PROJECT FINAL REPORT

Publishable

Grant Agreement number: 257894

Project acronym: IMPROV

Project title: Innovative Mid-infrared high Power source for resonant ablation of Organic based photovoltaic devices

Funding Scheme: STREP

Period covered: from 01.09.2010 to 28.02.2014

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

H. Grunert, K. Ulbrich, Laser Zentrum Hannover e.V., Hollerithallee 8, Hannover, Germany

Tel: +49 511 2788 123

Fax: +49 511 2788 100

E-mail: h.grunert@lzh.de

Project website address: http://www.fp7project-improv.eu

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

Final publishable summary report

1. Executive Summary

IMPROV (Innovative mid-infrared high power source for resonant ablation of organic based photovoltaic devices) is dedicated to developing a highly innovative mid-infrared ultrashort laser source for use in the processing (resonant infrared ablation) of organic based photovoltaic devices. So far, ultraviolet lasers have proven their full potential for patterning single organic layers, but in a multilayer organic device the obtained layer selectivity is limited as all organic layers show high UV absorption. In this project, we introduce mid-infrared (IR) resonant ablation as an alternative approach, in which a short pulse mid-infrared laser can be wavelength tuned to one of the molecular vibrational transitions of the organic material to be ablated. As a result, the technique is selective in respect of processing a diversity of organics, which usually have different infrared absorption bands.

Therefore, the major objectives of IMPROV were:

- to provide a novel and innovative mid-infrared laser source
- to develop the necessary components and devices for such laser.
- to investigate and to evaluate resonant infrared ablation as a high performance processing scheme regarding organic based thin films used in photovoltaics.

The approach to achieve these objectives was to combine fibre laser technology with sophisticated (orientation-patterned GaAs crystals based) nonlinear frequency conversion stages and to address scribing of different reference materials used in photovoltaics. The key developments were:

- high energy multi-stage short pulse fibre laser systems operating around 2 µm used as pump source for
- frequency converters based on orientation patterned GaAs for the spectral range with tuning ranges between 3 and 6 µm.
- passive components, like Thulium-doped photonic crystal fibres, semiconductor saturable absorbers for modelocking, fiber pump combiners etc.
- selective patterning of relevant thin film materials, e.g. planarization layers, hole transport layers, high-efficiency absorber materials, etc.

For the planned work, a consortium of 7 European partners with 2 global players, 2 SMEs and 3 research institutes has been established, representing a goal-oriented combination with competencies and skills which are required for a successful project progress. Within IMPROV different laser prototypes have been developed, consisting particularly on short-pulse mode-locked Thulium doped fibre oscillators which have been used as seed source for corresponding high energy Thulium fibre amplifiers. These systems were applied as front-end for frequency conversion stages based on orientation patterned GaAs crystals in order to access the wavelength range above 3 µm. Different reference materials, e.g. PEDOT:PSS, BPAPF, α-NPB, HDR014, and DCV4T-Et2 used in photovoltaic devices have been selected and characterized. Based on those results, infrared ablation experiments have been performed at wavelengths which are on-resonant and off-resonant, respectively of the corresponding absorption bands. Selective scribing of PEDOT:PSS on PET could be achieved.

2. Summary description of project context and objectives

Thin polymer films are extensively used in a variety of applications including sensor technology, medicine and photonics. For the processing of these materials several conventional methods, e.g. chemical etching can be used but with obvious drawbacks concerning environmental pollution. Lasers can also be employed and in most cases UV sources (that suffer from maintenance costs and practical issues) are the only choice for the moment. Another promising approach was introduced at the beginning of the 21st century to address this issue named Resonant Infrared Laser Ablation (RIA). This method uses a short pulse mid infrared laser system, which can be wavelength tuned to one of the molecular vibrational transitions of the polymer to be ablated. As a result the laser energy absorbed by the thin layer leads to vibrational and not to electronic excitation, thus avoiding chemical alterations of the sample. In addition and very important, this technique is selective in respect of processing a diversity of polymers, which usually have different infrared absorption bands. RIA is therefore a selective laser technique free of thermal effects.

In applications like Organic Light Emitting Diodes (OLED), Organic Thin Film Transistors (OTFT), and Organic Photovoltaic solar cells (OPV), where multiple conductive polymer layers are used, a selective ablation method is a very important step. Due to the impressive market potential of these devices, tremendous effort has been done on the material development in the past. However, a limiting step in laser based processing and fabricating, including patterning and scribing, of those devices can be attributed to the actual laser technology. Indeed, on one hand, UV laser processing cannot cope with selectivity issues and on the other hand, RIA has been already used for OLEDs high quality thin film layer sputtering but with the help of a complex and costly Free Electron Laser (FEL) at the moment, which is obviously incompatible with industrial environment.

Anyway, when the above mentioned organic based devices are fabricated onto a hard inorganic material, like Indium Tin Oxide (ITO) still UV or ultra-short pulse lasers can be used for some steps. When the ITO layer is replaced by another conductive organic material, selective ablation with low thermal damage and alteration is essential. This means RIA, in combination with a reliable, compact and maintenance free tunable pulsed mid infrared laser, will be a technological breakthrough in future large area fabrication of flexible devices by preparing the integration of this ablation technique in an industrial environment.

This preliminary consideration indicates, that the high power mid infrared laser sources operating between 2.5 µm and 11 µm are the fundamental limitation and bottleneck for a widely used laser technology based on RIA. Especially, several secondary features, like compact size, stable operation, low cost and high reliability cannot be provided by the few systems available. Regarding these properties, a short pulse fibre laser and a subsequent wavelength conversion stage based on nonlinear crystals can be a promising solution to this problem. This Master Oscillator Power Amplifier (MOPA) concept has a high integration potential combined with the above mentioned characteristics.

In order to address these considerations, an European consortium has been founded with the intention to provide corresponding solutions within a common project IMPROV. The

IMPROV consortium consists of two global players, Thales Research, France and NKT Photonics, Denmark, two SMEs, Heliatek, Germany and Batop, Germany and three research institutes, Multitel, Belgium, IMEC, Belgium and Laser Zentrum Hannover, Germany. Thus European key players in the field of photonic crystal fibres and nonlinear optical components, both with integrated functionalities, short pulse 2 µm fibre laser sources and processing of OPVs has been established in IMPROV adding their core competencies to a well-balanced working team.

IMPROV focuses first on the development, investigation and realisation and of a highly integrated mid-infrared laser source. Its layout is based on a Master Oscillator Power Amplifier (MOPA) short pulse Thulium all-fibre laser operating around 2 µm. This laser source is used as front-end of an Optical Parametric Generator (OPG) enabling the generation of mid-infrared radiation at wavelengths between 3 and 10 µm. The latter one is based on highly efficient orientation-patterned quasi-phase matched GaAs crystals. In addition, Resonant Infrared Ablation (RIA) for processing Organic Photovoltaic solar cells (OPV) is investigated within IMPROV.

The general structure of IMPROV can be described as follows:

- Development of a short-pulse mid-infrared MOPA laser source based on
  - ➢ Thulium fibre oscillator operating around 1.9 µm as seed source
  - ➢ High power Thulium fibre amplifier chain
  - ➢ OPG/OPA nonlinear wavelength conversion unit stage
- Evaluation of resonant infrared ablation (RIA) of OPV stacks
  - ➢ Preparation of a process evaluation set-up
  - ➢ Integration of the mid-infrared laser source
  - ➢ Ablation tests of single and multilayer organic photovolatic elements
- Demonstration of the functionality of the mid-infrared tunable laser source regarding
  - ➢ Mechanical and optical parameters
  - ➢ Integration and compatibility with a practical industrial application

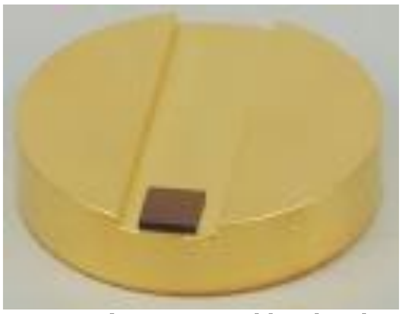
For the MOPA pump source different integration aspects have been addressed in order to fully benefit of a waveguide device. This include the development of fibre-coupled saturable absorbers, large mode area (LMA) photonic crystal fibres (PCF) for high power operation, pump/signal combiners based on LMA-PCFs and novel concepts for fibre amplifiers with integrated core-pumping schemes. The wavelength conversion unit have been realised with integrated wavelength tunability and structural design. This MIR-laser operated in the wavelength region above 3 µm with a pulse duration around 500 picoseconds and a repetition rate which could be adjusted due to the pulse-picker of the oscillator section. For validation of the developed laser source tests concerning the processing of organic photovoltaic solar cell have been accomplished.

3. Description of the main S&T results/foregrounds

Saturable absorber and laser oscillator

Laser oscillator development started with numerical simulations of the mode-locked 2 µm-fibre oscillator and corresponding saturable absorber mirrors (SAM) in order to make first estimations of cavity configurations and suitable optical parameters of the fibre oscillator and especially of the SAM. These investigations indicated, that the parameters of the SAM are more critical compared to those of the fibre sections and lay-out. The best laser performance could be achieved applying a SAM with a modulation depth of 30 % and a saturation fluence of 70 µJ/cm^2.

Based on these design studies BATOP developed and grew first reflective absorbers with corresponding parameters by using low temperature molecular beam epitaxy. Assembled SAMs have been passed to LZH for mode-locking experiments. In a second step, two types of transmissive saturable absorbers were developed. Type 1 without a partial reflector with absorbance of 25 % and 43 %, respectively, which can be used e.g. as mode-locker in fibre ring cavities and type 2 with a reflection coating, which can be applied as mode-locker and simultaneously as output coupler.



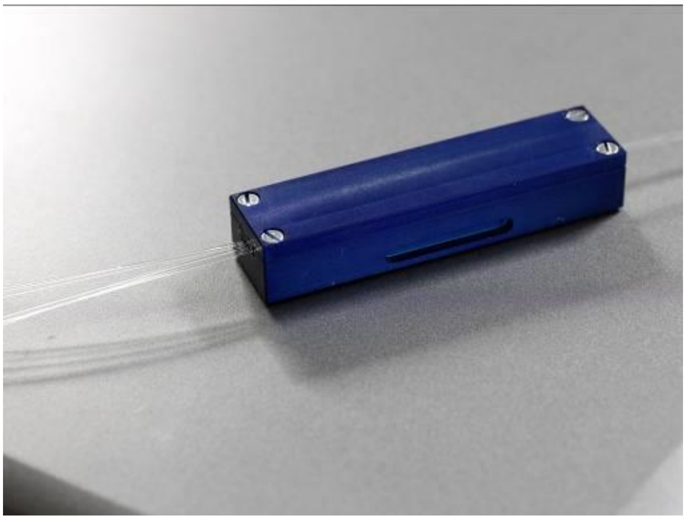
Semiconductor saturable absorber mirror (SAM) mounted on a heat sink

First experimental results have shown that a large absorption value > 30 % is needed for stable mode locking. Consequently more saturable absorbers with larger absorption values for the spectral region between 1900 nm and 2000 nm has been grown and passed to the partners LZH and Multitel. The carrier relaxation time has been measured to about 10 ps.

Fibre-coupled SAM

In addition to saturable absorbers, different fibre components like wavelength division multiplexers (WDM), output couplers and pump/signal combiners are needed for the development of 2 µm fibre lasers but are only commercial availability is limited. Therefore these components have been developed at LZH coupler facility. In particular, 1560 nm/1980 nm WDMs, pump combiners for 793 nm clad pumping and tab couplers for the signal wavelength have been fabricated and successfully implemented in different short-pulse fibre oscillators.

At first, a Thulium-fibre oscillator based on a ring cavity, mode-locked by non-linear-polarisation evolution and operating in a pure soliton regime was built up. In order to tune the wavelength from the free running value of 1.90 µm to the long wavelength edge (planned wavelength was 1.98 µm), a corresponding interference filter placed inside the laser cavity was used. However, laser operation beyond 1.97µm could not be achieved. In addition, the spectral bandwidth exceeded 8 nm yielding in a pulse duration below 500 fs, which doesn't fit with the required parameters. Therefore, a linear cavity set-up was realised, mode-locked by using a saturable absorber mirror provided by BATOP. The operation wavelength was fixed due to a linear fibre Bragg grating with a centre wavelength at 1978 nm and a bandwidth of 1 nm. This soliton laser system delivered 4.7 mW average output power at a repetition rate of 26 MHz, corresponding to a pulse energy of 180 pJ. In order to increase the pulse energy, the overall cavity dispersion of the oscillator was changed to net normal dispersion by applying a chirped fibre Bragg grating with a group velocity dispersion of 8 ps^2. This system, which has been delivered to MULTITEL as a first fixed wavelength prototype, operated in the dissipative soliton regime with output pulse energies of 1.4 nJ and pulse durations below 90 ps.



2 µm fibre pump combiner

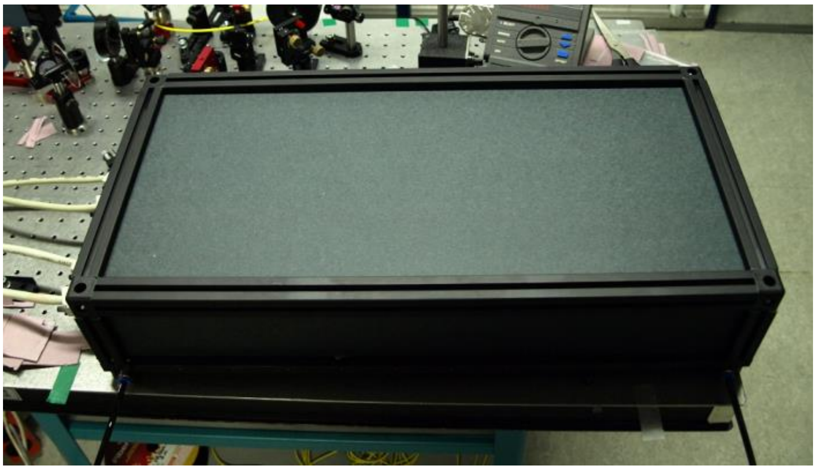
However, the pulse duration did not match the target of 250 ps and therefore was not suitable as seed source for the following amplification stages because nonlinear effects prevented the generation of high power radiation. As a consequence, a completely new oscillator lay-out with extended capabilities was developed. It consists of a Tm-fibre oscillator, cladding pumped by using a 793 nm laser diode and mode-locked by a fibre-based saturable absorber mirror, provided by BATOP. The output wavelength was fixed to 1.98 µm, applying a Fibre-Bragg-grating (FBG), which serves as output coupler as well. This laser generated an output power of 14 mW with a

Tm-doped oscillator

spectral width of the power spectrum of 0.4 nm, a repetition rate of 20 MHz and a pulse duration of 14 ps. In order to achieve a pulse duration of 250 ps, several pulse stretching techniques have been investigated fibre.

