIX”. Key specifications of the YBIX-laser are a pulse duration of 180 femtoseconds emitted at a wavelength of 1040 nm with an average output power of >2.5 Watts. Figure 25 shows the final commercial product as depicted in the product data sheet. First units of this laser have already been sold and are successfully used in microscopy-applications.

One key concept of Time-Bandwidth Products' commercial micromachining lasers is the user adjustable pulse repetition rate, implemented in a way that the laser's full average power is always at the user's disposal. By changing the repetition rate, the pulse energy can be optimized for maximal efficient material removal, leading to energy-efficient production and maximum productivity. This concept is especially important for high-power lasers, which otherwise would always be used in sub-optimum operation modes. The same concept is implemented in the LIFT laser system. A user-adjustable pulse-picker after the seed laser controls the number of pulses sent through the amplifier stages, thereby controlling the pulse-energy at the output of the laser.

To reduce nonlinear effects or even damage in the fibre amplification stages originating from the extremely high peak powers generated (multi-hundred megawatts), the system implements the scheme of Chirped Pulse Amplification (CPA): as shown in Figure 26, the 200-fs seed laser pulses are temporally stretched by a factor of 700 with a strong dispersive element before they are launched into the amplifying fibres.

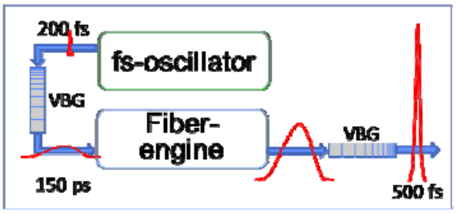

Figure 26: Scheme of Chirped Pulse Amplification (CPA)

After the amplification they are re-compressed by another strong dispersive element of opposite sign and same magnitude. Usually free-space configurations combining two optical gratings for each of these functional units are used for this purpose. The footprint of such setups can easily reach multiple square decimetres (for both, stretcher and compressor each), preventing a compact packaging. In the LIFT-laser pulse-stretching and re-compression is performed by highly compact and efficient Volume Bragg Gratings (VBG) with a footprint of only 30x8 mm^2 each. Fine-tuning of the dispersion is performed by an additional small, adjustable grating compressor.

After amplifying the seed laser pulses to an intermediate power level with a fibre amplifier based on NKT Photonics' flexible PCF-products, the common fibre engine developed under LIFT was used to boost the power to the final specifications. *Table 2* shows the main numerical targets for the ultrashort-pulsed MOPA system together with the lab demonstrator performance. The average output power exceeded the project objectives and is currently limited by modal instabilities which occur above a certain threshold. These power dependent instabilities are inherent to LMA-fibre in general and not peculiar to the LIFT system or its components. Pulse energy targets have been exceeded and also the output beam quality of the system is diffraction limited as desired. The pulse duration is still power depended but will be constant at a low level in a commercial product.

Parameter	**Goal**	**Objective**	**Lab demonstrator**
Average power	>200W	>100W	125 W
Pulsewidth	<500 fs	<1 ps	700 fs @ 25 W 1.9 ps @ 105 W
Pulse Energy / Rep Rate	>100 µJ @ 2 MHz	>15 µJ @ 10 MHz	> 110 µJ @ 300 kHz > 17 µJ @ 3 MHz
Centre Wavelength	1030-1040 nm	1030-1070 nm	1030 nm
Beam quality (M^2)	<1.2	<1.5	<1.3

Table 2: Key laser parameters of the ultrashort-pulsed MOPA system

Compared to Time-Bandwidth Products' current high-power product portfolio, the lab demonstrator laser system represents an increase in average power by a factor of three and a reduction of the pulse duration by a factor of up to fourteen. Because of this performance increase, the LIFT system will serve as a future product platform for the company. Time-Bandwidth Products is planning to do a stepwise exploitation of the LIFT results. The seed-oscillator has already been transferred successfully into a commercial product. In a next step a low-power MOPA system, implementing only one amplification-stage, will be release before a final high-power product is commercialized.

Applications

During midterm of the LIFT project a demonstrator laser system with an average output power of 50 W was used for applications trials in the labs of Tampere University of Technology. In various processing tests, feasibility of multiple very challenging applications have been proven with the delivered laser. Femtosecond pulses have demonstrated clear advantages over conventional pulsed laser systems in processing of sensitive material like ceramics and organic polymers, used for example in life science applications. The trend towards miniaturized sensing and analysis elements in drug testing and environmental monitoring is demanding high precision processing of the used brittle materials like ceramics and organic polymers. The first processing results based on the demonstrator laser have been very promising. Especially in the processing of Aluminium-oxide ceramics Volume Removal Rates (VRR) of up to 2.4 $mm^3/(min \cdot W)$ have been demonstrated while currently values of 0.1-0.2 $mm^3/(min \cdot W)$ are commonly cited in the literature. This is an increase in productivity by a factor of 10.

