1. Publishable summary

Project context and objectives

www.isla-project.eu
Fibre lasers have already had a major impact in the marketplace for laser products. Their small size, flexibility and high power has proved highly desirable and the range of applications is growing all the time, ranging from sensing and measurement to cutting and marking. Most fibre lasers operate at around 1 μm because there are high power pump diodes and an array of technology building blocks developed for erbium-doped fibre amplifiers (EDFAs) which make this a convenient and low cost route to fibre laser sources.

The ISLA consortium believes that fibre lasers emitting radiation at around 2 μm will have an increasingly important role to play in this rapidly expanding market. Two micron fibre lasers offer a clear route to higher power fibre lasers and can be built using established silica fibre technology. The ISLA project has worked on the development of an integrated modular common platform of fibre and components to support high power CW SM, Q-switched pulsed and sub-ps pulsed lasers.

In this summary, the key elements of the project are briefly reviewed and the objectives defined. Readers wishing to know more about the project are invited to contact the individuals identified for each technology area.

Technical objectives

Rare-earth-doped fibres
ISLA worked on the optimisation of the core composition to enhance the cross-relaxation process in Tm-doped silica fibres to realise efficiencies close to the theoretical limit. This required a carefully tailored host core composition to allow the incorporation of a high concentration of rare earth ions and to avoid unwanted parasitic spectroscopic processes.

ISLA also optimised Ho-doped silica fibres for in-band pumped Ho fibre lasers. A family of compatible fibres were developed in SM, PM and photo-sensitive variants to provide a broad platform for integrated ISLA devices operating in CW and pulsed modes.

Fibre-coupled isolators
The weak Verdet constant and high loss of traditional optical isolator materials (e.g. TGG; terbium gallium garnet, BIG; bismuth iron garnet) at 2 μm make isolators a critical component for 2 μm lasers. ISLA explored newly available materials and new disruptive designs to provide fibre-coupled prototype isolators in the 2 μm region.

Fibre-coupled modulators
ISLA developed modulator devices as part of an integrated platform, so that these devices may be combined with other components to simplify design and improve performance. These included a specialised acousto-optic tunable filter (AOTF) for laser tuning with greatly reduced sidelobes, and several AO modulators for operation at various power levels.

Nanocarbon-based modelockers
Nanocarbon-based composites offer an exciting disruptive technology for saturable absorber modelockers which may be made using low cost laboratory techniques. These devices offer considerable advantages over SESAMs (semiconductor saturable absorber mirrors), the preferred modelocker technology at 1 μm, e.g. a much broader tuning range, large absorption cross-section, and fast time constants to support sub-picosecond pulse formation.

Fibre-coupled bulk optic components
Using both commercially available fibres and the fibres developed in the project, a set of fused fibre components optimised for the ISLA fibre lasers were developed for single-mode (SM), multimode (MM) and polarisation maintaining (PM) fibres. These fused components have been developed to provide system elements (e.g. taps, WDMs) as well as high power pump combiners (e.g. 19×1 combiners, 6+1×1 combiners etc.) as an integral part of an integrated common platform.

Laser pump diodes
In the ISLA project several novel techniques were investigated by II-VI to improve the threshold currents and efficiency of laser diodes at 79x nm. Power levels of 4 W and higher from 100 µm stripe width were targeted during the project; twice that of reported devices to date. In fact 12.5 W in CW operation for 94 µm wide broad-area single-emitters and 19.5 W qCW operation has been achieved.

Integrated fibre laser design and demonstration
To demonstrate the technology platform developed in the ISLA project, three Demo Lasers were planned:

- Demo Laser 1 500 W CW SM 2.0-2.1 µm Ho-doped fibre laser
- Demo Laser 2 ns-pulsed 2.0-2.1 µm Q-switched fibre laser
- Demo Laser 3 100 W sub-ps SM ~2.1 µm Ho-doped fibre power amplifier

Dissemination activities

- Dissemination of project results to industry, the public and investment communities
- Public website with project presentation, video and information
- ISLA Advisory Group (IAG)

Main S&T results

The ISLA project finished at the end of June 2015. Over the last three and a half years the project has had a major impact on the development of components for 2 µm fibre lasers.

Fibre

- Thulium fibres with 70% slope efficiency at >100 W output
- Holmium fibres with 75% slope efficiency

Recently the ORC has started to sell research-grade fibres through its Zepler Institute (http://www.zeplerinstitute.com/fibre) and Tm and Ho fibres derived from the ISLA project will soon be commercially available for R&D from the ORC. This is relatively small volume production in order to stimulate research and collaborative work with industry and end-users. The plans to take this forward (particularly the Tm fibres) have already attracted significant interest, but the details are still confidential.

- Fibre OH contamination reduction
- CO_2 preform milling process

These processes have already attracted a great deal of interest (e.g. following the Munich conference and workshop in Jun-2015) and are both fantastic enabling technologies. It is hoped that ORC can either licence this technology or undertake work on a sub-contract basis.

