## 3.1 Publishable summary – 2nd reporting period (09/2011 – 08/2012)

During the second reporting period, a new Tm-doped fibre oscillator system was developed at LZH, emitting 250 ps pulses at an operation wavelength of 1.98 µm. The repetition-rate was adjustable from single-shot up to the fundamental rep.-rate of the oscillator by using a fibre-coupled acousto-optical modulator. In addition, a tunable fibre oscillator by using stretching/compressing of a Fibre-Bragg-grating has been realized. In both set-ups, mode-locking was performed by using fibre-coupled saturable absorber mirrors, developed at Batop. Meanwhile, Multitel used a gain-switched laser diode as seed source for the amplification stages and investigated Thulium-doped photonic crystal fibres with 30 and 50 µm core sizes, developed by NKTP. Owing to the lack of experience in splicing PCFs fibres a first amplifier system was built employing a commercially available step-index fibre with 25 µm core diameter. The average output power was 3 Watt at a rep.-rate of 250 kHz, corresponding to a pulse energy of more than 10 µJ. This system has been delivered to Thales in February 2012 and was used as pump source for realizing the first Optical Parametric Generator operating in the 250 ps regime applying OP-GaAs crystals. In order to start ablation tests as soon as possible, Multitel prepared a picosecond infrared scribing system based on an available 1.03 µm laser source combined with a PPLN crystal provided by Thales. In addition, Thales provided a modified nanosecond laser source, tunable around 3.3 µm with output energies of 15 µJ. This system was prepared by Thales and IMEC for further resonant ablation tests at IMEC. Both laser systems were used for scribing of bulk polymer materials (PET, PEN) as well as multilayer samples (PEDOT:PSS on PET), prepared by Heliatek. The samples were investigated by different sophisticated methods at IMEC and Heliatek and a clear evidence of resonant ablation was demonstrated for the bulk polymers.

### *Project context and objectives*

High power and in particular tunable mid-infrared short pulse laser systems operating in the wavelength range between 3 µm and 11 µm have a large potential in different applications, e.g. analytics, medicine and micromachining. Up to now, those systems are only be realised by multistage set-ups consisting of bulk four or five different units, a configuration which is of course very complex and expensive with low efficiency operation. This situation has not changed over the last years, but now with the project IMPROV a solution seems to be appearing.

IMPROV focuses first on the development, investigation and realisation and 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 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. Using this laser, a promising application, namely 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 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 will be addressed in order to fully benefit of a waveguide device. This includes the development of fibre-coupled saturable absorbers, large mode area (LMA) photonic crystal fibres (PCF) with functionalities regarding wavelength tuning capability, 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 2.5 µm to 11 µm with a pulse energy of up to 30 µJ, a pulse duration between tens to hundreds of picoseconds and a repetition rate between 0.1 to 1 MHz. For validation of the developed laser source, tests concerning the processing of organic photovoltaic solar cells will be accomplished.

## *Work performed since the beginning of the project and the main results achieved so far*

**WP2: Saturable absorber and laser oscillator** 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.

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.

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, 70/30 fibre couplers at 1980 nm based on SMF28 fibres and pump combiners for 793 nm clad pumping as well have been fabricated and successfully implemented in different short-pulse fibre oscillators.

At first, we build up a Thulium-fibre oscillator based on a ring cavity, mode-locked by non-linear-polarisation evolution and operating in a pure soliton regime. 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), we used a corresponding interference filter placed inside the laser cavity. 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 $ps^2$ (provided by MULTITEL). 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.

However, the above mentioned pulse duration did not match the target of 250 ps, which we have redefined and fixed at our consortium meeting in Dresden, March 17$^{th}$, 2011. Thus, the delivered system 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 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, including a normal dispersion fibre (Nufern UHNA3) and a chirped FBG. However, due to the small bandwidth of the power spectrum, fiber length of more than 2 km is necessary to achieve the above mentioned long pulse durations. This is not suitable due to nonlinear effects in the small core normal dispersion fibre and its strong losses. 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 adjusted 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 is realised in an all-fibre configuration and based on polarisation maintaining (PM) fibres.

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.

The tunable laser should be delivered to Multitel Month 24, but there are still open questions concerning the 250 ps pulse duration in combination with the wavelength tuning. Several options have already been identified, but further experiments are necessary.

In **WP3: Photonic Crystal fibre, combiners and amplifier integration** a comprehensive study on available 2 µm off-the-shelf components has been performed by MULTITEL, which are essential for building the whole laser system operating around a wavelength of 2 µm. This include active components, like Thulium-doped fibres, signal sources and pump sources and passive components, e.g. wavelength division multiplexers, splitters, isolators, circulators, polarizers, Fibre Bragg Gratings, etc. as well. In addition, these devices have been characterized and compared to the data sheets of the corresponding manufacturer. Additionally, preliminary amplification experiments were done with existing components and light sources at MULTITEL. As seed source a soliton shifted femtosecond Erbium fibre laser has been applied with a centre wavelength around 1.85 µm. Amplification up to 1.4 Watt at that wavelength could be achieved.