Therefore, the output pulses have been stretched by using a chirped FBG with a dispersion of 250 ps/nm. The necessary power spectrum width of 1 nm has been achieved by nonlinear broadening behind the oscillator by means of a passive fibre due to self-phase modulation (SPM). In a next step, the reduction of the repetition-rate of the oscillator has been addressed. Former experiments concerning this issue by using a longer laser cavity showed that the laser became unstable at rep.-rates below 5 MHz. Thus, a fibre-coupled acousto-optical modulator (AOM) as pulse-picker has been implemented in the set-up, providing adjustable rep.-rates from single-shot up to the fundamental rep.-rate of the oscillator. However, operating the system for instance at a rep.-rate of 100 kHz, the average output power will be reduced by a factor of 200 in our case. In order to compensate this reduction, a pre-amplifier stage was used resulting in an output power of 2.4 mW at 500 kHz rep.-rate. The complete system was realised in an all-fibre configuration and based on polarisation maintaining (PM) fibres.

Due to the relatively complex set-up using nonlinear methods, this system was very sensitive in terms of variations of the oscillator's output parameter, which can occur for instance as a result of ambient temperature changes. Small alterations, e.g. of the output power, had a strong influence on the emission bandwidth behind the passive SPM fibre and subsequently on the pulse duration behind the 250 ps/nm FBG. Therefore, usage of this oscillator system as reliable seed source for the power amplifiers is hardly feasible. Therefore, a third oscillator with long pulse duration (500 ps) emission directly out of the oscillator has been developed. The cavity design of this system is very similar to the previous oscillator setup and consists of a saturable absober mirror, an inline polarizer, a WDM for pump light coupling, the thulium-doped fiber and a narrowband fiber Bragg grating, which was used as output coupler. The oscillator is core-pumped via an amplified diode laser with an output power of about 250 mW at 1572 nm. The pulse repetition rate was about 13.4 MHz corresponding to the cavity length of about 7.7 m. The narrowband FBG limits the FWHM of the output spectrum to below 0.05 nm. Correspondingly, the duration of the pulses delivered by the oscillator is about 500 ps. The oscillator has been completed by a Thulium-doped fibre pre-amplifier, pumped by a 35 Watt output power laser diode operating at 793 nm via a multi-mode pump combiner. Behind the amplifier a fibre-based acousto-optical modulator as pulse-picker was



Long pulse duration Oscillator-preamplifier system assembled on a water-coolable breadboard implanted, providing adjustable pulse repetition rates. The average output power of this oscillator system was 500 mW at the fundamental repetition rate of 13 MHz, corresponding to 38 nJ output energy. In order to make this system resistant against ambient temperature variations it has been assembled on a water-coolable breadboard and packaged into a housing. A stable version of this system has been used as seed source for the realisation of a high energy amplifier based on the rod-type fibre by Multitel.

For the realisation of a tunable Tm-fibre laser, several tuning elements have been investigated, e.g. bandpass filters, fibre-based etalons and Fibre-Bragg gratings. Using bandpass filters, only wavelengths below 1.965 mm could be attained and the tuning range applying fibre-based etalons was restricted to a few nanometers. Thus, compressing/stretching of FBGs has been employed for the tunable laser. It consists of a linear cavity, core-pumped by using an Erbium laser operating around 1560 nm. Mode-locking was achieved by a saturable absorber mirror. Output coupling and wavelength tuning was accomplished by a specially mounted FBG (centre wavelength at 1.98 µm), which could either be compressed or stretched. With this device an overall tuning range of 30 nm could be achieved, covering a wavelength range from 1.96 µm up to 1.99 µm. By using an FBG with a central wavelength of 1.95 µm, the tuning range spans more than 60 nm. The average output power of this laser was 2.4 mW, which corresponds to a pulse energy of 200 pJ, taking the fundamental rep.-rate of 12 MHz into account.

However, these first promising results could not be confirmed in case of the long pulse duration oscillator. Wavelength tuning was investigate by using different tuning devices and methods, particularly a bulk grating in Littrow/Littmann mount, stretching/compressing of FBG in a flexible bending device, compressing FBG in a linear v-groove support and compressing of FBG using fibre ferrules. In all cases, the laser parameters could not be maintained and strong variations of average output power, intensity and even mode-locking failures occurred. Alternatively, a resonator set-up has been investigated using an optical switch and FBGs with different centre wavelengths in the output channels to provide different distinct output wavelengths instead of a tunable output. But due to losses inside the switch no reliable mode-locking could be observed.

Photonic Crystal fibre, combiners and amplifier integration

NKT Photonics (NKTP) has within IMPROV developed the world's first Thulium-doped photonic crystals fibres (PCF). Both a 30 µm core and a 50 µm core single mode flexible PM fibre have been developed and been used in amplifier and laser set-ups at 2 µm with excellent beam quality (M^2<1.2). The latter has a mode field diameter of 38 µm, which is more than fifty percent more than what has been demonstrated by a pedestal fibre design outside IMPROV. Furthermore the PCF maintain their excellent beam quality in a high power amplifying regime, whereas it has been observed that for a commercial pedestal design fibre up to 30% of the power was in a higher order mode when operated a high power. The fibre is bendable to a diameter down ot approximately 40 cm and initial test showed no signs of photodarkening. The optical slope efficiency of the Tm doped PCFs have been measured up to 37% when using a cladding pumped configuration with 793 nm pumped. This result is somewhat behind the state of the art on Tm doped silica fibre where >60% have been demonstrated by Nufern on smaller core fibres. Two different Tm concentration have been tested (2.5 wt% and 3.6 wt% Tm) and within the measurement uncertainty gave similar results. The reason for this difference in optical slope efficiency is currently investigated. In parallel NKTP are currently investigating the potential markets for the Tm PCFs for applications where low non-linearity and beam quality are more important than slope efficiency. Initial results show that even the 50 µm core fibre might not be large enough for the IMPROV demonstrators. Accordingly an 80 µm core inflexible ROD fibre has been developed, and drawn fibre.

Passive PCF-combiner placed on a heat sink

The pulses delivered by the first seed oscillator from LZH were pre-amplified and chirped to have 300 mW power and 800 ps pulse duration before the power amplification stage. Two amplification methods were compared with four different pump wavelengths. The core pumping tests showed that the shortest necessary doped fibre length could be reached by pumping at 1560 nm with 38% slope efficiency. At 1270 nm the slope efficiency was higher (44%) but a longer piece of doped fibre was required. The maximum total power achieved was 6.5 W that meant 1.8 µJ pulse energy at 3.6 MHz repetition rate. Core pumping of large mode area photonic crystal fibres fabricated by NKTP were tested as well by Butt coupling with passive LMA fibres. The maximum slope efficiency was measured to be 28%.

The highest output power was reached by clad pumping, however the doped fibre used for the experiment was more than 4 m long so the SPM became significant. The slope efficiency of the clad pumping was 43% and the maximum output power was 8 W that meant 2.22 µJ pulse energy.

During the second period more core-pumping amplification tests were performed with different pump sources (three main wavelengths tested: 1540 nm, 1565 nm and 1270 nm). Both step index fibres and photonic crystal fibres from NKT were evaluated. The best conditions for amplification were determined and core pumping at 1270 nm was decided to be the preferable solution.

Because of the relatively high repetition rate of the seed oscillator and because this first prototype was not supposed to be tunable, a gain-switched laser diode was used as the seed source of the first system. The diode was modulated at a repetition rate of 250 kHz and emitted 250 ps pulses. The output power was very low and then amplification had to be optimized with several filtering elements to avoid important noise due to spontaneous emission. The booster was based on a commercial step-index fibre with 25 µm core diameter. The first prototype delivered more than 3 Watts at 250 kHz, resulting in more than 10 µJ and 40 kW peak power in a 1 nm spectral linewidth. The output fibre was pigtailed and collimated with a fibre collimator. A free space isolator was used for protecting the laser from back reflections. The laser fulfilled most of the requirements in the project but the output beam shape was not stable in function of the pump power. This was related to the step index fibre used for the last amplification stage and should be solved by the use of photonic crystal fibres.

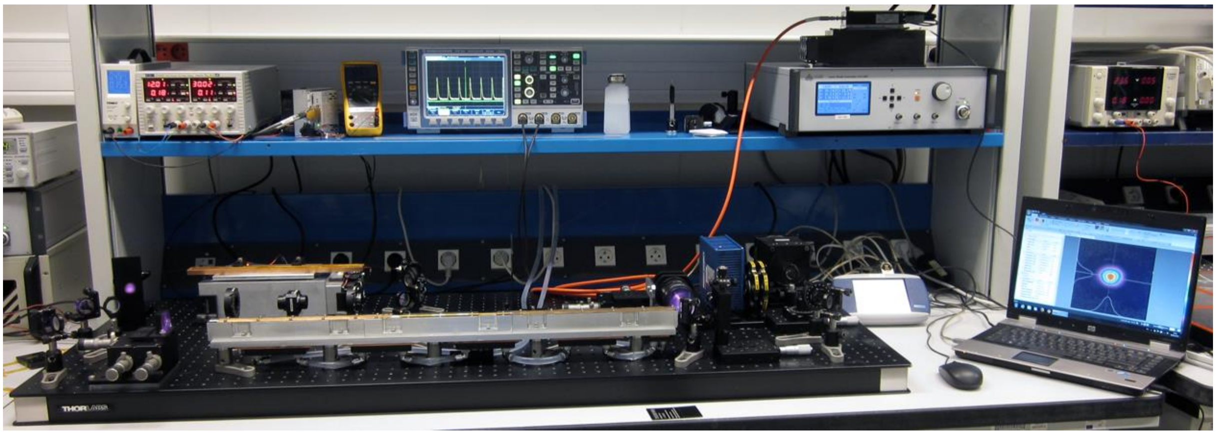
MULTITEL first amplifier with the 25 µm step-index fibre.

Furthermore, splicing tests of the Photonic Crystal Fibers provided by NKT were proceeded to define the parameters of the mode field adaptors and of the splices to achieve a stable and Gaussian beam profile. These experiments were carried on for both the 30 µm and the 50 µm fibres.

With such fibre, more than 40 µJ per pulse were achieved with sub-nanosecond pulses. By using the gain-switched laser module with pulses duration around 2 ns we demonstrated 100 µJ per pulse. Such pulse duration is particularly more adapted for Optical Parametric Oscillator cavities pumping.

MULTITEL gain-switch laser prototype (left) and amplifier with pulse stretchers (right).

A second laser from LZH was delivered to MULTITEL. This laser is linearly polarized and equipped with a pulse picker that permits to achieve low repetition rates. In order to achieve more than 100 µJ per pulse with this seed (i.e. with sub-nanosceond pulses), we used a ROD-type fibre from NKT in the last amplification stage. This fibre has a core diameter of 80µm. Using such fibre permitted then to reach 120 µJ with 520 ps pulses corresponding to a peak power of about 130 kW.



ROD-type amplification experiment.

Another laser system was prepared in parallel for achieving resonant infrared ablation tests at MULTITEL. This set-up is based on a solid-stage high power laser (that was already available at MULTITEL) at 1.03 µm combined with a Periodically Poled Lithium Niobate crystal (PPLN) provided by Thales. Changing the temperature of the PPLN crystal permitted to change the mid-IR wavelength output. Then the laser system available at MULTITEL was tunable from 3 to 3.5µm. The pulse duration was 250 ps and the available energy at 3 to 3.5 µm was 8 µJ. This system has been used simultanously to the development of the fibre based source for resonant infrared ablation tests.

Finally regarding dissemination, the work on Thulium amplification has been presented in four peer reviewed international conferences: Photonics West (San Francisco), Photonics Europe (Brussels), JNOG (France), Europhoton (Sweden), POEM (Wuhan, China), ASSL (Paris) and International Journal of Modern Physics B.

Mid-IR tunable laser source prototyping started with design studies of the frequency converter based on orientiation-patterned GaAs crystals (OP-GaAs). It could be shown that a single grating with a period around 56 µm can accommodate the requirements of the planned polymer ablation tests due to a reasonable temperature tuning of the output wavelength. In addition, other opto-mechanical properties, like crystal length, width and thickness which are influencing the conversion efficiency have been reviewed. Damage threshold issues have been taken into account and a corresponding design tool has been established. Applying this tool, slightly larger crystal dimensions than initially planned must be considered in order to avoid crystal damage and to handle pulse durations of 500 ps. The corresponding fabrication process has started thank to a dedicated photolithographic mask. In order to facilitate the optical design of the first fixed-wavelength prototype before the fibre pump from MULTITEL is available, a laboratory experiment has also been set up. It was based on an available 1064 nm source operating at low repetition rate and two PPLN crystals in an OPG/OPA configuration to obtain 1.98 µm pulses suitable to pump OP-GaAs crystals and measure relevant parameters such as the beam quality and spectral widths of the mid-infrared signal and idler beams.

Taking the first review of the project and the slower than expected development pace of the pump from Multitel dedicated to the first prototype source at fixed wavelengths (3.3 and 4.9 µm) into account another laser prototype was built with similar pulse durations (i.e. in the hundreds of picoseconds) based on a simpler design (1 µm pump from Multitel and PPLN crystal provided by Thales) but nevertheless allowing moderate tunability around 3.3 µm only. After the first material tests made with this source, located at Multitel, it proved useful to enable the researchers from IMEC to also make ablation tests in their premises. To benefit from larger pulse energy than what was available from the first planned prototype source, a nanosecond laser source available at Thales was modified also allowing moderate tunability around 3.3 µm and delivered to IMEC.