However, most high-quality results during the tests were obtained at relatively low average output powers, limited by the dynamics of the available beam delivery system. Using the available power to full extend usually resulted in an overall poor quality. The used state-of-the-art Galvanometer-scanner, identical to those most commonly implemented in production environments, offered scanning-speeds of about 3 m/s. High power Ultrafast lasers should be operated at pulse repetition rates of multiple megahertz, to take full advantage of the available power. Otherwise the emitted pulse energy will be too high, leading to highly inefficient laser processes and poor quality products. At repetition rates of multiple MHz and lateral scanning speeds of only a few meters per second, the spatial overlap of the individual pulses on the workpiece becomes greater than 99%, leading to undesired, strong heating effects in the material thereby nullifying the most important advantages of ultrafast lasers, namely the cold ablation processing capabilities.

Time-Bandwidth Products was addressing this important issue during the course of the project's last year and put increased effort into setting up an ultra high speed scanning workstation for the femtosecond MOPA system to investigate the real potentials of the laser. A polygon-mirror scanner, allowing lateral scanning speeds of up to 100 m/s was implemented into a laser processing workstation.

Figure 27 shows the scan-head during processing of a large-area structuring application.

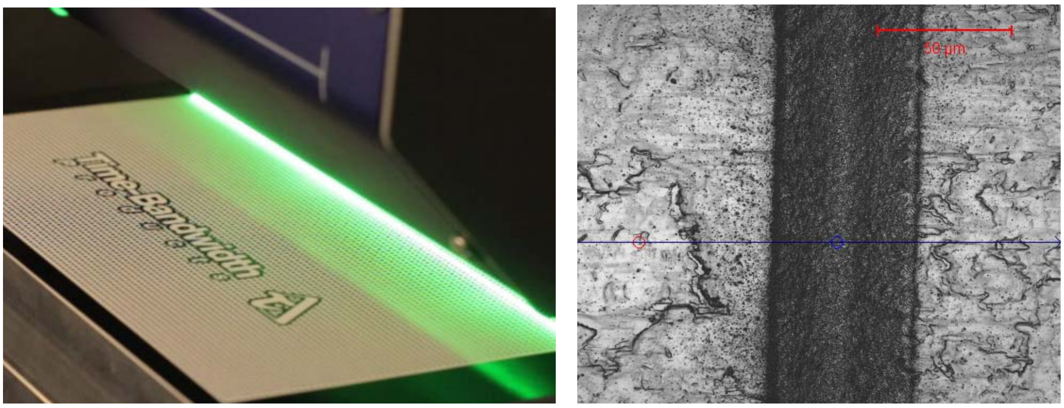

Figure 27: Structuring with the ultrafast polygon-scanner at 100 m/s (left) and groove in stainless steel (right)

Through a recent commercial request, the setup could already proof its capabilities: in a customer's process, grooves with 10 µm depth and 50 µm width are to be engraved into stainless steel. The process is done at the customers site with a 50 W picosecond laser and a commercially available galvanometer-scanner with a final processing speed of 5-10 mm/s. With the new processing workstation, these grooves could be cut with up to 150 mm/s at an average power of 40 W (s.

Figure 27). This is an increase by a factor of 15. The process speed was thereby still limited by the scanning speed of the polygon-scanner of 100 m/s. As the laser-system would deliver about three times more power, it is envisaged that the processing speed could be improved by another factor of three with an improved scanhead. This result impressively demonstrates the impact of the implemented beam delivery and offers an outlook on possibilities in the future.

3.5 All-in-fibre high-peak-power flexible nanosecond laser systems

Objectives

The aim was to develop an "all-in-fibre" nanosecond pulsed system with high peak power, variable repetition rates and pulsewidths, and flat-top beam profile. The Key Laser Performance Goals which were identified were; pulsed nanosecond laser sources with pulse energy greater than 10 mJoules, possibility of >100 kW peak power, a flexible architecture for user-adjustable pulse width and repetition rate, all-fibre beam delivery with flat-top profile and optical isolation, non-photodarkening fibre. Another goal was to reduce laser system cost from ~1000 €/W to 300 €/W. In order to realize the goals of the laser system on a practical basis, substantial improvements or new developments were required in a number of laser components. A substantial increase in pump power/brilliance was required to be able to construct the laser in a practical, cost-effective manner. New seed lasers were required to achieve the required range of pulse durations, and high power fiberised components needed to be developed in order to achieve the "all-in-fibre" architecture which provides compactness, high-wall-plug efficiency, reliability and maintenance-free operation.

Substantial developments in the fibres themselves and their packaging were required to achieve the pulse energy and average power goals.

The extreme flexibility of the output of the laser means that it potentially has applications in a wide range of materials processing applications, including cutting, drilling, engraving, marking and microstructuring a variety of materials. High average power increases possible processing speeds. Applications trials were intended to provide an assessment of the potential of the laser system for a range of industrial applications.

Components / Subsystems

Seed lasers:
Thank's to the LIFT project, 3S Photonics were able to develop a high power (1W) pulsed seeder module with a rapid rise time. With a suitable driver this provided the capability to produce pulses with a very wide range of pulse duration, from a minimum of about 300ps up to 100s of nanoseconds, which were used to seed the LIFT demonstrator laser. LIFT also supported work on the pulsed seeder component & module design to achieve very high reliability, demonstrating the capability to deliver a reliable product with these capabilities.