NKT Photonics (NKTP) has within IMPROV developed the world's first Thulium doped photonic crystals fibers (PCF). Both a 30 µm core and a 50 µm core single mode flexible PM fiber 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 fiber 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 fiber up to 30% of the power was in a higher order mode when operated a high power.  The fiber 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 fiber where >60% have been demonstrated by Nufern on smaller core fibers. 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 fiber might not be large enough for the IMPROV demonstrators. Accordingly a 80 µm core inflexible ROD fiber has been developed, and drawn. This fiber was sent to MULT just after the end of review period 2 and will be tested in review period 3.

Finally work has begun on making a monolithic pump/signal combiner for the 50 µm core fiber. The combiner will have a step-index input fiber and can be spliced to a conventional fiber. It has a forward pumped configuration with 9 pump fibers (105/125 µm 0.22 NA) surrounding the signal fiber. Work is progressing as planned, and it is expected having the first prototype of this combiner ready by the end of 2012, which is in-line with the statement of work. The work has been reported in deliverable report D3.2, D3.3, D3.7 and D3.8, which were all handed in on time. Furthermore the work has been disseminated in two Optics Letters papers and five papers from peer-reviewed international conferences.

After receiving the oscillator from LZH, amplification tests were done at MULTITEL. Pulses were pre-amplified and chirped to have 300 mW power and 800 ps pulse duration before the amplification. Two amplification methods were compared with four different pump wavelengths. The core pumping tests showed that the shortest necessary doped fiber 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 fiber 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 fibers. The maximum slope efficiency was measured to be 28%.

The highest output power was reached by clad pumping, however the doped fiber 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. We determined the best conditions for amplification and decided that core pumping at 1270 nm will be the preferable solution.

Because of the relatively high repetition rate of the first laser received from LZH and because this first prototype was not supposed to be tunable, we decided to use (as discussed and agreed during the first review meeting) a gain-switched laser diode 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 reasons for using such fibre instead of a Photonic Crystal Fibre were principally related to practical aspects: lack of experience with the splicing of the PCF fibres and therefore we wanted to avoid a risk of splice burning during operation; no availability of a fibre system for collimating the light at the output of such a PCF fibre, or then a passive fibre will be required at the PCF output inducing additional splicing issues.

So the prototype was delivered to Thales in February 2012. We had 3 months delay with this mainly because of a fibre collimator that we received very lately. The 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.

Meanwhile the laser was at Thales, we proceeded with the splicing tests of the Photonic Crystal Fibers provided by NKT. We defined 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.

Deliverable 3.5 was completed in February 2012, when the laser was transferred to THALES. The second laser prototype was supposed to be delivered at Month 27 but could not be completed yet because of the availability of a tunable laser oscillator on one side and because we believe that for the second prototype a ROD-type fibre will be necessary for further amplification without spectral deformation.

A second laser from LZH was delivered to MULTITEL during the second hals for reporting period 2. This laser is linearly polarized and equipped with a pulse picker that permits to achieve low repetition rates. Amplification of this laser is to be tested during reporting period 3.

For the moment (beginning of reporting period 3) it is planned to provide Thales with a second prototype with 30 µm PCF output fibre for a stable mode operation. The output energy of this prototype will be equivalent to the first one. We expect only an improvement of the spatial shape. The increase of energy will be achieved with a subsequent ROD fibre amplifier.

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 in WP5 for resonant infrared ablation tests.

Finally regarding dissemination, the work on Thulium amplification has been presented in four peer reviewed international conferences: Photonics West, Photonics Europe, JNOG and Europhoton.

**WP4 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 fiber pump from MULTITEL is available, a laboratory experiment has also been set up. It is 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.

Following the first review of the project, the recommendations and requests included the following comments: “Make sure that interaction of laser light with polymer stacks is investigated soon. Lots of uncertainties in the nature of the resonant infrared ablation (RIA), especially in polymer multi-layers, should push to get experimental results on this topic as soon as possible. These studies will also help to set specifications for the source (pulse duration, energy, repetition rate, wavelength, etc…). First preliminary results requested by month 18.”

Taking this 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, the consortium decided at the end of 2011 to quickly build another laser prototype 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 in Multitel, it proved useful to enable the researchers from IMEC to also make ablation tests in their premises. To benefit from a higher pulse energy than what was available from the first planned prototype source, the consortium decided in May 2012 to modify a nanosecond laser source available at Thales also allowing moderate tunability around 3.3 µm and deliver it to IMEC.

In parallel, the first prototype planned in the Description of Work was developed by Thales. It is pumped by a 2 µm fibrer laser from Multitel, delivering 250 ps pulses at 250 kHz in a 1 nm spectral linewidth. Several recently fabricated 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.

Last but not least, the versatility of OP-GaAs crystals has been presented at a conference and emphasized in a paper with reference to the IMPROV project.