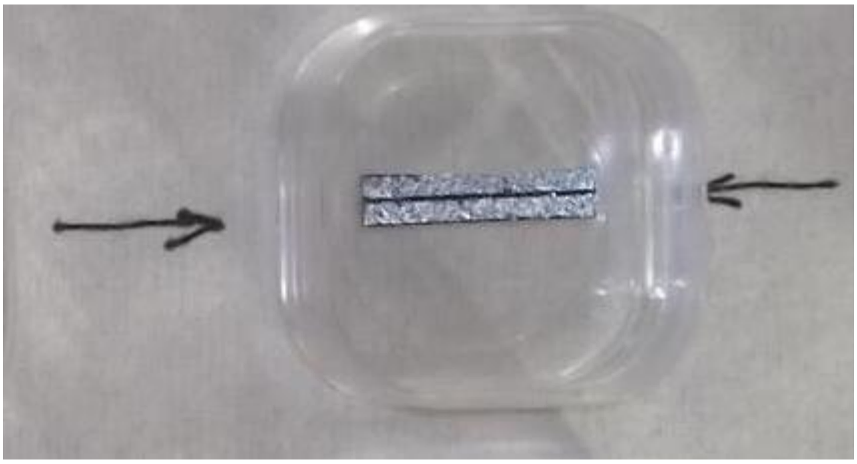
In parallel, the first prototype planned in the Description of Work was developed by Thales. It is pumped by a 2 µm fibre laser from Multitel, delivering 250 ps pulses at 250 kHz in a 1 nm spectral linewidth. Several dedicated OP-GaAs crystals were tested to obtain wavelength conversion at fixed wavelength. Anticipating the tuning needs of the other partners, a crystal oven has also been implemented. To the best of our knowledge, the first Optical Parametric Generator operating in the hundreds of picoseconds regime and based on OP-GaAs has thus been demonstrated. It is tunable from 3 to 3.3 and 4.9 to 5.6 µm and delivers a total mid-IR energy up to 0.3 µJ for 6 µJ of pump. This prototype source was not actually used for material testing but rather stayed at Thales to enable useful characterizations until the end of the second Reporting Period. One of the key findings is that the beam quality of the pump proves to be one of the most important factor to obtain a satisfying conversion efficiency.

Further developments were carried out in parallel during the last part of the project to take advantage of the above experiments:

- The picosecond PPLN-based source was upgraded by Multitel from an OPG to an OPA configuration. The improved beam quality made it possible to carry out ablation tests with fluences 3 times above the expected ablation threshold.
- The PPLN OPO setup installed by Thales at IMEC provided useful additional comparisons between nanosecond and picosecond regimes.
- Another OPO setup has been provided by Thales. Based on an OP-GaAs crystal, this module gives access to the nanosecond regime in a wavelength range well above the PPLN-based sources around 3 µm, compatible with strong absorption bands of specific polymers selected by Heliatek. IMEC was thus able to make ablation tests around 5 µm in resonant and non-resonant conditions.

An important effort was dedicated to wavelength conversion experiments using OP-GaAs crystals and the various versions of fiber pumps provided by the other partners. Two main characteristics proved more difficult to reach than expected at the beginning of the project. First, mid-IR wavelength tuning obtained through pump tuning around 2 µm has not been implemented to date in the first building block of the final prototype, i.e. the fiber oscillator from LZH. Nevertheless, polymer studies and ablation tests made with the alternative sources demonstrated that the useful range could be a narrowed to two windows (roughly from 3 to 3.4 and 6 to 7 µm) compatible with simpler temperature tuning of the frequency converting crystals. Second, the generation of pump pulses with the required energy required significant efforts to ensure at the same time both the spectral width and the beam quality necessary to obtain a satisfying conversion efficiency. The latest pump source built by Multitel and based on a rod-type fiber amplifier from NKTP overcame several issues but could only be completed shortly before the end of the project. It was nevertheless possible to improve the wavelength conversion and get mid-IR energies over an order of magnitude higher that in the previous experiments.

Last but not least, various OP-GaAs crystals were fabricated to accommodate the different pumping options and mid-IR requirements. In the example shown below, two gratings of slightly different periods can be seen (the arrows indicate the input and output facets). With moderate temperature tuning and translation of the sample, they enable a continuous wavelength tuning of more than one micron around 6 µm.

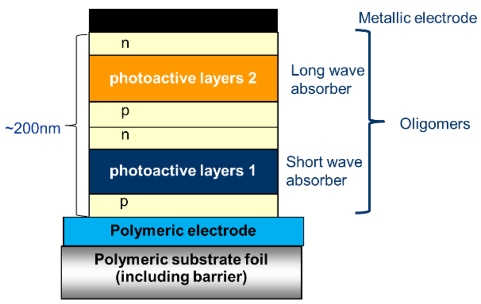


Orientation patterned GaAs crystals with different periods

Resonant infrared ablation for structuring OPV

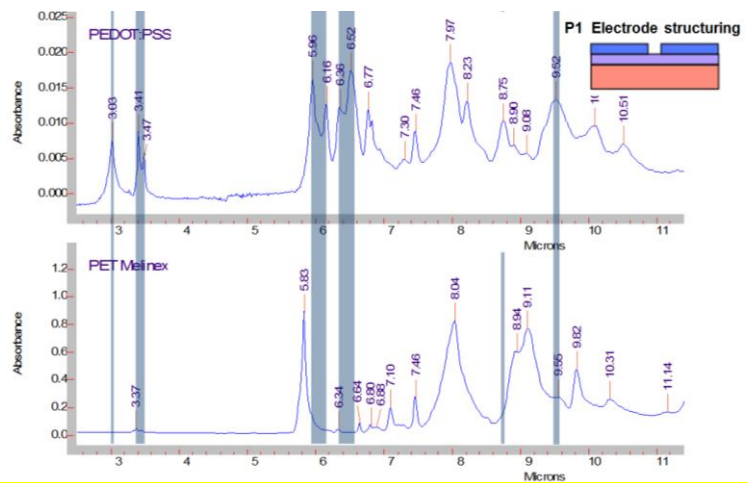
The wavelength of the mid-infrared laser can be tuned to one of the molecular vibrational transitions of the organic material to be ablated. For that reason, the IR absorption spectra of the organic materials used in a typical organic photovoltaic device were characterized in the wavelength region that can be reached by the laser setups.

In addition to the substrate foils (PET or Polyethylene Terephtalate), focus was on three materials prototypical for organic solar cells: as a planarization layer the polymer PEDOT:PSS (poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)); as hole transport layer two typical materials, that can be used alternatively in OSCs: BPAPF (9,9-bis[4-(N,N-bis-biphenyl-4-yl-amino)phenyl]-9H-fluorene) and α-NPB (N,N'-diphenyl-N,N'-bis(1-naphthyl)-1,1'-biphenyl-4,4"-diamine), and as a typical high-efficiency absorber materials we selected Heliatek's HDR014 (an oligothiophene derivative with non-disclosed structure), and DCV4T-Et2 (2,2'-[(3,3'''-diethyl[2,2':5':2'':5'',2'''-quaterthiophene]-5,5'''-diyl)dimethylidyne]bis-Propanedinitrile). BPAPF and α-NPB are widely used as hole transport materials in organic solar cells and organic light-emitting diodes. HDR014 is a donor material with strong absorption in the red spectral region.



OPV tandem cell indicating the stack of polymer thin-films to be patterned by laser technology.

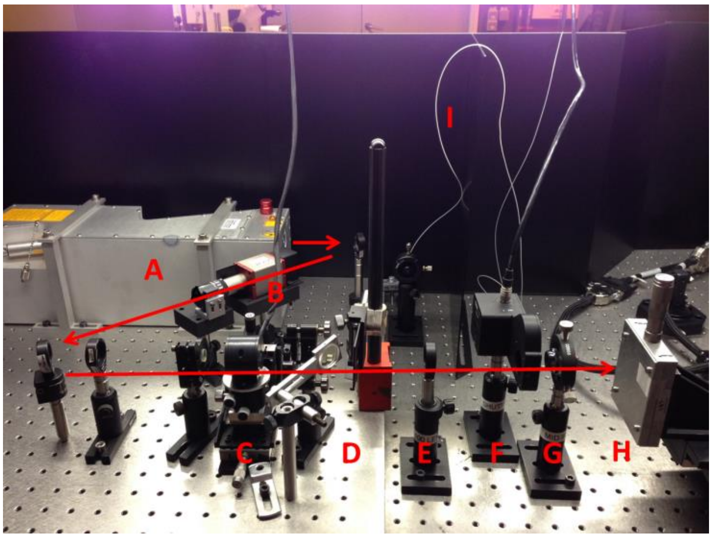
Attenuated total reflectance infrared spectroscopy (ATR-IR) was employed to characterize the substrate foils, since a measurement in transmission requires a sample thickness limited to a few tens of µms. The thin-film materials were deposited on an IR transparent substrate material (e.g. CaF_2), to avoid overlap in the spectra of thin-film coating versus substrate material. Reliable spectra could be obtained using measurements in transmission and in reflection. Further, powder spectra in KBr pellets were collected for comparison with thin-film measurements.



Example IR absorption measurement for PEDOT:PSS and PET, providing a selection of potential wavelengths for on-resonant and off-resonant IR ablation.

As an outcome of this study, a number of scenarios for selective patterning was proposed, based on the characteristic wavelengths for each material, and focussing on the wavelength regions which will be targeted by the available IR laser sources.

The mid-IR ablation experiments were performed using two set-ups, providing nanosecond and picosecond pulses. The nanosecond laser is based on a commercial laser at 1064 nm pumping with ~15 nanosecond pulses at a repetition rate of 20 kHz. A singly resonant Optical Parametric Oscillator (OPO) build around a PPLN crystal with several Quasi-Phase Matching (QPM) periods was used in this configuration. In the OPO cavity, the signal can oscillate between 1500 nm to 1650 nm wavelengths, corresponding to idler wavelengths from 3660 to 2996 nm. Coarse tuning can be obtained by translating the PPLN crystal, thus changing the QPM period. In addition, a wavelength fine tuning is achieved by heating the crystal, which allows us to achieve continuous wavelength tuning between 3000 nm to 3600 nm. This means that by combining coarse and fine wavelength tuning, it is possible to address the IR absorption bands in the range of 3 to 4 µm.



Nanosecond laser set-up: A - Laser, B - Isolator / attenuator unit, C - PPLN crystal / OPO section, D - Filtering section, E - Collimating lens, F - Shutter, G - mid-IR objective, H - Sample / translational stages, I - Coupling fiber to OSA.

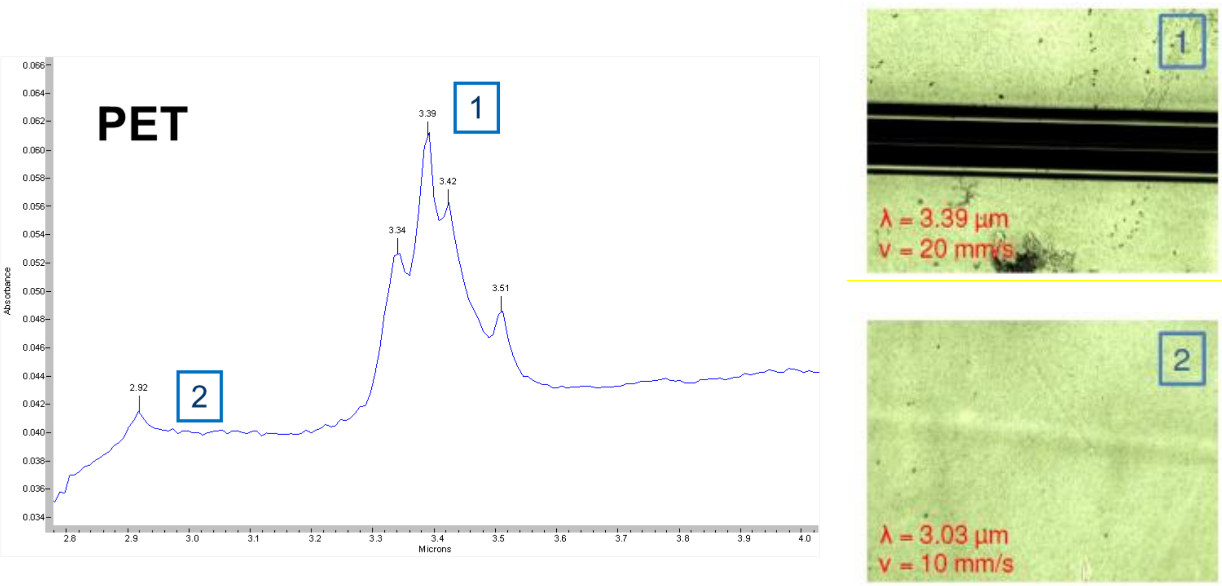
After the OPO and filtering section designated to remove residual pump and signal, the laser beam is loosely collimated by a Si plano-convex lenses (25 mm focal length), and focused by a mid-IR microscope objective (6 mm focal length). The samples were mounted on an automatic translational stage to allow for a controlled amount of laser shots, a key parameter in thin-film patterning. During the experiments, the influence of scanning speed, pulse energy and mid-IR wavelength was studied. Pulse energies were adjusted by varying the power (attenuator unit) while keeping the pulse repetition rate fixed at 20 kHz. The average power varied from 120 mW to 170 mW, resulting in corresponding pulse energies of 6 µJ to 8.5 µJ. The signal wavelengths (around 1500 nm) were measured by an optical spectrum analyzer (OSA), whereas the corresponding idler wavelengths (around 3 µm) were calculated.

On the other hand, the picosecond laser set-up is based on a commercial laser (Amplitude Systems, France) emitting at 1028 nm and modified to have 250 ps pulse duration at the output. The repetition rate has been fixed to 25 kHz and the maximum power at 4 W which corresponds to a pulse energy of 160 µJ. A multi-grating PPLN crystal has been used for the experiments in a double pass OPA configuration. The signal source (CW, 5 mW) to be amplified is tunable between 1460 nm and 1580 nm making possible to have an idler between

2.94 µm and 3.47 µm. The maximum output power obtained is typically between 80 mW and 160 mW. An aspherical lens has been used to focus the beam on the sample to process. The M^2 of the beam is unknown but for a perfect beam (M^2=1) the spot diameter is estimated to be around 12 µm in the focal plane.

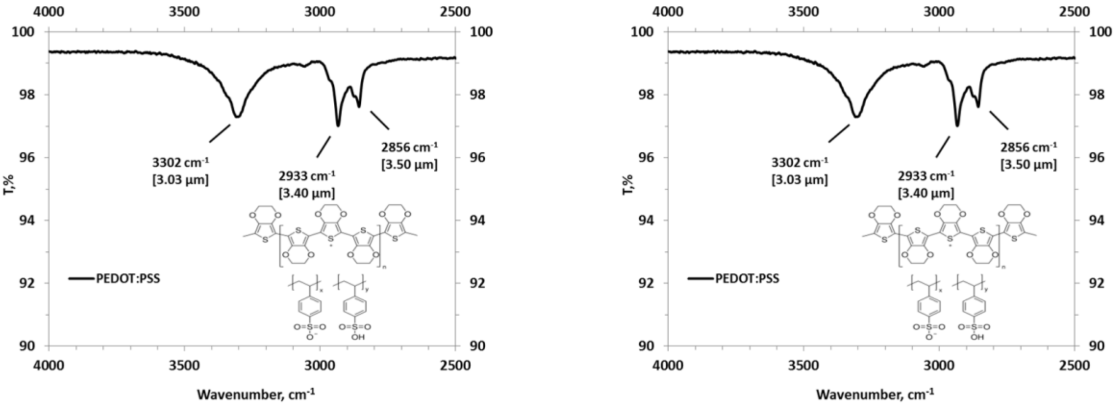
The investigation and analysis of the samples after experiments were performed by using an optical microscope and a non-contact optical profiler. Scanning electron microscopy (SEM) was used to investigate the surface topography and possible contamination after the ablation experiments. For elemental surface analysis, energy-dispersive X-ray spectroscopy (EDX) was carried out to get spatially highly resolved elemental surface mapping.