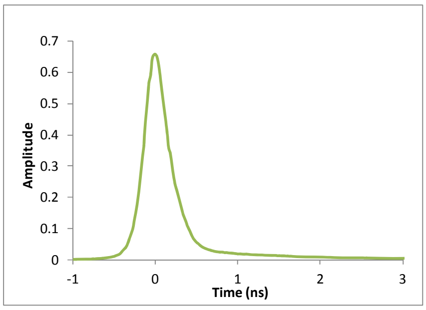

Figure 28: 300ps optical pulse from 3S Photonics seeder laser

Pump modules:

The LIFT project supported the development and testing of Oclaro's multimode single emitter based laser diode modules running at 30 W (4 chips) and 65 W (8 chips) output power. The 65 W pump module leverages a new generation of laser diode chip with increased efficiency and reliability. A controlled under-filled NA along with a cladding mode stripping feature allows low loss and highly reliable fibre combining. A compact, rugged housing offers superior thermal management. Automated alignment and manufacturing processes enable high volume deliveries with highest consistency in module-to-module performance. Tests by SPI Lasers of these modules in conjunction with a suitable combiner show that they can deliver more than enough power to achieve the LIFT project goal for average power from a fibre laser.

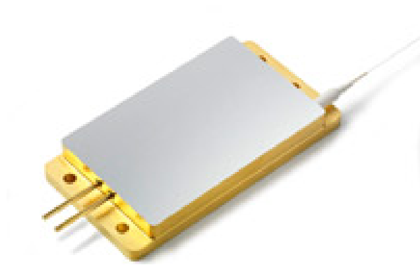

Figure 29: Oclaro BMU65 pump module

Optical fibres:

SPI Lasers has considerable experience in the development of non-photodarkening optical fibres. Within the LIFT program, SPI developed a new family of active Ytterbium-doped fibres with improved material deposition techniques for manufacture of photo-darkening-resistant fibre with large cores to address high peak power and high pulse energy. SPI also developed matching passive optical fibres for beam delivery.

Fibre thermal management technology:

One of the crucial factors in the development of a high average power laser system is thermal management. Within LIFT, SPI made improvements to fibre laser thermal management, developing new spool architectures and techniques to manage waste-light in fibre lasers.

Electronics:

The LIFT project also supported SPI in developing new control and drive electronics for its lasers allowing an extension of the range of pulse durations, and results utilizing SPIs newly developed components in the LIFT laboratory laser and LIFT demonstrators for applications trials show that much higher powers are possible. High-efficiency, low-cost high-power drivers are crucial to increasing the average power of lasers.

Fibreised optical components:

The LIFT program assisted Gooch and Housego in the development of a variety of fiberised high-power optical components. Two were relevant to the flexible all-fibre system. 1) Fibre In Beam Out (FIBO) isolators handling 100 W cw were developed by G&H for system use in the demonstrator. They represent a new branch to G&H portfolio and were an ambitious leap. Good beam quality and thermal lensing performance have been measured under stretching conditions. As an extension and complementary to this work G&H have developed Fibre In Fibre Out (FIFO) isolators. These have been tested to in excess of 30 W cw with loss<0.5dB and low PDL and with exciting prospects of further development for future pulsed laser systems. 2) A high power acousto-optic modulator (AOM) with 30 ns rise-time, 5 W power handling and extinction ratio 50 dB. This represents a step-change improvement in performance. It allows for manipulation of the laser pulses at an intermediate stage of amplification, giving greater control over the output of the laser system.

Figure 30: Gooch and Housego high power fiberised acousto-optic modulator

Optoskand are providing a 100x100 µm square-core optical fibre built into an RQB fibre connector followed by an external collimator as well as a new fibre-to-fibre coupler (FFC) from OSK to couple the beam from the output QBH fibre, to splice the output of SPI LIFT laser to the square fibre, offering a new type of beam profile for applications work.

Figure 4: Optoskand Fibre to Fibre Coupler

Flexible All-Fibre Laser System Performance

The flexible all-fibre laser system is a Master Oscillator Power Amplifier system where pulses from a seed laser are amplified in several stages. The system has a compact, all-fibre and fully spliced construction. All the amplification stages use non-photodarkening Yb-doped fibres and are based on SPI's proprietary GT-Wave® fibre coupling technology.

Parameter	unit	SPI capability –pre-LIFT	LIFT Objective	LIFT Goal	SPI LIFT lab demonstrator laser	G4 format laser
Av. Power	W	40	>100	>200	265	100
Pulsewidth (min)	ns	10	1	0.5	0.5	3 –500
Pulsewidth (max)	ns	200	200	500	500	500
Pulse energy (at 10ns duration)	mJ	0.15	0.5	1	1	0.5
Pulse energy (long)	mJ	1.3	5	10	10.6	5

Table 3. Key laser parameters: Project objectives and goals and SPI capabilities

The main numerical targets for the flexible all-fibre laser system and the achieved results are shown in *Table 3*. All the project goals were achieved or exceeded by the laboratory laser system. Originally the LIFT project called for 2 laser architectures, one for short pulses and another for long pulses, but the components developed under LIFT proved to be sufficiently flexible in performance to achieve all goals in a single architecture. Pulse characteristics can be changed on a pulse-to-pulse basis.

