VERSATILE INFRARED LASER SOURCE FOR LOW-COST ANALYSIS OF GAS EMISSIONS

DELIVERABLE D1.4

Pulsed Tm-doped fibre master-oscillator power-amplifier

Project co-funded by the European Commission

within the Sixth Framework Programme (2002-2006)

Project acronym & number: VILLAGE – 034010
Project name: Versatile Infrared Laser source for Low-cost Analysis of Gas Emissions
FP6 Action Line: IST-2005-2.5.1 Photonic components
Project start date & duration: 01/07/2006 for 3 years, extended to 30/11/2009
Contract Type: Specific Targeted Research Project
Consortium members:

Participant name	Short name	Country
Thales Research & Technology (Coordinator)	TRT	France
Norsk Elektro Optikk	NEO	Norway
Heinrich-Heine Universität Düsseldorf	HHUD	Germany
University of Southampton	ORC	United Kingdom
Universidad de Valladolid	UVA	Spain

Dissemination level for present deliverable: PU
Delivery date: 24/07/2008

Project web site: http://www.neo.no/village/.

CONTENTS

Pages :

1. INTRODUCTION

The threshold pump power for a continuous-wave singly-resonant optical parametric oscillator (SRO) based OP-GaAs is estimated to be in the region of 50 – 80 W taking into account current values for loss and effective nonlinear coefficient for the OP-GaAs samples fabricated by Thales. This far exceeds the output power that has so far been demonstrated from a single-frequency Tm fibre source and the development of such a source is beyond the scope of the Village project. To remedy this problem it is necessary to use a slightly more complicated SRO design in which the pump light is also resonated to increase the intracavity pump power in ordeer to reach threshold. This has the attraction that a much lower power Tm pump laser can be employed providing that the resonator losses are low. An alternative approach is to use a pulsed pump laser exploiting the long upper-state lifetime of the gain medium to achieve much higher peak power that when operating in cw mode. In this way it should be possible to reach threshold for the SRO with relatively low average pump power and hence minimize heat loading in the OP-GaAs crystal. In order to achieve narrow-line width output from the SRO with well-behaved characteristics, the pump pulse must be long enough for quasi-cw pumping. Crude estimates suggest that pulse durations of ~ 1 µs (or longer) are needed. One of the tasks of Work Package WP1 is to identify a suitable approach for achieving the desired pulse output for quasi-cw pumping of an SRO and to produce a prototype source (Deliverable D1.4) planned for T0+21.

There are two main approaches for producing a pulsed output from a DFB fibre laser. The first is via the use of an external modulator and subsequent amplifier stages exploiting the high small single-gain in the amplifiers to achieve higher peak power than when operating in cw mode. This approach has that attraction that the pulse shape can be controlled using the external modulator, but has the disadvantage that it requires more amplifier stages to reach a given peak power and is therefore more complicated and less efficient. The second approach, and the main focus of our work, is to use the technique of gain-switching to achieve a pulsed output from the fibre DFB laser followed by the necessary amplification stages. This approach has the attraction of simplicity and higher efficiency, but has limited flexibility in terms of pulse duration.

2. GAIN-SWITCHED DFB FIBRE LASER

The experimental set-up for the gain-switched Tm DFB fibre laser is shown in figure 1. Pump power was provided by a 10 W Er,Yb fibre laser operating at 1565 nm, and was coupled into the Tm DFB fibre laser via an acousto-optic modulator. The latter was used to modulate the pump beam to achieve the required pump pulses for gain-switching the DFB laser. The Tm fibre used in the DFB laser has a ~10 µm Tm,Ge co-doped alumino-silicate core with a Tm concentration of approximately 1 wt.%. The DFB laser was approximately 8 cm long and the end facets were angle-cleaved to suppress broadband feedback due to Fresnel reflection. The maximum pump power launched into the DFB was ~8 W. Figure 2 shows a typical pump pulse and the resulting gain-switched pulse from the DFB laser at the maximum pump power. Figure 3 shows gain-switched pulse shapes as a function of absorbed pump power. It can be seen that the pulse duration decreases with pump power from ~190 ns (FWHM) at 0.66 W of absorbed pump power to ~45 ns (FWHM) at the maximum absorbed pump power of 5.3 W. There is a corresponding increase in peak power from 0.2 W to ~4.4 W (see figure 4). Thus, there is a significant increase in the peak power over the maximum output power that can be achieved in cw mode.