The objective of **WP5: Resonant infrared ablation for structuring OPV** is to validate the mid-infrared laser source for structuring organic photovoltaic material stacks. In the resonant infrared ablation process the wavelength of the mid-infrared laser will be tuned to one of the molecular vibrational transitions of the polymer to be ablated. For that reason, the IR absorption spectra of the prototypical materials used in an OPV were characterized in the wavelength regions that will be reached by the final laser setup. Focus was on OPV substrate materials – PET (Polyethylene Terephtalate), transparent conductive materials – PEDOT:PSS, as well as oligomeric hole transport materials – BPAPF. Attenuated total reflectance infrared spectroscopy (ATR FT-IR) was employed to characterise the substrate foils, since a measurement in transmission requires a sample thickness limited to a few tens of microns. The thin-film materials were applied on an IR transparent substrate material (e.g. NaCl or CaF2), 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. Using infrared spectroscopy the location and width of the absorption bands could be precisely determined, but it is difficult to obtain a one-to-one quantitative comparison of the strength of the absorption bands for different materials having different layer thicknesses. As an outcome, a number of potential scenarios for selective patterning was proposed, as a starting point for the experimental investigation using the mid-infrared laser.

Two experimental set-ups have been prepared, the first set-up operating in the picosecond regime, and the second set-up operating in the nanosecond regime. The picosecond resonant infrared scribing system has been prepared by MULTITEL. As explained in WP3 the laser source for his system is an off-the-shelf 1.03 µm laser source available at MULTITEL and combined with a PPLN crystal . The laser delivered 8 µJ at 3 to 3.5 µm. The pulse duration was 250 ps (the same as targeted for the IMPROV laser). The laser beam quality was very poor ($M^2$ estimated to be higher than 10!).

The nanosecond resonant infrared scribing system has been prepared by TRT and imec. Among the mid-infrared sources developed by TRT prior to the project, one of them, still available, had emission characteristics close to the needs of the IMPROV project. In order to facilitate material tests, it has been upgraded and delivered to imec. The setup is based on a commercial laser at 1064 nm pumping with ~15 nanosecond pulses at a 20 kHz repetition rate a singly resonant Optical

Parametric Oscillator (OPO) built around a PPLN crystal with several Quasi-Phase Matching (QPM) periods. Following a replacement of the mirrors forming the OPO cavity, the signal can now oscillate between 1500 and 1650 nm, corresponding to idler wavelengths from 3000 to 3600 nm. Coarse tuning can be obtained by translating the PPLN crystal, thus changing the QPM period. The crystal holder has also been modified to allow temperature control and provide some fine tuning. Taking into account the various filters used after the OPO cavity to remove the remaining pump and signal photons, this OPO delivers more than 0.3 W of mid-IR power, corresponding to 15 µJ pulses.

In both set-ups the laser beam is focussed using Si plano-convex lenses (25 and 100 mm focal length), and the sample is mounted on a motorized stage, to allow for a controlled amount of laser shots, a key parameter in thin-film patterning. Experimental studies with varying mid-infrared wavelengths, pulse energies, and scribing speeds (amount of shots) were completed in the pico- and nanosecond regime, both for bulk polymer materials (e.g. PET or PEN), as well as for multilayer OPV samples, as prepared by HELIATEK (e.g. PEDOT:PSS on PET).

The samples were investigated in detail using optical and scanning electron microscopy, optical and mechanical profilometry, and a focussed ion beam (FIB) was used for providing high quality cross-sections . The influence of the wavelength on the ablation process was studied, and clear evidence of resonant mid-infrared ablation was demonstrated for the various bulk polymer materials, in the wavelength range between roughly 2.8 and 3.6 micron. Exploiting resonant mid-infrared ablation for selective removal of organic thin-films is currently still under investigation. Initial proof of selective PEDOT:PSS removal from PET is demonstrated at a wavelength of 3.03 micron, in well agreement with results from the spectroscopic analysis. Although this is an encouraging result for further studies in reporting period 3, the required energy density for exceeding the material ablation threshold without excessive heat accumulation is around 500 mJ/cm2, which is certainly challenging to achieve.

### *The expected final results and their potential impact and use*

The overall aim of the project is the development, realisation and investigation of a highly integrated reliable, compact short-pulse Mid-infrared laser system based on a mode-locked Thulium fibre laser pumping a nonlinear wavelength conversion unit and its validation concerning Resonant-Infrared-Ablation of Organic-Photovoltaic-Devices.

The project IMPROV is driven by an industrial application that has a potential of large economical and societal impact. Indeed, a method for fabricating flexible organic solar cells can be an advance for European citizen through many every day life products. 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 Organic Light Emitting Diodes (OLED) or Organic Thin Film Transistors (OTFT) and other functional products like stents, particles filters etc.. Beyond micromachining other applications in the field of spectroscopy and medicine can also benefit from the advances in the project IMPROV.

The homepage of the project IMPROV can be found at:

http://www.fp7project-improv.eu