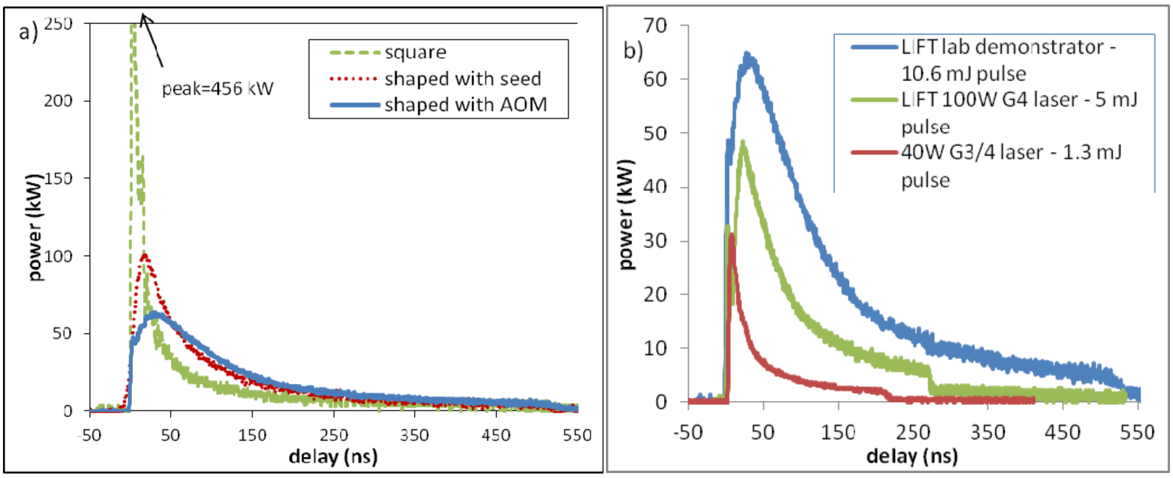

Figure 31: a) 10.6 mJ pulses from the demonstrator laser, demonstrating the ability to control peak power by pre-shaping of the pulses before the final amplification stage. b) Comparison of pulses from SPIs highest pulse energy laser prior to the LIFT project (1.3 mJ), the highest pulse energy (4 mJ) from a production standard laser based on LIFT and the highest pulse energy from the LIFT laboratory demonstrator laser(10.6 mJ).

The shortest pulses produced by the demonstrator system were 500 ps (slightly broadened during amplification from the 300 ps output of the seed), with peak powers up to 110 kW. With longer pulses, very high peak powers can be demonstrated. Reshaping, either through control of the seeder laser, or for a greater level of control, mid-stage pulse-shaping utilising the high-power acousto-optic modulator, allows control of the peak power of the laser, independent of the pulse energy. Control of peak power is significant a) because different applications may have lower or upper bounds on the required peak power and b) because high peak power pulses may suffer spectral degradation in the delivery fibre. The upper limit on peak power will be determined by the spectral requirements of the process and the length of delivery fibre. For a 2 m delivery fibre the practical limit is probably about 150 kW for the fibres used here. The lasers have an M^2~7, (M^2~5 for the G4 format laser), with a fairly flat topped beam profile.

Figure 32: SPI redEnergy G4 pulsed laser

Compared to pre-LIFT SPI laser products, this laser represents an x8 increase in maximum pulse energy, x5 increase in peak power, x6 increase in average power and an increase in longest/shortest pulse width ratio from 25 to 1000. The LIFT project has been integral to the ongoing development of SPIs redEnergy G4 pulsed laser platform. Enhanced pulse performance has been realized in SPIs new G4-EP range of lasers, which offers a range of pulse duration 3-500 ns (compared to 10-200 ns in previous models). At the start of the LIFT project SPIs highest power pulse lasers had 40 W average powers. SPI now sells G4-high power lasers with >70 W average power. The thermal management techniques developed under LIFT also benefit SPIs range of cw lasers. At the start of the LIFT program SPIs highest pulse energy laser delivered 1.3 mJ. The G4 demonstrator developed for LIFT applications trials is capable of 4 mJ, and SPI expects to realize higher pulse energies in manufacturable format in the near future. Fibres initially developed as part of the LIFT development program also facilitated SPIs new high-pulse energy, low-moded G4-Z variants. Development work under LIFT which has benefitted SPI laser manufacturing includes fibre manufacture processes, novel fibre designs, efficient PSU and diode driver electronics, seed sources, isolators, high power thermal management, high power laser chassis design, pump modules, pumping architecture and pulse shaping technologies. The cost reduction targeted by LIFT has been amply achieved. SPI expects that the technical achievements of the LIFT program will continue to feed through to its commercial laser portfolio over the next several years.