It was decided to focus first on proving the resonant ablation process for bulk polymers (e.g. typical OPV substrate foils, PMMA, and other), and continue with thin-film patterning relevant for organic photovoltaic applications. As an example result, the effect of changing the wavelength from on-resonant (3.39 micron) to off-resonant (3.03 micron) for PET is significant. Keeping in mind the typical OPV scribing steps (e.g. PEDOT:PSS removal on PET), this result suggests the use of 3.03 micron as mid-IR wavelength, so to remove the PEDOT:PSS without damaging the PET substrate (off-resonant absorption).



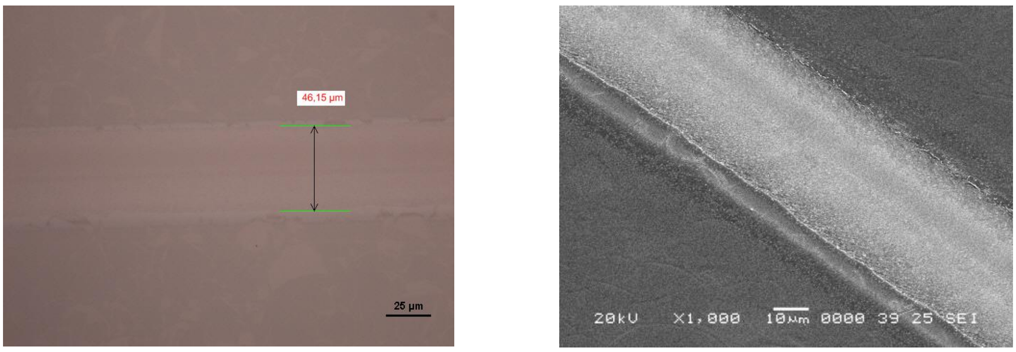
PET mid-IR absorption properties between 2.8 and 4 micron (left).
Qualitative confirmation of mid-IR resonant ablation using PET as a reference polymer (right).

During the next step of the investigation, we evaluated the use of a long wavelength mid-IR laser (nanosecond) for ablation of a thin organic film. To study the influence of overlap between the absorption of the organic thin-film and the substrate, both glass and PET foil carriers were selected. As an example, the results for PEDOT:PSS are presented here. From the IR spectra, it is observed that PEDOT:PSS has two absorption bands around 3.4 and 3.5 µm, and a second broader absorption band at 3.03 µm. The latter can be ascribed to the O-H stretch of PSS-H. The band around 3.4 µm can be assigned to the asymmetric aliphatic C-H stretch of the PSS units. The other band around 3.5 µm arises from the symmetric aliphatic C-H stretch of PSS. PET has absorption bands at 2.91 µm, and around 3.37 µm. The band around 2.9 µm arises from the O-H stretch of the PET functional end groups. The band at 3.37 µm can be assigned to the asymmetric C-H stretch of CH_2 moieties. Already now it is clear from the overlap in spectra between PEDOT:PSS and PET, that for selective removal of PEDOT:PSS from PET, the absorption band around 3.4-3.5 µm has to be avoided, because of cross-sensitivity with the PET substrate. On the other hand, a wavelength of 3.03 µm, could be a good candidate.



PEDOT:PSS and PET IR spectra in the wavelength region that can be reached by the mid-IR laser set-ups.

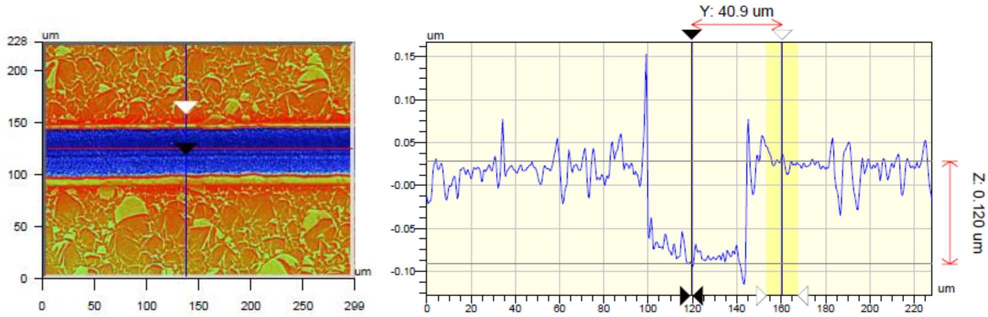
The initial goal of the experiments was to prove that a mid-IR laser could be used for removing a thin organic film, and to check the influence of on- and off-resonant wavelengths. As an example the results for PEDOT:PSS are discussed here, for which on-resonant absorption corresponds to a wavelength of 3.40 µm, and off-resonant to 3.30 µm. The (nanosecond) laser parameters used during these experiments are 160 mW of power, 20 kHz pulse repetition rate and various scan speeds. Removal of the PEDOT:PSS film was demonstrated for resonant ablation (3.4 µm), for which the optical microscope and SEM images are shown below. A clean and debris free ablation suggests the avoidance of material defragmentation, but rather evaporation because of a thermal assisted material removal process. This assumption is supported by the low ablation speeds which are required for material removal to occur.



PEDOT:PSS on glass patterning, using resonant ablation at 3.40 µm.
Optical microscopic image (left) and SEM micrograph (right).

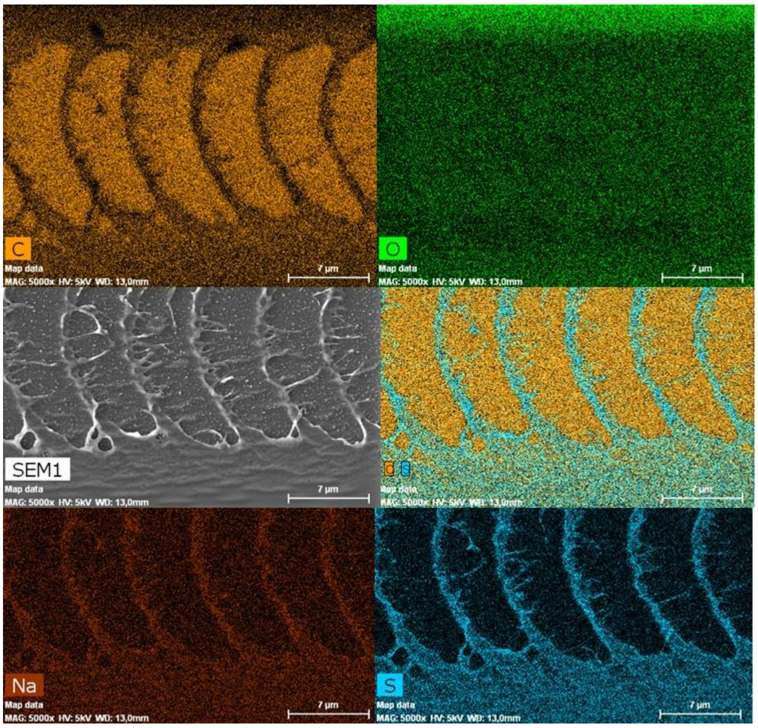
In addition to visual inspection, the depth profile of the ablated track has been measured using a non-contact optical profiler. Apart from the fact that the surface roughness of the

PEDOT:PSS film seems to be high, the measured depth of the ablated crater is about 120 nm, well corresponding to the specified layer thickness of 140 nm, so we could assume that the complete organic layer has been removed (although this was not verified by more detailed surface analysis). The spike at the left edge of the ablated groove is attributed to a measurement artifact of the optical profiler. Hence, mid-IR resonant ablation has been shown for thin organic films for the first time.



Depth profile measurement (non-contact optical profiler) after mid-IR laser ablation of PEDOT:PSS (specified layer thickness of 140 nm).

In a second step, we addressed the real scientific challenge of selective removal of thin organic films on foil substrates. The picosecond laser results for PEDOT:PSS removal on PET are included here as an example, so on-resonant absorption for PEDOT:PSS is combined with off-resonant ablation for PET, leading to a selected wavelength of 3.03 µm. For a pulse energy of 3 µJ, at a repetition rate of 25 kHz and a scanning speed of 100 mm/s, successful scribing of the PEDOT:PSS layer could be demonstrated, as depicted below.



SEM micrograph and corresponding EDX elemental maps after picosecond laser ablation (3.03 µm) of 140 nm PEDOT:PSS on PET. Laser parameters: 100 mm/s, pulse energy ~3 µJ, spot diameter in the focal plane of 12 µm.

Other organic photovoltaic materials like HDR014 and DCV4T-Et2 were also ablated in this pulse regime. The experiments confirmed a dependence of the wavelength absorption coefficient on the ablation thresholds and showed the possibility to obtain clean grooves at low scanning speeds. Because of the overlap on absorption spectra with PET, it is difficult to find a clear selective absorption band in the accessible wavelengths range of the currently available mid-IR laser system. To fully address the potential of resonant ablation in organic electronic applications, access to longer wavelength mid-IR lasers is required.

4. Potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

4.1 Potential impact

The goal of the project IMPROV was to develop and to demonstrate a high performing processing scheme for the fabrication of organic based photovoltaic devices by using mid-infrared short-pulse laser systems in combination with the technique of resonant infrared ablation. It stimulates the competitiveness of the EU in the major field of photonic components, concerning all-fibre based mode-locked oscillators, power amplifiers, mid-infrared wavelength conversion stages, sophisticated fibre-integrated devices and photonic components. In addition, the project has a huge impact on the exploitation of new applications that involve patterning and scribing of organic based devices. The research in fibre laser development, wavelength conversion stages and optical components belongs to the fields where the EU has a world leading position next to the USA. It is expected that the novel laser source developed within this project will offer advantages over competing systems which are operating in the ultraviolet and the near-infrared spectral range, respectively. At the moment, no other laser system emitting in the mid-infrared wavelength region with comparable parameter specifications is commercially available.

Pulsed laser systems tunable in the mid-IR have in general a great market potential for a variety of applications. As a replacement to conventional light sources in spectroscopic systems, they can impact important areas, such as food or environment. Some of them are industrial and urban pollution monitoring, air quality control, gas leak detection and pipeline inspection, moisture measurement and quality control in food processing, determination of acid content in vegetable oil, monitoring alcohol and sugar content as well as carbonation in beverages, bio-diesel content in fuel mixtures.

In the field of nanotechnology, short IR pulses at any desired wavelength can be conveniently exploited for nano-patterning, enabling the creation of waveguides for a number of photonic devices and inscriptions in transparent media towards new developments to use it in anti-counterfeiting.

The proposed sources also show promises for medical and, in particular, surgical applications. The high absorption of human tissue at mid-IR wavelengths allows a very well-defined and localised incision with low lateral damage. Very precise and smooth cutting of tissue is possible. The high optical beam quality also allows focusing to very small beam diameters when using long focal lengths in non-contact operations. Thus, for any micro-surgical application in which no flexible endoscope is employed (e.g. in neurology or ENTO), such a laser system could be a superior alternative to the commonly used CO2 medical lasers.

Besides the development of a high power tunable mid-IR source, the project IMPROV targets mainly the fabrication of flexible organic solar cells and organic opto-electronic devices, in order to break a technical limit. Today, most approaches to organic photovoltaics follow the route of polymer blends which gives rise to high power conversion efficiencies. Similar results are more difficult to reach with small molecules, because they are so-far less main-stream. However, as experience with OLEDs has shown, small molecule devices may be optimised by appropriate stacking of well-designed materials, which finally led to the higher power efficiencies and lifetimes for small molecule OLEDs as compared to polymer ones (the latter, however, catching up in recent years). This gave rise to follow a similar approach for OPVs as well.

The forecast of worldwide thin film PV market shows, that OPV will play only a minor role up to 2013, mainly due to their lower efficiencies and lack of production technology. However, as soon as OPV will achieve similar performance values as other photovoltaic modules, it will enter the market with increasing volume. In 2018 the market potential will be exceeding 1 Billion Euro for the first time. In 2023, analysts expect a volume of nearly 6 Billion Euro and after that OPV has the potential to become the leading thin film technology[1].

Job creation is of similar importance as market potential. The value chain of the PV industry can be divided into two categories of jobs: direct jobs created by PV companies, such as Heliatek, including engineers, scientists, construction and manufacturing workers, senior executives etc. – indirect jobs in supporting companies, which are responsible for services, e.g. material suppliers (gases, dopants, etc.), production equipment, electrical devices. The PV industry provides jobs all along this value chain. The companies create up to 7 direct jobs in the production and up to 20 corresponding indirect jobs per MWp produced. Half of these jobs relate to the production phase of the PV chain and the other half to installation and maintenance[2].

In absolute numbers, the PV industry directly employs about 435,000 people wordwide and 265,000 people in Europe, respectively. These direct jobs are supported by roughly one million indirect full time jobs. Based on a study of EPIA, the increased market demand for solar technology generates a job creation of 10 to 20 % per year[3]. For Europe, job creation can reach 1 million in the year 2020. In addition, there is a significant increase of electricity needs worldwide, around 84 % by 2035 and more than double by 2050[4]. The PV industry will strongly contribute to the creation of value and jobs.

References:

[1] Towards Green Electronics in Europe: Strategic Research Agenda & Large Area Electronics, http://cordis.europa.eu/fp7/ict/photonics/docs/reports/olae-sra_en.pdf

[2] Global Market Outlook, EPIA, Brussels

[3] Sustainability of Photovoltaic Systems, EPIA, Brussels

[4] International Energy Outlook 2011, EIA, U.S. Energy Information Administration

4.1.1 Market potential of mid-infrared laser technology

The laser technology, developed in the project IMPROV can be used in a variety of fields like medicine, sensing and of course material processing, all of them having a large market potential. This will be summarized in the following.