Passive components

- Fused fibre components optimised for 2 µm

G&H has already advanced the technology developed in ISLA to produce new products, and a range of fused components for 2 µm are now available from the G&H website, including (other custom products are available on request):

  - High power pump combiners
  - WDM components (including PM)
  - Wavelength-flattened couplers

- Fibre-coupled isolators (FIBO & FIFO)

G&H has developed a flexible isolator platform based on new Faraday materials, providing over 30 dB isolation, low insertion loss and 30 W power handling in a fibre-in, fibre-out version. See the Proc. SPIE **9346**, 93460O (2015). More information is available on request.

Modulators

During the ISLA project, Gooch & Housego (UK), based in Ilminster, has successfully developed a number of acousto-optic (AO) devices specifically for operation in the 2 µm region. These components include new types of modulators and novel tuneable filters.

- General-purpose AO modulator based on tellurium dioxide (TeO_2)
- AO modulator (AOM) based on chalcogenide glass
- Narrow resolution AO tuneable filter (AOTF)
- Zero frequency shift AOTF

These devices are already available as either data-sheet products, or as custom devices, from G&H (UK). More information, is available from the website (www.goochandhousego.com).

Modelockers

Know-how in the manufacture and characterisation of graphene and related materials, and the understanding of the underlying physics have led to a number of journal publications, and this high profile work is ongoing. Specific examples include:

- Graphene saturable absorber mirror (SAM) design
  - Patent application in progress
- Reduced noise measurement technique for non-linear materials (I-Scan)
  - Improved graphene deposition methods
  - Drop-casting
  - Vacuum filtration film method

All these improved processes will be taken up by the TCD research group, and will be applicable for other wavelength domains.

Pump diodes

Within the ISLA project, II-VI Laser Enterprise (formally Oclaro Switzerland) has developed pump laser diodes at 79x nm that are optimised for pumping thulium (Tm) doped double-clad fibres. High power conversion efficiency in excess of 60% was demonstrated. For high power applications such as thulium fibre laser pumping, an output power of more than 12.5 W in CW operation for 94 µm wide broad-area single-emitters and 19.5 W quasi-CW (qCW) operation has been achieved.

Wavelength stabilisation of these laser diodes was accomplished by using a distributed feedback grating (DFB). 60% power conversion efficiency was also achieved in these stabilised devices. Locking has been obtained over the full current range between 1 A and 6 A tested so far with some margin for temperature variation.

For efficient fibre laser pumping the laser diodes were integrated in a multi-emitter platform, achieving 38 W out of a 105 µm fiber within 0.15 NA.

Laser development

Demo Laser 1 (CW laser)

The ISLA 0.5 kW CW 2 µm laser is currently being integrated at ORC, built from components made during the project. It will reside in Southampton until the end of 2015, and will be used for

further research into high power 2 µm sources. Several papers are expected from the application, characterisation and study of this world-beating source.

The CW laser will then be shipped to Rofin in Jan-2016 and there will be six months of testing under industrial conditions in the Applications Laboratory in Hamburg. This will be an opportunity to re-engage with several organisations contacted during the ISLA project that were very interested in industrial testing of high power 2 µm lasers. It will also be an opportunity for Rofin to demonstrate the advantages of the technology and begin to develop the 2 µm market with its existing customers.

Demo Laser 2 (ns-pulsed laser)
ISLA Demo Laser 2 targeted a ns-pulsed 2 µm laser. Laser pulses with a length of 2.5 ns at a repetition rate of 150 kHz have been generated from a passively Q-switched microchip laser. This laser consists of a Tm:YAP crystal and a SESAM Q-switch carefully matched to allow lasing only in a narrow spectral range around 1950 nm. At a resonator length of only 2.5 mm, this enables the generation of regular pulse trains with high repetition rate and short pulse duration.
This solid-state microchip laser can then serve as a seeder for a Tm fibre amplifier using the components developed within the ISLA project, boosting its output power from less than 100 mW to the 10 W range.

Demo Laser 3 ps-pulsed laser
The building of ISLA Demo Laser 3, a SM ps-pulse master oscillator power amplifier (MOPA), is underway. Unfortunately it was not possible to complete the integration within the project timescale, but the work continues using components from the ISLA partners. A CW oscillator has been implemented to verify the functionality of the ISLA components. The ISLA team is currently focused on achieving mode-locking of the oscillator and integrating it with an industrial grade housing which also accommodates the fibre-coupled AOM (from G&H), the pulse stretcher and pre-amplifiers stages. Integration is one key to robustness and transportability allowing for efficient demo activities.

ISLA workshop

For a detailed summary of the project, the reader is directed to the slides from the ISLA workshop, which was held 26-Jun-2015 in Munich. The slides from the workshop are available from the project public website: http://isla-project.eu/outputs/isla-workshop/

ISLA at Photonics West 2016

As a direct result of the success of the workshop, ISLA was invited to have a dedicated session on the project at Photonics West 2016 (San Francisco, USA; Feb-2016). It will be part of LASE conference LA105 “Component and packaging for laser systems” and will consist of four presentations on ISLA results. Details should be announced in Sep-2015.

Please see the project website (www.isla-project.eu) for more details.