Applications Trials

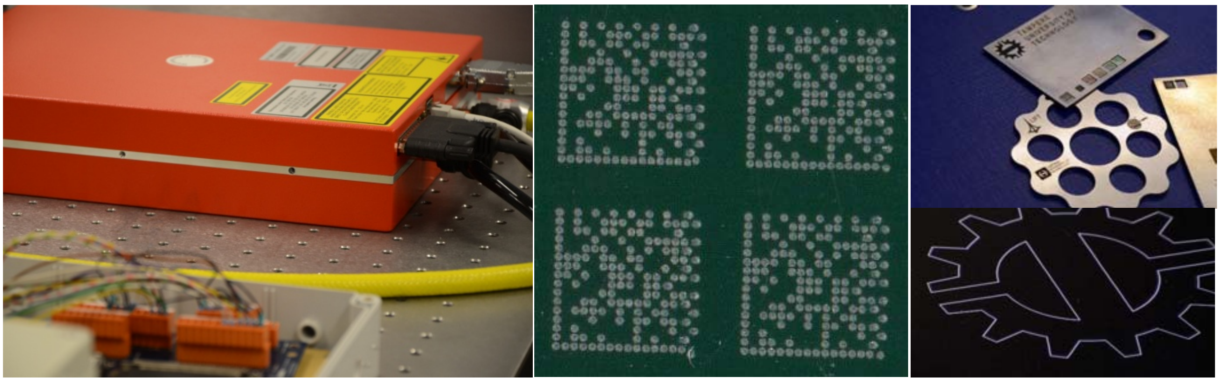

Figure 33: a) 85 W, 3.4 mJ water-cooled G4 engineering prototype laser for applications trials, b) Example application trial: marking green coating on aluminium with LIFT demonstrator laser – dot diameter 148um – time taken ~0.65 s, c) various engraving and drilling samples from TUT

A laser with 85W average power, 3.4 mJ pulse energy and M2~5 was produced in SPIs redEnergy G4 pulsed laser format, for use in applications trials. (This has since been upgraded to 4mJ).

At SPI, preliminary evaluation was carried out for paint removal, ablation marking of coloured coatings on aluminium and point hole drilling on anodized aluminium, and comparisons made with a commercial SPI 40 W/1.3 mJ/M^2~3 G4 laser. Paint removal was demonstrated to be substantially faster with the 3.4 mJ than the 1.3 mJ laser. Marking on the black, green, orange and red coatings tested was much clearer with the 3.4 mJ laser than the 1.3 mJ laser. The 3.4 mJ laser was able to produce marks of excellent quality (good enough to allow code scanning with a smartphone camera). The 3.4 mJ laser was able to drill aluminium much more rapidly than the 1.3 mJ laser because the larger pulse energy/spot size meant that dithering was not required to open up the spots to the required size.

Tampere University of Technology conducted tests on various materials from metals to ceramics. Materials were engraved, drilled, cut and marked for test purposes.

Ceramic nickel based fuel-cell cathode material was cut with the demonstrator. Usually this material is cut mechanically, which makes the cutting process time consuming. High pulse energy combined with low repetition rate gave promising results. The reduction in processing time was encouraging and quality of the cuts relatively good.

Low Temperature Cofired Ceramic is commonly known to be hard to process and processing times can be long, so laser processing can be a good alternative. Compared to previous processing tests with a femtosecond laser, higher quantities of material could be removed in shorter time by the demonstrator laser, though the femtosecond laser offered higher quality and more accurate features.

Stainless steel and aluminium were marked and engraved with good results. Short pulse widths suit engraving, as less heat is produced. The ability to change pulse length combined with a wide scale of parameters enables easy colour marking, since picking up the right combination for each material produces different scale of different colours. Using the appropriate pulse length is one of the most important parameters when colour marking metals. Engraving of aluminium was easy and fast due to the high pulse energy. By changing the laser parameters the properties of the mark appearance can be changed according to need. Also deeper engravings can be made by operating first with parameter leading to high removal rate and finish using low power and varying pulse width for better surface quality. Cutting of stainless steel and drilling of steel and aluminium were also demonstrated.

The trials of the laser show promise in a variety of applications, including demonstrating good quality processing on materials which we could not previously process with fibre lasers. The high pulse energy has expanded the range of potential applications compared to our previous lasers. The value of the highly flexible pulse duration was demonstrated. Although preliminary, these trials have shown that this laser system is likely to have a significant impact

.

4. The potential impact

The expected impact areas listed in the NMP work programme were:

1. A clear strategic contribution to establishing a European high value photonics industry
2. New, cost efficient production methods to improve/extend the lifetime and quality of products
3. Impact in high market value segment.

The LIFT partners succeeded in developing an internationally leading position for Europe in fibre laser technology. The development of a new generation of high brilliance lasers expanded the limits of advanced materials processing. Exploitation of the results from this project helped to push high throughput manufacturing technologies, and LIFT participated in the expansion of a greater market share for existing applications, the creation of new areas of exploitation for manufacturing and helped to build a network of European research institutes, component suppliers, laser system manufacturers, system integrators and final users of fibre lasers.

The most relevant and visible impact of the LIFT project in regard to the NMP work programme targets is without doubt the Key Project Results. As part of the project, the LIFT partners have developed 36 exploitable products and the 12 finalized exploitable results are mainly components to be integrated into high-power, high-brilliance fibre lasers. These components include pump modules, passive components such as pump combiner, isolators, but also, fibres. All these results are participating in a vivid competition on the fibre lasers and fibre components market in Europe.