In medicine, lasers are used in a wide range of applications, covering for instance diagnostics and therapy. Therapeutic laser applications of the medical laser market are estimated to reach $ 3.7 billion with a compound annual growth rate (CAGR) of 10.5 % over a period of 5 years. The highest growth is expected for the diagnostics application segment with a CAGR of more than 30 % during the 5-year period. This sector is expected to increase to $ 3 billion in 2016. The global market for medical laser devices should therefore reach a total amount of $ 6.8 billion in 2016 with a CAGR of 17 % [1]. Additionally, the medical laser technology is continuously growing due to the development of new laser sources, including fibre lasers and organic light emitting diodes (OLEDs). Surface emitters based on organic foils could become important as an irradiation source in photo-dynamic therapy (PDT). Laser applications such as nanosurgery with picosecond 3 µm lasers, optical coherence tomography (OCT) and fluorescence microscopy based on 2 µm short-pulse lasers open new possibilities and could stimulate the medical laser market as well. In particular, nanosurgery, OLEDs in PDT and fluorescence microscopy can be directly addressed with the developed IMPROV laser technology.

Mid-infrared laser sensors are used in military applications, infrared countermeasures, explosives detection, remote gas leak detection, pollution monitoring and real-time combustion controls. Military applications account for a major part of the market, anticipated to increase to $ 5 billion in 2018 with a CAGR of 10 % [2]. Although spectroscopic related mid-infrared sensors (military) are dominated by Quantum-Cascade Laser technology, applications like hyperspectral imaging, atmospheric sensing and pharmaceutical process analysis rely on broadband, high power laser sources. These sources can be realised with mid-infrared supercontinuum technology, based on thulium-doped short-pulse oscillator- amplifier systems, operating around 2 µm. Therefore, the 2 µm pump source, developed in the frame of IMPROV can be directly applied in this technology. According to bccResearch, the market segment to supercontinuum sources will increase to more than $ 600 million in 2016 with a CAGR of 45 % [3].

Concerning material processing, Heliatek evaluated the prospects of mid-IR RIA laser ablation for internal use. The conclusion is that this method is one of the few very interesting options for selective structuring organic-on-organic material. At the current state-of-the-art, the basic principle has been shown, but the TRL is not advanced enough for immediate use in production. Further RIA work will be required for achieving a higher TRL, with the main directions of the availability of reliable, high-power mid-IR laser sources in the 3 µm and 5-6 µm domains. Main topics for future work should be enough power to achieve the ablation threshold, as well as reliability of the laser sources. Wide spectral tunability is less critical. As soon as these challenges are solved, RIA mid IR laser structuring by ablation may be exploited in a variety of applications of organic and large area electronics, like OPV, OLED, but also in RFID and OFET. Suitable markets can be OLED lighting and OPV. IDTechEx (in 2013) predicted 40-50% annual growth of the OLED lighting market from 2013 to 2023 reaching 1.3 billion USD in 2023. The OPV market is less developed and more segmented, and will reach in between 87 million USD (for 2023, IDTechEx) [4] to multi hundred million USD (in 2018, Nanomarkets) [5]. Heliatek considers the IDTechEX prediction as way too pessimistic. Since both technologies are under fast development, predictions of market sizes are very difficult and often strongly differing. Laser structuring is one of the enabling technologies required for these products. EU has the potential of gaining a significant market share due to its traditionally very strong machine engineering industry.

	Medical technology	Sensing		Material processing	
	total	total	SuperC	OPV	OLED
Market value (billion $)	6,8	5,0	0,6	0,1	1,3
Year	in 2016	in 2016	in 2016	in 2023	in 2023
Annual growth rate	17.3 %	10%	45%	20%	40-50 %

References:

[1] Report on medical lasers, www.bccresearch.com

[2] MID-infrared sensors market shares and forecasts, www.wintergreenresearch.com

[3] Photonic crystals: materials, technologies and global markets, www.bccresearch.com

[4] IDTechEx, Printed and Thin Film Photovoltaics and Batteries, www.idtechex.com

[5] Nanomarket, OLED Lighting Materials Markets, http://nanomarkets.net

4.2 Main dissemination activities and exploitation of the results

To promote the IMPROV project and its developments and to get a high visibility in the research, various dissemination activities were done during the project. Some key dissemination tools and dissemination activities are listed below:

- Website of the IMPROV project
- Logo, Power Point template and deliverables template
- A Power Point project presentation containing all relevant information on the project goal, schedule and partners
- Press releases
- Hand outs and factsheets
- Meetings with participants of other projects
- Dissemination at conferences, fairs etc.

Standard templates have been used when creating the presentations in order to make sure that a unified graphic design is preserved.

In the following, dissemination materials and tools are described.

Project website

The website of IMPROV is available since November 2010 at www.fp7improv-project.eu and provides information on the project details as well as all press releases, publications and public deliverables. In order to show IMPROV's potential in terms of the wider societal implications, an article prepared by the consortium has been published at our website. The website was registered by LZH and will be maintained and updated by LZH beyond the lifetime of the project in February 2014.

Logo and templates

A logo was created at the beginning of IMPROV in order to maintain the corporate the identity of the project. Templates for Power Point presentations and deliverables were designed by LZH. The deliverable template is used by all project partners in order to make sure that deliverable documents, especially the cover page are consistent in due form. It contains the name of the deliverable, name of authors, due date of the deliverable and version number, the project logo and the logos of all partners. In addition, it includes all relevant information like project acronym, project name, call identifier, activity code, start and duration of the project, contract type, and dissemination level of the deliverable. Finally, it acknowledges the source of funding. The template is available as MS Word file.

Power point presentation

A Power Point presentation has been prepared at the beginning of the project IMPROV. It starts with a project organisation slide including general information, followed by an overview about the main subjects of IMPROV. After that, the workplan by means of the different work-packages of the project is depicted in detail. This presentation was provided to the consortium partners and the EC and is intended for the general use in public events.

Press releases

At the beginning of the project different press releases have been distributed to a multitude of media, e.g. PhotonicNet Newsletter, Eurolaser, Laser Magazin, OPN Optics and Photonic News, Laser Focus World etc. The intention was to inform stakeholders and business partners about the project and to communicate this technology with its goals and potential to a broader public community. Therefore, the LZH press release was prepared and published in English and German in a generally understandable manner. The LZH press release can be downloaded by using the following link:
http://idw-online.de/pages/en/news395810

Hand-outs/fact sheets

Two-page fact sheet has been established in order to distribute vision and aim of the IMPROV project. Furthermore, all relevant information, e.g. project partners, contact, budget and timeline have been displayed. It should be used at various events at which the IMPROV consortium or parts of it are present.

Work-shops

The project IMPROV has been presented at the 38th European Conference and Exhibition on Optical Communication hold on 16 - 19 September 2012 in Amsterdam, The Netherlands together with further FP7 research projects, PLAISIR, SensHy and Clarity. The work-shop, named Mid-IR Photonics, Prospects and Challenges was organized by Prof. Syvrides, University of Athens in Greece. Here, the ideas and results of IMPROV could be discussed in an international frame with participants from Asia, America etc.

At another work-shop, which was organized by Prof. Morgner, Institute of Quantum Optics, Leibniz University of Hannover the project IMPROV has been presented as well. This work-shop “Laser Summit”, was hold on 24 February 2014 and mainly concerned to the laser development in IMPROV. Anyway, the addressed application RIA but also further applications were important issues which had been discussed intensively. More than 50 students, PHD students and scientific staff attended this work-shop.

Conferences and exhibitions

The project results of IMPROV were presented with more than 20 contributions at the following fairs, conferences and workshops:

- Photonics West 2011, 2012, 2013, 2014, San Francisco, USA
- LASER World of Photonics 2011, 2013, Munich, Germany
- CLEO Europe 2013, Munich, Germany
- 38th European Conference and Exhibition on Optical Communication, ECOC 2012, Amsterdam, The Netherlands
- Advanced Solid State Photonics 2012, San Diego, USA
- Advance Solid State Laser 2013, Paris, France
- Specialty Optical Fibers & Applications 2012, Colorado Springs, USA

- Photonics Europe 2012, 2014, Brussels, Belgium
- Laser and THz Science and Technology 2012, Wuhan, China
- 6th International congress on laser advanced material processing 2013, Niigata, Japan
- CLEO 2012, 2014 San José, USA
- SPIE Defense, Space & Security (DSS) 2012, Baltimore, USA
- Fiber Lasers and Applications (FILAS) 2012, San Diego, USA
- Europhoton 2012, Stockholm Sweden
- Journées Nationales d'Optique Guidée (JNOG 2012), Lyon, France
- IEEE Photonics Conference 2011, Arlington, USA
- "Laser Summit 2014", Hannover, Germany

Publications

10 peer-reviewed papers in the most relevant journals have been published, e.g. in Optics Express, Opt. Mat. Express, Optics Letters etc. These articles reflect all topics and outcome of IMPROV. They describe the main results of laser sources, corresponding components and devices and processing of different materials via resonant infrared ablation. A complete list can be found under www.fp7project-improv.eu or in the tables on the following pages.

4.3 Dissemination in numbers

- More than 26.000 visits to the website www.fp7project-improv.eu with more than 55.000 page visits, in detail per year:

1&1 webstatistics	2011	2012	2013	2014	total
Visits	1.913	7.676	13.030	3.409	26.028
Page visits	9.360	15.015	22.979	8.153	55.507

As can be seen, a strong increase of visits in 2013 can be observed, almost 100 % compared to 2012, which can be attributed to all dissemination activities of the IMPROV consortium.

- 10 peer-reviewed papers published in journals
- 23 presentations at different international conferences
- 22 conferences, exhibitions, workshops attended
- Lasers, devices and components developed in IMPROV presented at 6 exhibitions
- more than 900 leaflets, flyers distributed

5. Website and Contact

Website

The IMPROV website can be found at the following link:

http://www.fp7project-improv.eu

Coordination

The project is coordinated by LZH.

Coordinator

Dieter Wandt
Laser Zentrum Hannover e.V.
Hollerithallee 8
30419 Hannover
Germany
Phone +49 (0)511 2788 214
Fax +49 (0)511 2788 100
e-mail d.wandt@lzh.de

Project Logo

List of participants with contact names

Laser Zentrum Hannover e.V.
Dieter Wandt

Multitel asbl
Yves Hernandez

Batop GmbH
Wolfgang Richter

NKT Photonics
Lasse Leick

Thales Research and Technology
Arnaud Grisard

IMEC
Geert van Steenberge

Heliatek
Karsten Walzer

6. Use and dissemination of foreground – Section A

6.1 Dissemination measures

Within the course of IMPROV, the consortium partners have spent a reasonable amount of time and efforts to the dissemination of foreground, towards the scientific community, the interested public and companies as well. The main target of these activities and efforts was to promote the exploitation of the project's results, which was one of IMPROVs medium term objective.

The consortium of IMPROV was built up by two global players, two SMEs and two research institutes coming from France, Denmark, Belgium and Germany. Each participant has a demonstrated excellence in their specific area, partly derived from earlier R&D activities. In addition, they have established an own efficient contact network including relevant stakeholders, industrial representatives etc. However, the partners of this consortium used the corresponding activities in merging these networks in order to multiply the value of up-taking and exploitation of the results. Thus, during the 42 months of the project activities, the dissemination tools could be used in an effective manner.

The main focus of the dissemination strategy was to encourage the use of foreground and to promote the project's results in terms of the developed laser sources, the corresponding devices and the application of processing and structuring organic materials. In the project IMPROV a high power tunable mid-IR source – based on Thulium doped fibre oscillator/ amplifier systems and orientation-patterned GaAs frequency converters - have been designed and realized in order to break a technical limit in the fabrication of flexible organic solar cells and organic opto-electronic devices in general. Today, most approaches to organic photovoltaics follow the route of polymer blends which gives rise to high power conversion efficiencies. Similar results are more difficult to reach with small molecules, because they are so-far less main-stream. However, as experience with OLEDs has shown, small molecule devices may be optimised by appropriate stacking of well-designed materials, which finally led to the higher power efficiencies and lifetimes for small molecule OLEDs as compared to polymer ones (the latter, however, catching up in recent years). This gave rise to follow a similar approach for OPVs as well.

Particularly, Thulium -doped fibre lasers, which operate at 1.9–2.1µm, are emerging as the latest revolution in high-power fibre laser technology. This technology falls into the 'eye-safer' category, promising advantages over 1 µm lasers for industrial, sensing and military directed-energy applications. The potential for scaling up the power in pulses is beginning to be realised, with peak powers now approaching 100 kW without requiring excessively complicated fibre designs or sacrificing beam quality. Such laser can be future solutions for LIDAR (eye-safe remote sensing, detection of CO_2), medical (surgery) and even micromachining. A report from OPTECH Consulting reveals that the market of fibre lasers has grown of 42% over the three last years, gaining more and more space in the lasers applications.

Associated with a Mid-IR conversion unit, the potentiality of the source is significantly enlarged, opening the markets of gas sensing, spectroscopy, biomedical etc. Indeed, pulsed laser systems tunable in the mid-IR have in general a great market potential for a variety of applications. As a replacement to conventional light sources in spectroscopic systems, they can impact important areas, such as urban pollution monitoring, air quality control, gas leak detection and pipeline inspection, moisture measurement and quality control in food processing.

In the project IMPROV, the field of organic materials processing and in particular the fabrication of flexible opto-electronic devices has been adressed. Nevertheless the field of polymers processing is very wide and includes thin-film photovoltaic devices, organic light-emitting diodes, organic printed electronics etc. and the consortium was aware that strong measures have to be used to promote dissemination and exploitation of the project's results.

In order to achieve a successful dissemination and exploitation, three different activities were executed:

- General awareness of the project work and objectives
- Workshop and exhibitions
- Publications and discussions at conferences

6.2 General awareness of the project work and objectives

Concerning this subject, different dissemination activities have been used: a web portal, a project presentation, a fact sheet and articles, especially for the interested public.

The IMPROV website was realised at the beginning of the project and went online November 2010. This website, www.fp7project-improv.eu, provides information on the project details as well as all press releases, publications, public deliverables and other relevant data.

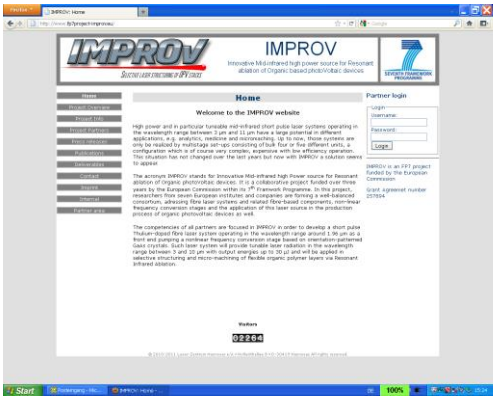


Fig. ..: Webpage IMPROV

The website was and is essential in creating awareness of the context and activities of IMPROV, and therefore important for the use and dissemination of its results. As the website will remain online beyond February 2014, which is the formal end of IMPROV, it will be one of the main dissemination tools for possible results in the future.