Most of the project results have been presented during Laser World of Photonics in May 2013 and are already in the sales catalogue of their owner. Some examples are presented hereunder.

Quantel EYLSA Fibre Laser

The new EYLSA fibre laser uses Quantel's fibre laser expertise to offer highly reliable and maintenance-free visible fibre lasers for the scientific market. With a large touch screen and integrated into a 19" 3U rack, EYLSA is the most compact, easy-to-use, Plug & Play platform for scientific experiments using visible fibre lasers.

Figure 34: Quantel EYLSA and ROFIN FL020 fibre lasers as results of LIFT project

ROFIN FL Series

ROFIN FL Series of fibre lasers have already firmly established themselves within the industrial production sector and are synonymous with efficiency, precision and cost-effectiveness in a large number of applications. With a new generation of fibre lasers, the ROFIN Macro Group is now enhancing its position as a quality supplier of high-performance fibre lasers.

The ROFIN FL 020 is the first model from this series. Smaller, more compact and easier to use best describes the new performance and design enhancements. The 2 kW fibre laser that can be equipped with up to 4 fibre outputs, comes in a smaller, wall-mountable housing, with simultaneously improved fibre handling and with reduced water requirement.

Intellectual Property

The general principles for Intellectual Property Aspects set out by the EC for 7th FP RTD projects apply. The use of existing know-how is limited to use for the achievement of the project goals and for the duration of the project.

Knowledge or results (IPR created during the project) is owned by the partner or partners who developed the results. Each partner is responsible for taking the appropriate steps for securing intellectual property of the knowledge or results created during the project (e.g. filing of patent applications). Any owner of any result is free to use such result and to commercialise and distribute it. Results from the project have been made available free of charge to partners of the consortium for research purposes within the scope and the duration of the project.

One Consortium partner, NKT Photonics, filed patent applications.

Type of IP rights	Confidential (Yes or No)	Foreseen embargo date	Application reference(s)	Subject or title of application	Applicant
Patent	Yes	janv-11	Filed June 2010	Large core area single mode optical fiber	NKT Photonics
Patent	Yes	Dec 2012	WO2011160646	Novel design type for ROD type fibers	NKT Photonics

Table 4: List of Applications for Patents, Trademarks, Registered Designs, etc.

Standards

LIFT Partners worked on standards development in cooperation with CEN in order to insure that the project's initiatives are harmonised with other players in Europe and elsewhere. LIFT partners have joined their effort to the appropriate technical committee: CEN/TC-123 on lasers and photonics. At this point no standards have been approved.

DISSEMINATION

The dissemination activities aimed to reach three important audiences:

- The international professional R&D community by sharing pre-competitive information and results in order to lead and encourage technology progress.
- The general public in Europe in order to explain how European R&D programmes are improving the quality of life and the competitive position of European business
- The next generation of young students to encourage careers in science and technologies.

Information Portal

Thanks to highly efficient tools the LIFT project has been widely disseminated to reach the target audience. The LIFT website (www.lift-project.eu) was operational in month 2 of the project. The number of visitors has been growing constantly to reach more than 12 000 visits by the end of the project and over 34 500 page views. Visitors came from 112 different countries and read an average of 3 pages by visit. As a comparison, the statistics show that the webpage has been viewed 2000 times the first year, 5536 times at the end of the 2nd year and 9000 by the end of the 3rd year.

Figure 35: Front page of the LIFT website

A Google search of “LIFT Fiber Laser Project” returns 180 000 results. A sample is shown at the end of this paragraph. These results demonstrate the activity of many project beneficiaries in dissemination. These results additionally show that many other organisations, from broad-based organisations like Amazon, to IPG a leading manufacturer of fibre lasers are reporting on the LIFT project.

LIFT PROJECT
www.lift-project.eu
The LIFT project will establish international leadership for Europe in the science, application and production technologies for material processing by fibre lasers ...

LIFT Project on Euronews Quantel Visible Fiber Lasers – YouTube ► 3:01► 3:01
www.youtube.com/watch?v=1_f7rpKouco
Ajouté par TampereUniTechTTE
LIFT partner Quantel is developing visible fibre lasers in the EU project LIFT David Pureur and Mathieu...

LIFT Project on Euronews_Quantel Visible Fiber Lasers.flv – YouTube ► 3:01► 3:01
www.youtube.com/watch?v=7GIC8ZGGhOc
Ajouté par EPIC photonics

EPIC member Quantel is developing visible fibre lasers in the EU project LIFT (www.lift-project.eu). David...

EC funds fiber laser project (FIBER OPTICS): An article from...
www.amazon.com
fiber-laser-project.../B0036SDW...
LIFT--Leadership In Fiber laser Technology--is a collaborative, large-scale integrated project funded by the NMP Directorate in the 7th Framework Programme of ...

EC-funded LIFT project takes leadership in fiber lasers - Industrial...
www.industrial-lasers.com
LIFT - Leadership In Fibre Laser Technology, is a collaborative, large-scale integrated project funded by the NMP Directorate in the 7th...

EC-funded fiber-laser project LIFT takes off - Laser Focus World
www.laserfocusworld.com/
The European Commission (EC) has announced the launch of Leadership In Fibre Laser Technology (LIFT)...

News - 06/01/2012 - Company focus - LIFT-project Partner Quantel ...
www.routedeslasers.com/
As Quantel develops its products, it is working with other high-tech partners in an EU project LIFT on fibre lasers. We bring together people...

OUTREACH

The outreach programme is composed of activities to pro-actively reach a wide range of audiences including: young students, the general public and the professional scientific community.

Social Network

In September 2010, the project has created and maintains a social network site on linked-In. (http://www.linkedin.com/groups?gid=3459529&trk=hb_side_g)

This site has now 2 594 members and a very active discussion platform for fibre laser technologies and it is used as a portal for LIFT-related announcements and dissemination.

Press Release and articles

The public announcement of the LIFT project was disseminated as soon as the website was made active. There was a strong response over the following 30 days. Information from the Press Release was widely published in key professional websites and magazines, such as: Opto IQ, Laser Focus World, Optics.org, and Photonics21. This interest from the media remained constant during the 4 years of the project.

Best example is a reportage broadcast on EuroNews television network on Quantel Visible Fiber Lasers which is visible on YouTube:
http://www.youtube.com/watch?v=C3_1lod6S_s&feature=player_embedded,
but also the interview of Udo Klotzbach, LIFT project's coordinator by Photonics Media editors Melinda Rose & Laura Marshall during Laser World of Photonics in May 2013 http://www.tinyurl.com/LIFT-LWP2013. Photonics Media and Photonics.com are part of Laurin Publishing, USA. Finally, the LIFT project has been the subject of an article in research*eu magazine in June 2013.

A LIFT for fibre lasers

LIFT - Leadership In Fibre Laser Technology, is a collaborative, large-scale integrated project funded by the NMP Directorate in the 7th Framework Programme of the European Commission. European industry today leads in industrial laser processing. Continuous innovation and adoption of novel technologies are required to maintain this position. Fibre lasers represent only 10% of an estimated market volume of 2 billion Euros worldwide for industrial lasers. The market share of fibre lasers is expected to double by 2010 and double again by 2013, when fibre lasers will account for more than 30% of all industrial lasers.

In order for Europe to advance its position as technology and manufacturing leader in industrial laser processing, it is imperative for European manufacturers to take the Leadership In Fibre laser Technologies. That is exactly the goal of the LIFT project. This project will establish an internationally leading position for Europe in the science, application and production technologies of fibre lasers.

The consortium will develop innovative laser sources with intelligent beam delivery systems and dynamic beam manipulation, in continuous-wave, nanosecond pulsed, and ultra-short pulsed femtosecond laser sources, operating at power levels ranging into the kilowatt regime. LIFT will enable a greater market share for existing applications, create new application areas for manufacturing, and build a European network of components' suppliers and laser system manufacturers.

Demonstrations will show the potential of this technology in domains where there are large existing markets such as high-speed remote cutting and welding, medical diagnostics and treatment, TFT patterning or where there are potential markets such as solar cell fabrication and cold ablation for ceramics manufacturing.

The results will bring radical advances in four important application areas:

- Laser Materials Processing
- Health Care Delivery
- Cost-Effective Manufacturing of Solar Cells for Renewable Energy
- Manufacturing of the next-generation of ICs with nanometre feature size.

Figure 36: Article published by Compound Semiconductor Vol. 14 #8 Page 7

International Expositions: Lasys, Photonics West, Laser World of Photonics

LIFT participated in the major international Laser trade fairs especially LASER World of PHOTONICS that took place in Munich, Germany, in 2011 and 2013. In 2013, the timing of the exhibition was very good for the dissemination of the LIFT project.

The anniversary laser event closed with a record number of 1,135 exhibitors and represented companies. With almost 27,000 trade visitors from 74 countries, visitor numbers again reached a very high level. The number of LIFT partners among the exhibitors was also remarkable, 17 partners from LIFT consortium were present exhibiting over ten different products including component and technologies developed during the project.

To promote the project already in advance, TUT prepared a video to show all the LIFT products displayed at the fair. Video is available in YouTube: http://www.youtube.com/watch?v=05XFLqYzg0Q.
Along with the products on partner stands, some processing samples done with the developed LIFT laser sources were also displayed on the LIFT booth.

Figure 37: LIFT project presence at Laser World of Photonics 2013 in Munich, Germay: visitors, components on display, roll-up display

LIFT produced for both Laser World of Photonics trade fairs a flyer and a brochure. Hereunder is the front page of the brochure.

LIFT

LASER World of PHOTONICS
May 13-16, 2013
Munich, Germany
Visit LIFT–project at stand: C2.330

LIFT product line at LASER World of PHOTONICS 2013

Quantel

EYLSA Fiber Laser

The new EYLSA fiber laser uses Quantel's fiber laser expertise to offer highly reliable and maintenance-free fiber lasers for the scientific market. With a large touch screen and integrated into a 19" 3U rack, EYLSA is the most compact, easy-to-use, Plug & Play platform for scientific experiments. With EYLSA, focus on research.