In order to support IMPROV's dissemination, a Power Point presentation has been prepared at the beginning of the project. In contains the project organisation, general information, an overview about the main subjects and the work-plan by means of the different work-packages. This presentation was provided to the consortium partners and the EC and is intended for the general use in public events.

A two-page fact sheet has been established in order to distribute vision and aim of the IMPROV project. Furthermore, all relevant information, e.g. project partners, contact, budget and timeline have been displayed. This flyer specifically addresses the key aspects of the project and have been distributed at events, like conferences, exhibitions etc.

TECHNOLOGY FOCUS LASERS FOR PHOTOVOLTAICS

Solar breakthrough

Dieter Wandt, IMPROV project coordinator at Laser Zentrum Hannover (LZH), explains a novel mid-infrared short-pulse laser system for structuring organic photovoltaic devices

Thin polymer films are used in a variety of applications including sensor technology, medicine and photonics. For the processing of these materials several conventional methods, such as chemical etching, can be used – but with drawbacks related to environmental pollution. Lasers can also be employed and, in most cases, UV sources (that suffer from maintenance costs and practical issues) are the only choice. Another promising approach, named resonant infrared laser ablation (RIA), was introduced at the beginning of the 21st century to address this issue. This method uses a short pulse mid-infrared laser system, which can be wavelength-tuned to one of the molecular vibrational transitions of the polymer to be ablated. The laser energy absorbed by the thin layer leads to vibrational and not to electronic excitation, thus avoiding chemical alterations of the sample. In addition, and very importantly, this technique is selective in respect of processing a diversity of polymers, which usually have different infrared absorption bands. RIA is therefore a selective laser technique, free of thermal effects.

In applications like organic light emitting diodes (OLEDs), organic thin film transistors (OTFTs), and organic photovoltaic solar cells (OPVs), where multiple conductive polymer layers are used, a selective ablation method is a very important step. Due to the impressive market potential of these devices, tremendous effort has been put into the development of materials. However, a limiting step in laser-based processing and fabrication of those devices, including patterning and scribing, can be attributed to the actual laser technology. Indeed, UV laser processing cannot cope with selectivity issues. Although RIA has already been used for high-quality thin film layer sputtering in OLED manufacture, it has used a complex and costly free electron laser (FEL), which is obviously incompatible with an industrial environment.

When the above mentioned organic devices are fabricated onto a hard inorganic material, like indium tin oxide (ITO), UV or ultra-short pulse lasers can again be used for some steps. When the ITO layer is replaced by another conductive organic material, selective ablation with low thermal damage and alteration is essential. This means RIA, in combination with a reliable, compact and maintenance-free tuneable pulsed mid-infrared laser, will be a technological breakthrough in future large area fabrication of flexible devices by preparing the integration of this ablation technique in an industrial environment.

This preliminary consideration indicates that the availability of high power mid-infrared laser sources operating between 2.5µm and 11µm is the fundamental limitation and bottleneck for a widely used laser technology based on RIA. Several secondary features, like compact size, stable operation, low cost and high reliability cannot be provided by the few systems available.

European key players in the field of photonic crystal fibres (PCFs) and nonlinear optical components (NKT Photonics, Denmark; Batop, Germany; Thales Research and Technology, France), short pulse fibre laser systems operating around a wavelength of 2µm (Multitel, Belgium; LZH, Germany) and processing OPVs (IMEC, Belgium; Heliatek, Germany) have joined forces in a collaborative project named IMPROV (Innovative Mid-infrared high Power source for resonant ablation of Organic based photoVoltaic devices). This project focuses first on the development, investigation and realisation of such a highly integrated mid-infrared laser source. Its layout is based on a master oscillator power amplifier (MOPA) short pulse thulium all-fibre laser, operating at around 2µm. This laser source is used as the front-end of an optical parametric generator (OPG), enabling the generation of mid-infrared radiation at wavelengths between 3 and 10µm. The latter is based on highly efficient orientation-patterned quasi-phase matched GaAs crystals.

Regarding wavelength tuning of the laser system, two options will be investigated: One solution consists of a fixed-wavelength MOPA system and a multiple-period GaAs crystal, the second of a tunable MOPA and a single period nonlinear crystal. Also, for processing OPV solar cells, RIA is being investigated within IMPROV.

For the MOPA pump source, different integration aspects will be addressed in order to fully benefit from a waveguide device. These include the development of fibre-coupled saturable absorbers, large mode area (LMA) photonic crystal fibres (with wavelength tuning capabilities, mode-filtering and high power operation), pump/signal combiners based on LMA-PCFs and novel concepts for fibre amplifiers with integrated core-pumping schemes. The wavelength conversion unit will be realised with integrated wavelength tunability and structural design. This MIR-laser will operate in the wavelength region from 2.5µm to 11µm with a pulse energy of up to 30µJ, a pulse duration of tens to hundreds of picoseconds and a repetition rate between 0.1 and 1MHz. For validation of the developed laser source, tests concerning the processing of organic photovoltaic solar cells will be undertaken.

So far, laser and component design studies, including resonator simulations, have been completed, first saturable absorber devices are realised and preliminary studies of the polymers used in OPVs have been performed. Now, the fibre oscillator/amplifier set-ups and corresponding components are under investigation.

IMPROV is driven by an industrial application that has a potentially large impact. The potential field of micromachining applications based on the laser developed in IMPROV is not restricted to the OPVs market, but also addresses other optoelectronic polymer devices like OLEDs or OTFTs and other functional products like stents, particle filters etc. Other applications in the field of spectroscopy and medicine can also benefit from the advances in IMPROV.

For further information
IMPROV project (www.fp7project-improv.eu)

38 ELECTRO OPTICS • FEBRUARY 2011 www.electrooptics.com

In order to disseminate the aim and ideas behind of IMPROV, an article with the title "Solar breakthrough", has been prepared und published in Electro Optics, February 2011. It explains the background of resonant infrared ablation and its advantage compared to other processing schemes, the design of the laser source to be developed and outlined the consortium and who is working in IMPROV with its corresponding tasks. A second article has been written concerning the socio-economic aspects of the project IMPROV in order to address the general public. This article is published at the website of IMPROV and van be downloaded.

6.3 Workshop and exhibitions

The project IMPROV has been presented at the 38th European Conference and Exhibition on Optical Communication hold on 16 - 19 September 2012 in Amsterdam, The Netherlands together with further FP7 research projects, PLAISIR, SensHy and Clarity. The work-shop, named Mid-IR Photonics, Prospects and Challenges was organized by Prof. Syvrides, University of Athens in Greece. Here, the ideas and results of IMPROV have been discussed in an international frame with participants from Europe, Asia, America etc.

At another work-shop, which was organized by Prof. Morgner, Institute of Quantum Optics, Leibniz University of Hannover the project IMPROV has been presented as well. This work-shop "Laser Summit", was hold on 24 February 2014 and mainly concerned to the laser development in IMPROV. Anyway, the addressed application RIA but also further applications were important issues which had been discussed intensively. More than 50 students, PHD students and scientific staff attended this work-shop.

International, large exhibitions and trade fairs are important dissemination channels because nowhere else are so many decision-makers in such short period of time at one location present. The major trade fairs, traditionally accompanied by corresponding scientific conferences have been emerged with the Photonics West in San Francisco, USA and the Laser, World of Photonics in Munich, Germany. Both events have attracted in 2013 and 2014 more than 27000 participants coming from 74 different countries (Laser 2013) and more than 21000 attendees (Photonics West 2014), respectively.

Photonics West 2012

These events are focused not only on laser development and photonic devices but process technologies as well. Therefore, IMPROV's project results have been presented at both events, mainly on an own LTH booth, every year since 2010 in terms of all dissemination tools, described above. In addition, corresponding hardware, e.g. laser sources, fibre-based devices etc. has been exhibited. Due to these dissemination activities, many different stakeholders could be made aware and informed about the aim of IMPROV. Many of them tracked the progress year by year and several concrete requests have already been received. All requests have been documented and distributed to the responsible personnel for further handling. The results of an evaluation in terms of development items of IMPROV:

- (Fibre) Laser companies, operating word-wide (large, medium), are strongly interested in special fibre-components and tried to have access to the corresponding technology. Very concrete approach.
- SME's, laser developers are interested in Thulium-doped fibre oscillators and amplifiers, mostly for replacing their already existing devices by alternatives. Informal approach.

- Research institutes, universities which are looking for one special system, based on the IMPROV technology but with adapted parameters in order to perform fundamental research applications.
- Few defense companies are interested in the complete IMPROV MIR-laser source, for application in counter measures etc.
- (International operating) laser integrators, which are active in the field of plastics processing etc. are closely monitoring the development (including RIA) of IMPROV.

6.4 Publications and discussions at conferences

Presentations at conferences are a good opportunity to provide and distribute results in a more general manner, not only concentrated on target-related achievements of IMPROV but covering the more complete and comprehensive surroundings of the project. Therefore, these activities can be considered as multipliers for dissemination and exploitation of the whole results, which have been attained within the project.

Conferences, which have been attended by IMPROV partners in the last years in order to present the results, like Advanced Solid State Photonics (ASSP), Conference on Lasers and Electro-Optics (CLEO USA), Europhoton, Photonics Europe etc. More than 20 presentations have been given by the consortium partners, either in terms of oral talks or posters, respectively. Although the conferences are mainly attended by members of the scientific community, it is a first step to disseminate the project's outcome. At that events, basic developments and problem solutions have been discussed, which is important of a consequent work on a more scientific level. The aim was to improve the different set-ups and to discuss alternative laser development solutions. In addition, resonant infrared ablation and its application to other fields of interest, e.g. processing of plastics without the need of additional absorbers (dyes) was an issue in that framework. This topic is of interest because these dyes inside the materials have not only absorptions bands in the infrared but also in the visible spectral range. However, in many areas of applications, clear and transparent plastics are highly preferable. These discussions were very helpful and opened the look on similar developments and achieved results.

The above mentioned conferences are sub-divided, addressing several areas of research, e.g. biophotonics, medicine technology etc. Particularly, these are BIOS (Biomedical optics and imaging conference) and ECBO (European Conferences on Biomedical Optics) at Photonics West and Laser, World of Photonics, respectively. One topic in the last years was laser-based surgery using short-pulse laser systems. In this field, novel investigations and corresponding results yielded that picosecond lasers operating at a wavelength around 3 µm can significantly improve the quality of incisions in tissue thus having the potential of replacing currently used nanosecond lasers.

Due to these activities, the IMPROV partners could establish a network on a scientific level in different fields which helps to identify novel topics and its development potential. In addition, that will be the base for future research activities and projects.

6.5 Socio-economic impact and target groups for the results of the research

The results achieved in IMPROV will have impact in actual and further developments concerning selective processing of organic-based materials by using ultrashort-pulse lasers and the corresponding photonic devices. Key elements are Thulium-doped photonic crystal fibres, fibre combiners, semiconductor saturable absorber mirrors, Thulium-based fibre oscillators and amplifiers, orientation-patterned GaAs frequency converters on the one hand, OPV materials and their processing on the other hand.

Thus, IMPROV’s research can be divided into two different fields of development: a) short-pulse lasers and b) innovative organic-based materials and its processing technology, each with a large socio-economic impact.

- The frequency conversion crystals are pumped by novel 2 µm Thulium-doped mode-locked/short-pulse oscillator/amplifier systems. This concept to generate mid-infrared (MIR) radiation can provide laser sources with less sub-systems, compared to 1 µm-based MIR-systems, thus more efficient and more cost-effective. It could pave the way to a new class of lasers and can stimulate the extension of the product range of related European laser companies.
- Organic-based thin films are not only used in photovoltaics, the topic of IMPROV, but also in the area of organic light emitting diodes, electronics etc. Having a reliable and selective laser processing technology is of large importance as it is a competitive advantage of European companies, protecting and creating new jobs.

Additionally, IMPROV could strongly impact areas outside its investigated application, for instance in medical surgery. Tissue ablation with a picosecond mid-infrared laser as developed in IMPROV occurs via a photo-thermal process with thermal and stress confinement, without significant collateral tissue injury as observed with currently used nanosecond lasers. Thus, IMPROV’s results have the potential to replace these lasers by a novel class of picosecond lasers.

Processing of engineering grade plastics is another important application which can be targeted with the developed mid-infrared laser system. At the moment, absorption of these materials which is necessary for efficient laser processing, must be forced by incorporation of special dyes with corresponding drawbacks, e.g. lack of transparency. Therefore, the developed laser system, operating at wavelengths coinciding with natural absorption bands of these plastics could provide a simple and universal means for that task.

Combining the evaluation, described in a section before, and the discussion concerning impact of the project’s results, the target groups are:

- Solar industry based on organic materials
- Organic thin-film related electronics industry
- Medicine Technology, particularly surgery
- Companies related to laser processing of plastics

- Laser developing companies, operating in the fields of
    - fibre lasers/amplifiers at 2 µm
    - frequency conversion stages for wavelengths beyond 3 µm

7. Use and dissemination of foreground – Section B

7.1 General exploitation plan

During the project IMPROV, particularly in the last period, different strong interactivities among the consortium partners took place, not only between the laser source/ photonic devices developers and users, respectively but also in an interdisciplinary manner. Of course this was planned and described in the DoW, but some activities were beyond the original concept. Due to technical problems with the laser source to be developed in IMPROV, scribing tests must be performed by already available laser systems and contingency activities. Therefore, material processing tests were not only accomplished at IMEC, but also at Thales and Multitel as well. In more detail:

- Thales supplied an OPO-system to IMEC (20 ns pulse duration, operating around 3 µm), experiments were done at IMEC.
- Multitel modified an ultrafast regenerative amplifier with Thales nonlinear crystal (250 ps pulse duration, operating around 3 µm), experiments were done at Multitel.
- Thales provided an OPO-system (20 ns pulse duration, operating around 4.5 µm), experiments were done at Thales in collaboration with IMEC.

All samples were provided by Heliatek and a detailed analysis and evaluation of these different scribed materials have been carried out at IMEC and specifically at Heliatek by using their knowledge and their different advanced analysis tools.

This strong co-operation and the corresponding efforts demonstrate that it is the strong intention of the IMPROV partners to exploit RIA in combination with photovoltaic devices in a progressive manner. We thus emphasize the interest of the Consortium as a whole for future collaborative thesis proposals to further explore some of the novel questions that were raised thanks to the RIA experiments carried out during IMPROV.

Additionally, there are areas outside the project's scope which can be addressed for the exploitation of the results. Most prominent topics are laser surgery and micro-machining of plastic materials for instance.

In laser surgery, currently Erbium-based lasers, operating around 3 µm and emitting nanosecond pulses are used. This parameter regime induces ablation via photo-thermal and cavitation-induced photomechanical effects without thermal or acoustic confinement, leading to significant collateral tissue injury. Therefore, these lasers are suitable only for a more or less macroscopic surgery and not for minimally-invasive techniques. Picosecond laser systems with spectral emission around 3 µm however, selectively energizes water molecules in the tissue to drive ablation or cutting process faster than thermal exchange of energy and shock wave propagation, without plasma formation or ionizing radiation effects. This mechanism was first published in 2010[1,2]. The authors used a laser operating at a wavelength of 2.96 µm with a pulse duration of 100 ps, which is long enough to transfer the optical radiation into heat but much shorter than the times of thermal or acoustic relaxations, so that shock waves or thermal effects cannot be propagated. Anyway, the optimum pulse duration is not estimated yet.

Currently, laser machining of plastics is performed by using, e.g. a short-pulse laser operating at a wavelength around 1 µm. Therefore, the normally transparent materials have to be doped with dyes, providing absorption bands around 1 µm. Unfortunately, this procedure caused a discoloration of the plastics which is not desirable in many cases. Therefore, the IMPROV picosecond mid-infrared laser source, operating at wavelengths which coincide with the natural absorption bands of the materials could be used as an alternative laser system to the above mentioned 1 µm sources.

These above mentioned remarks clearly demonstrate further exploitation routes of the IMPROV results. The IMPROV laser system can easily be operated at a wavelength of 3µm and therefore applied in laser surgery. At the moment, the optimum pulse duration is not clear; if pulse durations around 500 ps are sufficient, the gain-switched laser diode, developed by Multitel, will be ideal as seed source. If shorter pulses, e.g. 100 ps and below are required, the mode-locked oscillator, developed by LZH, could be applied. In any case, the amplifier stages of Multitel using NKT photonic crystal fibers can provide the pump source for the nonlinear conversion stage of Thales. Almost the same can be applied for laser processing of plastic materials. Both aforementioned seed sources for subsequent fiber amplifier stages can be considered. However, longer wavelengths beyond 3µm have to be addressed, which is no problem for the GaAs-based frequency converters. Concerning this latter issue, discussions with two departments of LZH, "Materials and Processes" and "Productions and Systems" and related companies working on that issue have already started in order to define the necessary laser parameters.

Anyway, both application fields have the potential to exploit the results of IMPROV concerning the laser sources, at least in raising new, additional third-party funds with the corresponding IMPROV partners.

References:

[1] K. Franjic et al. "Vibrationally excited ultrafast thermodynamic phase transitions at the water/air interface", Phys. Chem. Phys. 12, 5225 (2010)

[2] S. Amini-Nik et al. "Ultrafast Mid-IR Laser Scalpel: Protein Signals of the fundamental Limits to Minimally Invasive Surgery", PLos One 5, e13053 (2010)

7.2 Exploitation plan of partners (Update of Annex I)

LZH is a non-profit laser research institute with an interdisciplinary structure, including physics, material development, production technique, biomedical optics and nano technology. Therefore multiple activities can be addressed from basic research through development to applications. One intention of the LZH is to transfer research results and application techniques to the industry and to support them in establishing related technologies.

In IMPROV, LZH has developed fibre-based components, like pump combiners for Thulium doped amplifiers and special WDM-couplers with input wavelengths at 793 nm and signal wavelengths around 1.95 µm. At the moment, LZH cannot provide devices based on polarization maintaining fibres, therefore a direct use by IMPROV partners was not possible. Currently a modification of the processing unit is in progress in order to make such PM-based components available. Anyway, due to dissemination activities at conferences, exhibitions etc., these devices have found great attention and samples, prototypes could already be supplied to different institutes and even companies. Over the last months, an increasing demand could be observed and therefore LZH will further explore and utilize it in future research projects.

The results obtained in IMPROV concerning the different Thulium-based fibre oscillator systems, have been disseminated at conferences and workshops. Several requests have been received regarding transfer of the results and will be addressed after completion of IMPROV. However, the achievements of IMPROV will potentially be used for further research projects with the same consortium, considering shorter pulse durations of the laser source.

Multitel is a research centre active in many fields, including Applied Photonics, and more particularly Fibre lasers. The aim of Multitel is to be a bridge between the academic and the industrial world. In the case of another EU project Multitel is participating to, the exploitation of the results are under discussion through a possible technology transfer from MULTITEL to a SME of the consortium. Such agreement could also be a possibility with a company of the IMPROV consortium or an external SME that would be contacted to ensure a future exploitation scheme. In the particular case of IMPROV, such scheme and also the possibility to launch a spin-off from the centre in the field of fibre lasers will be studied. These will be the two preferable routes towards exploitation for this research centre. Additionally, the opportunities for patenting in the field of laser processing will be closely investigated with the partners.

In the project IMPROV, MULTITEL finally developed two different potential products: a gain-switched amplified laser module and a high energy short pulse amplifier. As MULTITEL is allowed to perform and sell small series and prototypes, for the moment the strategy will consist on pursuing the development of these two technologies through potential contracts with end-users or integrators. At the moment there are three potential leads under investigation. The first one is with the partner of the project, company NKT, for which there could be an interest regarding the gain-switched module. Discussions are on-going about potential fabrication price. Two other contacts have been established outside of the consortium with two other companies interested by the gain-switching module or by the amplification competence. Preliminary tests have been performed with one company and other tests are planned with the other, with the target to present a new product at Photonics West 2015.

NKT Photonics now has a strong foothold in large mode area fibres for operation at 1 µm as well as within ultra broad band supercontinuum sources from 400 nm to 2400 nm. NKTP have within IMPROV developed large mode area thulium doped photonic crystal fibers for operation at 2 µm. This includes a flexible PM fiber with a 36 µm Mode-field diameter, a ROD type inflexible fiber with a mode field diameter of 60 µm and a pump/signal combiner to the flexible fiber.

The intent has been to sell these fibers for use in pulsed lasers. However, NKT have encountered a problem on realizing the required optical efficiency to be competitive against our competitors. NKT have tried three different material compositions with our vendor of active glass material, but neither of these has worked. No clear solution to the challenge has been identified yet. As a consequence, the fibers have not yet been launched as commercial products.

NKT have been very active in publishing results on the large mode area Thulium doped PCF, and as a result the company has been approached by some Universities wanting to buy fibers.

NKT is still very interested in making active large mode area fibers for longer wavelengths, but further steps would require an extensive study of active glass materials from different vendors, and is estimated costing 300-500.000 €. Hence this has not been initiated yet.

Batop has a strong expertise in the development and growth of semiconductor nonlinear optical devices, like SAM - saturable absorber mirrors and SOC - saturable output couplers for lasers. During the last years BATOP became a worldwide leading supplier of these devices for passive laser mode locking. Batop has the strong attempt to open new resources in the wavelength range around 2 µm, a strategy which is therefore in line with the proposed project. The exploitation of these novel saturable absorber devices will be therefore expand their production portfolio and will improve their market position.

During the IMPROVE project especially saturable absorbers for passive mode-locking of lasers at about 2 um wavelength has been developed extensively. This is actual a good base for an increasing business with such devices. Since 2013 we have a remarkable sales increase of 2 µm absorbers for fiber and solid state lasers. A a result of IMPROVE project the growth technology for these 2 µm absorbers is now developed at BATOP. Currently most of the customers are research groups, but also some laser companies are in the developing phase for products with our 2 µm absorbers. Therefore, we can expect a further increase of sales with these products.

Based on IMPROV project results with saturable absorbers for 2 µm laser wavelength BATOP now extends the wavelength region for such absorbers also to longer wavelengths up to 3 µm. Also these devices are already introduced in the market.

THALES Research & Technology (TRT):

Since the first successful HVPE growth runs on patterned GaAs template wafers carried out as a seminal work, the strategy followed by TRT has been to trigger or join collaborative projects to explore the application potential of OP-GaAs and thus pave the way toward a global market for those crystals above the critical size for profitability. In the frame of the IMPROV project, the exploitable foreground can thus be divided into:

<u>- OP-GaAs frequency converters:</u>
An important impact of the project is the availability of new optical materials suited to efficient wavelength conversion of fiber lasers around 2 microns up in the infrared, with pulse durations shorter than the state-of-the-art. Various crystal designs adapted to several optical implementation schemes can typically extend the wavelength choice from 3 to 12 µm and therefore address an array of application much wider than processing of polymer films, including for example:

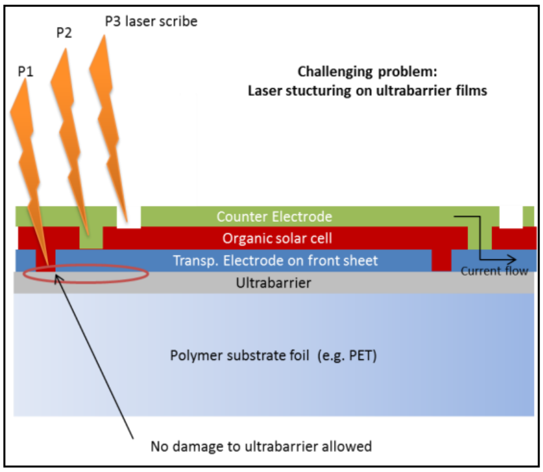
- Tunable sources for high sensitivity spectroscopic systems.
- Sources of entangled photon pairs for quantum cryptography.
- Fiber optic networks, in need of polarization independent waveband converters.
- Terahertz generation obtained by high efficiency mixing of dual frequency sources.
- Infrared laser sources for medical applications.

TRT is able to ensure small scale production of OP-GaAs crystals up to 20 to 30 samples per year. Above that number, a preferred solution would be to subcontract the template fabrication and dicing/polishing tasks and license the HVPE growth step with an emphasis on larger diameter growth. The preferred candidate for such developments is 3-5 Lab, targeting medium scale development of GaAs components.

The IMPROV project adds to **IMEC**'s general objectives to become an international centre of excellence in the area of micro- and nano-electronics and to reinforce the local industry. Within IMPROV, as in most others, IMEC performs basic fundamental research in combination with industrial research. An important commercial goal is to develop knowledge in the project suitable for intensification of bilateral collaboration with industry. IMEC is currently starting up new bilaterial collaborations with industrial partners, in the field of laser processing.

Laser processing is one of the key competences of IMEC, and evolved from a basic technology for drilling micro-vias, to an enabling technology for complex photonic structures, with developments in selective thin-film material removal, laser direct imaging, laser-induced forward transfer (LIFT), laser nanostructure formation, and femtosecond laser waveguide writing which are all investigated throughout different frameworks, including new EU projects. The process knowledge developed within the IMPROV project, is expected to play a key role in all these different areas.

Heliatek develops OPVs based on so-called small organic molecules, also known as oligomers, which are made by vacuum deposition processes to achieve best performance. Doing so, Heliatek is currently world-wide leading both with respect to OPV efficiency in lab scale (12% power conversion efficiency (PCE)) and in roll-to-roll-production (>6% PCE on flexible substrates, on 30 cm wide PET foil substrates). Heliatek operates nowadays the world's first vacuum-based OPV production line. Heliatek aims for a large scale, large volume production of organic solar cells suitable both for opaque and transparent PV products for special markets like building integration (BIPV) and the automotive sector. Key customers from both fields have been found, and joint product developments for these dedicated markets are under way. One prerequisite to do so is the ability to structure and encapsulate the organic devices.



The problem of laser scribing on top of ultrabarrier films

The current first OPV production line already uses ultrashort pulsed laser scribing with conventional wavelengths in the VIS range. Its limitation is the fact, that all devices need to be encapsulated behind expensive additional ultrabarrier foil after laser processing to achieve suitable lifetimes of >10 years. Direct laser scribing with VIS lasers would damage the barrier systems. A significant cost reduction will be possible, as soon as OPVs can be produced directly on top of ultrabarrier foil. IRR laser scribing at dedicated Near- to Mid-IR wavelengths is one possible way out of this dilemma. At the current level of laser development, the IMPROV project has laid the basics for such processes. However, the laser energy density so far is still too low for industrial proposes that require high reliability and reproducibility. As such, Heliatek is a potential customer to further developed Near- to Mid-IR systems using the IRR laser ablation effect.

Section A (public)

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages		Is/Will open access[2] provided to this publication?
1	High energy sub-nanosecond Thulium-doped all-fibre laser with photonic crystal fibre amplifier	Guillemet	International Journal of Modern Physics B	No28	World Scientific	USA	2014	1442006-1 - 1442006-8	www.worldscientific.com/doi/pdf/10.1142/S0217979214420065	yes
2	Quasi-phase-matched gallium arsenide for versatile mid-infrared frequency conversion	Grisard	Opt. Mat. Express	No2	OSA	USA	2012	1020-1025	http://www.opticsinfobase.org/ome/search2.cfm?reissue=J&journalList=24&fullrecord=grisard&basicsearch=Go	no
3	Mid-infrared resonant ablation of PMMA	Naithani	Journal of laser micro nanoengineering	Under review	JLPS	Japan	2014			yes
4	Lasing in thulium-doped polarizing photonic crystal fiber	Modsching	Opt. Lett.	No 36	OSA	USA	2011	3873	http://www.opticsinfobase.org/ol/abstract.cfm?uri=ol-36-19-3873	no
5	Monotonically chirped pulse evolution in an ultrashort pulse thulium-doped fiber laser	Haxsen	Opt. Lett.	No 6	OSA	USA	2012	1014-1016	http://dx.doi.org/10.1364/OL.37.001014	no
6	Ultrafast, stretched-pulse thulium-doped fiber laser with a fiber-based dispersion management	Wienke	Opt. Lett.	No 13	OSA	USA	2012	2466-2468	http://dx.doi.org/10.1364/OL.37.002466	no
7	Q-switched operation of a novel	Kadwani	Opt. Lett.	No37	OSA	USA	2012	1664-1666	http://www.opticsinfobase.o	no