- Reliable – Industrial grade components
- Easy to use – user-friendly touch screen
- Maintenance free – no water required
- Compact size – 19" rack
- Efficient wavelength locking
- Up to 1 W @ 780 nm available through single mode PM fiber
- Single frequency < 200 kHz
- High stability – over vibration and temperature

Quantel - Hall B1, Booth 680
More information, contact:
Cécile Barbier
cecile.barbier@quantel-laser.com
Phone: +358 500 910109

Corelase

O-lase: high power OEM fiber laser module

O-LASE is a high power fiber laser module to be integrated into cutting, welding and drilling systems. Compact design and flexible interfaces enable easy system integration. High optical to optical conversion efficiency of the module enables high total efficiency for the system. Output power from 500W to 4 kW depending on system configuration.

Corelase Oy, Finland - Hall C1, Booth 267
More information, contact:
Jari Sillanpää
jari.sillanpaa@corelase.fi
+358 500 910109

Fraunhofer IOF

Beam shaping optics

The Fraunhofer IOF developed a beam shaping optics to convert Gaussian into donut beam profiles for laser manufacturing applications. During the design process, care was taken to reduce optical losses, like scattering. The device can be used at high laser output powers. Also, adjustment of the donut beam size is possible.

Fraunhofer IOF - Hall B2, Booth 421
More information, contact:
Carolin Rothhardt
Carolin.rothhardt@iof.fraunhofer.de
Phone: +49 3641 807304

LIFT receives funding from the European Community's Seventh Framework Programme FP7-NMP-2008- 4.0.4 under grant agreement Nr. CP-IP 228587-1 – Contact: udo.klotzbach@iws.fraunhofer.de

Figure 38: Cover page of the 4-page brochure

LIFT Newsletters

15 issues of the LIFT Newsletter have been edited, broadly distributed and published online by end of June 2013. As an example the Newsletter Nr. 14 published in April 2013 presented some of the exploitable results of the LIFT project to be shown at Laser World of Photonics. A broad dissemination via the project website, the distribution lists of the LIFT partners and the social networks attracted interest from the laser community who attended the trade show in May.

NEWSLETTER LIFT #14
April 2013

LIFT

LIFT product line at LASER World of PHOTONICS 2013

LIFT product line at LASER World of PHOTONICS 2013

P1: Corelase
P1: Fraunhofer IOF
P2: Dilas
P2: NKT
P3: Gooch & Housego
P3: iXFiber
P4: Optoskand
P4: SPI Lasers

LASER World of PHOTONICS
May 13-16, 2013
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For more information: Carlos LEE
carlos.lee@epic-assoc.com

© Newsletter LIFT, April 2013

LIFT receives funding from the European Community's Seventh Framework Programme FP7-NMP-2008- 4.0.4 under grant agreement n° CP-IP 228587-1

Figure 39: LIFT Newsletter #14 published in April 2013

Publications, Presentations, Workshops

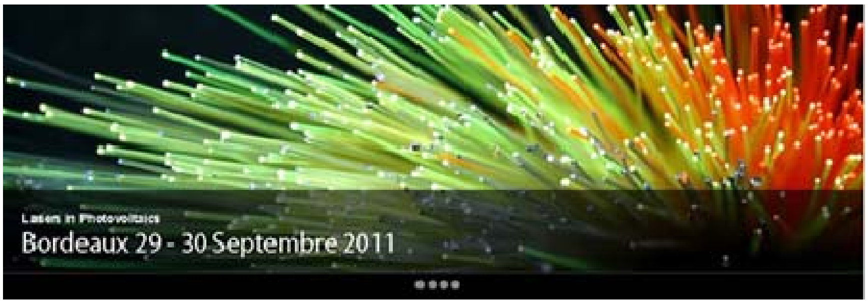
The LIFT Consortium partners have been active in participation in conferences and workshops, including the organization of workshops on key topics for fibre laser development.

More than 50 publications have been published and LIFT partners presented the fibre laser technology in the most important international conferences (Photonics West, Laser World of Photonics, FILAS, FiSC, CLEO, AKL, ICAN…).

The LIFT project has organised 3 workshops on fibre lasers.

In year 1, the LIFT 1st International Workshop on Photodarkening in Optical Fibers took place on Oct 5, 2010, at the International Congress Center Dresden, Germany, as part of the FiSC Symposium.

PERFOS organized a LIFT Workshop in Lannion, France, on 12 July 2011. The aim of the meeting was to gather a large part of the fibre community in Europe and some key fibre laser manufacturers to discuss the main issues related to power scaling in fibre lasers. It was the opportunity to report the last breakthrough in the field, in particular on topics such as photodarkening, preform fabrication, new design of photonic crystal fibres, rod-types fibres and much more!



Also in 2011, LIFT partners took the initiative to contact other closely-related projects: Polybright and Alpine to organize a joint workshop with the Alpine project on fibre-laser manufacturing of photovoltaic cells. The “Lasers in Photovoltaics” Workshop took place in Bordeaux, France on 29-30 September 2011. Topics covered the ability of to bring speed and quality in the solar cells or solar panel manufacturing.