[2] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	ultra-large mode area Tm3+ doped photonic crystal fiber								rg/ol/abstract.cfm?uri=ol-37-10-1664	
8	Cw-lasing and amplification in thulium-doped PCF rod	Gaida	Opt. Lett.	No37	OSA	USA	2012	4513-4515	http://www.opticsinfobase.org/ol/abstract.cfm?uri=ol-37-21-4513	no
9	Amplification of nano-second pulses to megawatt peak power levels in Tm3+-doped photonic crystal fiber rod	Gaida	Opt. Lett.	No38	OSA	USA	2013	691	http://www.opticsinfobase.org/ol/abstract.cfm?uri=ol-38-5-691	no
10	Comparison of higher-order mode suppression and Q-switched laser performance in thulium dopedlarge mode area and photonic crystal fibers	Kadwani	Opt. Express	No20	OSA	USA	2012	24295-24303	http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-20-22-24295	yes
11	Hybrid mode-locked thulium soliton fiber laser	Haxsen	IEEE IPC	885-886	IEEE	USA	2011			no
12	Positively chirped pulse evolution in a passively mode-locked thulium-doped fiber laser	Haxsen	ASSP	AM4A.24	OSA	USA	2012		http://dx.doi.org/10.1364/ASSP.2012.AM4A.24	no
13	High pulse energy sub-nanosecond Tm-doped fiber laser	Cserteg	Phot. West	8237-139	SPIE	USA	2012		http://dx.doi.org/10.1117/12.908115	no
14	Fiber based dispersion management in an ultrafast thulium-doped fiber laser and external compression with a normal dispersive fiber	Wienke	ASSP	AT4A.26	OSA	USA	2012		http://dx.doi.org/10.1364/ASSP.2012.AT4A.26	no
15	Comparison of different wavelength pump sources for Tm subnanosecond amplifiers	Cserteg	Phot. Europe	8433-3	SPIE	USA	2012		http://dx.doi.org/10.1117/12.922321	no
16	High normal group velocity dispersion photonic crystal fiber for wavelength tunable pulse stretching around 2 µm	Pureur	Europhoton		EPS	France	2012			no
17	High energy and low repetition rate picosecond thulium-doped all-fibre laser with photonic crystal fiber amplifier	Guillemet	ASSL	ATu1A.5	OSA	USA	2013		http://dx.doi.org/10.1364/ASSL.2013.ATu1A.5	no

18	High energy all-in-fibre Thulium laser	Guillemet	Laser and Tera-Hertz Science and Technology	MTh3A	OSA	USA	2012			no
19	Lasing in Thulium-doped polarizing photonic crystal fibers	Kadwani	Phot. West	82372Z	SPIE	USA	2012		http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1344571	no
20	Q-switched operation of a novel ultra-large mode area Tm3+ doped photonic crystal fiber	Kadwani	ASSP	AM4A	OSA	USA	2012		http://www.opticsinfobase.org/abstract.cfm?URI=ASSP-2012-AM4A.18	no
21	CW and pulsed performance of Tm-doped photonic crystal fiber lasers	Kadwani	DSS		SPIE	USA	2012		http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1385646	no
22	Modal analysis of large mode area photonic crystal fiber for high power 2µm fiber lasers	Salvin	FILAS	FTh4a.05	SPIE	USA	2012		http://www.opticsinfobase.org/abstract.cfm?URI=FILAS-2012-FTh4A.5	np
23	Peak power scaling in Tm-doped fiber lasers to MW-level	Gaida	Proc. SPIE	86012	SPIE	USA	2013		http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1671632	no
24	Modal properties of photonic crystal fiber for high power two µm fiber laser systems	Jollivet	DSS	No838, April 2012	SPIE	USA	2012		http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1385615	no
25	1mJ pulse energy in Tm-doped photonic crystal fiber	Kadwani	Specialty Op. Fibers, Fiber LasersII	SW2F	OSA	USA	2012		http://www.opticsinfobase.org/abstract.cfm?URI=SOF-2012-SW2F.3	no
26	Mid-infrared resonant ablation for selective patterning of thin organic films	Naithani	Conference on laser sources and applications	9135-19	SPIE	USA	2014			no
27	Mid-infrared resonant ablation of PMMA	Naithani	6th International congress on laser advanced materials processing				2013	Proceedings 1-5		no
28	Positivley chirped pulses from a mode-locked thulium fiber laser	Haxsen	Photonics Europe	8433-17	SPIE	USA	2012			no
29	Dispersion management with a normal dispersive fiber in an ultrafast thulium-doped fiber	Wienke	Photonics Europe	8333-13	SPIE	USA	2012			no

	laser									
30	Quasi-phase-matched gallium arsenide for mid-infrared frequency conversion	Lallier	ASSP	AMA1.1	OSA	USA	2012		http://dx.doi.org/10.1364/ASSP.2012.AM1A.1	no
31	Stretched-pulse operation of a thulium-doped fiber laser with a fiber-based disapersion management	Wienke	CLEO	CM1B7	OSA	USA	2012		http://www.opticsinfobase.org/ abstract.cfm?URI=CLEO: S and I-2012-CM1B.7	no
32	Positively chirped pulses in a mode-locked thulium fiber laser – simulation and experiment	Haxsen	CLEO	CTu1I.2	OSA	USA	2012		http://www.opticsinfobase.org/ abstract.cfm?URI=CLEO: S and I-2012-CTu1I.2	no
33	Photonic crystal fiber pump combiner for high-peak power all-fiber thulium lasers	Sincore	*Proc. of SPIE Vol*, vol. 8961	896133-1		*San Francisco, USA*	2014		http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1847511	

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[3]	Main leader	Title	Date/Period	Place	Type of audience[4]	Size of audience	Countries addressed
1	website	LZH	IMPROV website www.fp7project-improv.eu	11/2010	web	Scientific, Industry		International
2	Press releases	LZH	Multiple media	10/2010	web	Scientific, Industry		Germany
3	Press releases	LZH	Multiple media	09/2010	web	Scientific, Industry		International
4	Presentation	LZH	IMPROV	11/2010	web	Scientific, Industry		International
5	Article	LZH	Electro-Optics	02/10	web	Scientific, Industry		Internation
6	Flyer	LZH	Laser World of Photonics	05/11	Munich, Germany	Scientific, Industry		International
7	Flyer	LZH	Photonics West	02/11	San Francisco, USA	Scientific, Industry		International
8	Exhibitions	LZH	Laser World of Photonics	05/11	Munich, Germany	Scientific, Industry		International
9	Exhibitions	Batop	Laser World of Photonics	05/11	Munich, Germany	Scientific, Industry		International
10	Conference	LZH	SPIE IPC	09/11	Arlington,	Scientific,	100	Interbational

[3] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[4] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

					USA	Industry		
11	Flyer	LZH	Photonics West	02/12	San Francisco, USA	Scientific, Industry		International
12	Exhibitions	LZH	Photonics West	02/12	San Francisco, USA	Scientific, Industry		International
13	Conference	LZH	ASSP	02/12	San Diego, USA	Scientific, Industry	70	International
14	Conference	LZH	Photonics Europe	04/12	Brussels, Belgium	Scientific, Industry	50	International
15	Conference	LZH	CLEO	05/12	San José, USA	Scientific, Induatry	100	International
16	Conference	LZH	Photonics West	02/12	San Francisco	Scientific, Industry	80	International
17	Conference	Multitel	Photonics West	02/12	San Francisco, USA	Scientific, Industry	80	International
18	Conference	NKTP	Photonics West	02/12	San Francisco, USA	Scientific	50	International
19	Conference	NKTP	DSS	05/12	Baltimore, USA	Scientific, Industry	80	International
20	Conference	NKTP	ASSP	02/12	San Diego, USA	Scientific	30	International
21	Conference	Multitel	Photonics Europe	04/12	Brussels, Belgium	Scientific, Industry	50	International
22	Conference	Thales	ASSP	02/12	San Diego, USA	Scientific, Industry	70	International
23	Conference	NKTP	Specialty Op. Fibers	06/12	Colorado Springs, USA	Scientific	30	International
24	Conference	Multitel	Europhoton	08/12	Stockholm, Sweden	Scientific, Industry	70	International
25	Conference	NKTP	ASSL	10/12	Paris, France	Scientific, Industry	80	International
26	Conference	Multitel	Laser &THz Science and Technology	11/12	Wuhan, China	Scientific, Industry	80	International
27	Workshop	LZH	ECOC	09/12	Amsterdam,	Scientific,	70	International

					Netherlands	Industrie		
28	Flyer	LZH	Laser World of Photonics	05/13	Munich, Germany	Scientific, Industry		International
29	Exhibition	LZH	Laser World of Photonics	05/13	Munich, Germany	Scientific, Industry		International
30	Exhibition	Batop	Laser World of Photonics	05/13	Munich, Germany	Scientific, Industry		International
31	Conference	Multitel	ASSL	10/13	Paris, France	Scientific, Industry	80	International
32	Conference	IMEC	6th International congress on laser advanced materials processing	07/2013	Niikata, Japan	Scientific, Industry	80	International
33	Publication	NKTP	Proc. SPIE	03/13	San Francisco, USA	Scientific, Industry		International
34	Flyer	LZH	Photonics West	02/13	San Francisco, USA	Scientific, Industry		International
35	Exhibition	LZH	Photonics West	02/13	San Francisco, USA	Scientific, Industry		
36	Article	LZH	www.fp7project-improv.eu	Since 2013		Scientific, Industry		International
37	Conference	IMEC	Conference on laser sources and applications	04/14	Brussels, Belgium	Scientific, Industry	80	International
38	Publication	NKTP	Proc. SPIE	02/14	San Francisco, USA	Scientific, Industry		International
39	Workshop	LZH	Laser Summit	02/14	Hannover, Germany	Scientific	50	Germany
40	Flyer	LZH	Photonics West	02/14	San Francisco, USA	Scientific, Industry		International
41	Exhibition	LZH	Photonics West	02/14	San Francisco, USA	Scientific, Industry		International

Section B (Confidential[5] or public: confidential information to be marked clearly)
Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[6]:	**Confidential Click on YES/NO**	**Foreseen embargo date dd/mm/yyyy**	**Application reference(s) (e.g. EP123456)**	**Subject or title of application**	**Applicant (s) (as on the application)**
Background IPR	*NKT Photonics have a large patent portfolio for production of double-clad, active photonics crystal fibres. For brevity, the list here concerns US patents.* *Design of PCF: US6,792.188, US6,856,742, US6,892,018, US7,349,611, US6,539,155 US6,334,019* *Fabrication of PCFs: US7,327,922, US7,155,097, US6,888,992, US7,106,932* *Photonic Bandgap fibers: US6,845,204, US7,305,164* *PM fibers: US7,289,709, US6,542,681, US6,954,574*				NKT Photonics

[5] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

PART B2: PUBLIC

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
GENERAL ADVANCEMENT OF KNOWLEDGE	MASTER THESIS, PHD THESIS RESEARCH, PROPOSALS INLINE WITH IMPROV	NO	NONE	LASERS, AMPLIFIERS				LZH
COMMERCIAL EXPLOITATION OF R&D RESULTS	MODE-LOCKED TM ALL-FIBER OSCILLATORS	NO	NONE	NEW RESEARCH PROJECTS	1. MEDICAL 2. INDUSTRIAL	2014	NO	LZH
COMMERCIAL EXPLOITATION OF R&D RESULTS	FUSED PASSIVE FIBER COMPONENTS	NO	NONE	FIBER COMBINERS, WDM COUPLER	1. INDUSTRIAL	2014	IN PROGRESS	LZH
COMMERCIAL EXPLOITATION OF R&D RESULTS	SATURABLE ABSORBER FOR 2 µM WAVELENGTH	NO	NONE	SATURABLE ABSORBER FOR LASER MODE-LOCKING	1. RESEARCH 2. INDUSTRIAL	2013	PLANNED	BATOP
COMMERCIAL EXPLOITATION OF R&D RESULTS	OP-GAAS FREQUENCY CONVERTER	NO	NONE	APPLICATION-SPECIFIC OP-GAAS CRYSTALS	1. MATERIAL PROCESSING	2014	CONSIDERED	TRT
GENERAL ADVANCEMENT	COURSES,MASTER	NO	NONE	LASERS, MATERIAL				IMEC

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[8] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
OF KNOWLEDGE	THESIS PROPOSALS, AND PHD RESEARCH ALIGNED WITH IMPROV			PROCESSING, ORGANIC ELECTRONICS				
COMMERCIAL EXPLOITATION OF R&D RESULTS	SELECTIVE PATTERNING ORGANIC MATERIALS	NO	NONE	NEW RESEARCH PROJECTS	1. ORGANIC ELECTRONICS 2. MATERIAL PROCESSING	2013, 2014	NONE	IMEC
COMMERCIAL EXPLOITATION OF R&D RESULTS	LASER INDUCED FORWARD TRANSFER (LIFT)	NO	NONE	NEW RESEARCH PROJECTS	1. PACKAGING	2014	PLANNED	IMEC
COMMERCIAL EXPLOITATION OF R&D RESULTS	LASER NANOSTRUC TURE FORMATION	NO	NONE	NEW RESEARCH PROJECTS	1. PACKAGING	2014	CONSIDERED	IMEC
COMMERCIAL EXPLOITATION OF R&D RESULTS	LASER WAVEGUIDE WRITING	NO	NONE	NEW RESEARCH PROJECTS	1. MANU-FACTURE OF PRODUCTS	2014	PLANNED	IMEC

PART B2: CONFIDENTIAL

8. Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	257894
Title of Project:	Innovative Mid-infrared high power source for resonant ablation
Name and Title of Coordinator:	Dr. Dieter Wandt

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***NO***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	**No**
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	**No**

DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	N0

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	**Number of Women**	**Number of Men**
Scientific Coordinator	0	1
Work package leaders	0	5
Experienced researchers (i.e. PhD holders)	6	17
PhD Students	0	3
Other	2	9

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**1**
Of which, indicate the number of men:	1

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	○ x	Yes No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective … Very effective
❑ Design and implement an equal opportunity policy	○ ○ ○ ○ ○
❑ Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑ Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑ Actions to improve work-life balance	○ ○ ○ ○ ○
○ Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- ○ Yes- please specify
- x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- ○ Yes- please specify
- x No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- ○ Yes- please specify
- x No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- x Main discipline[9]:
- ○ Associated discipline[9]:
- ○ Associated discipline[9]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ x	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

[9] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**10**
To how many of these is open access[10] provided?	**3**
How many of these are published in open access journals?	**3**
How many of these are published in open repositories?	
To how many of these is open access not provided?	**7**
Please check all applicable reasons for not providing open access:	
X publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[11]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

x	Increase in employment, or	x	In small & medium-sized enterprises
❑	Safeguard employment, or	x	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* **1**

[10] Open Access is defined as free of charge access for anyone via Internet.
[11] For instance: classification for security project.

Difficult to estimate / not possible to quantify	

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes x No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes x No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

x	Press Release	x	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
x	Brochures /posters / flyers	x	Website for the general public / internet
❑	DVD /Film /Multimedia	x	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

x	Language of the coordinator	x	English
x	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

1. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1.	
2.	
n	
Total	