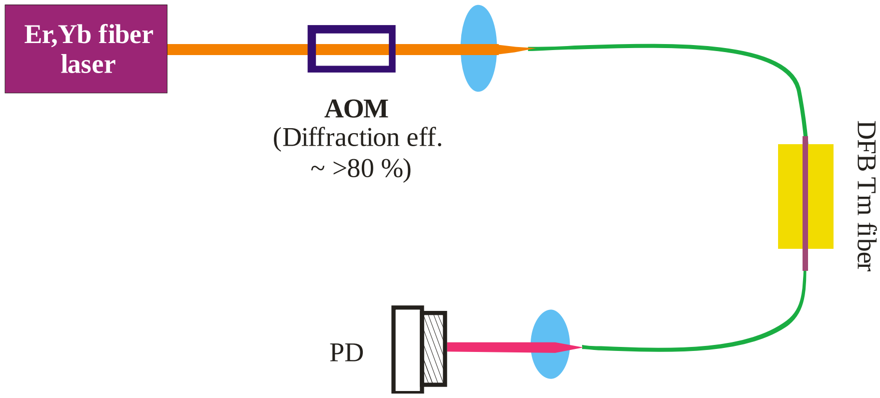

Figure 1: Schematic diagram of the experimental set-up

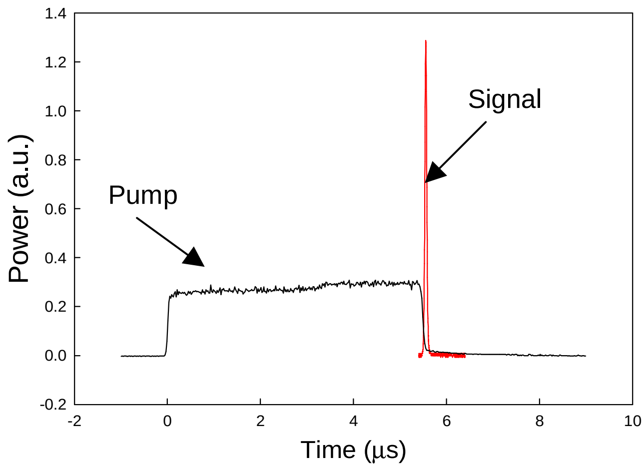

Figure 2: Pump pulse and gain-switched pulse.

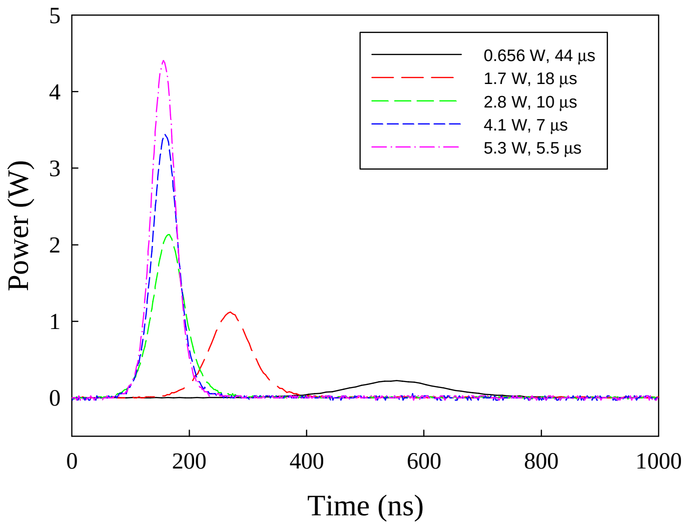

Figure 3: Temporal shape of the output pulses as a function of absorbed pump power.

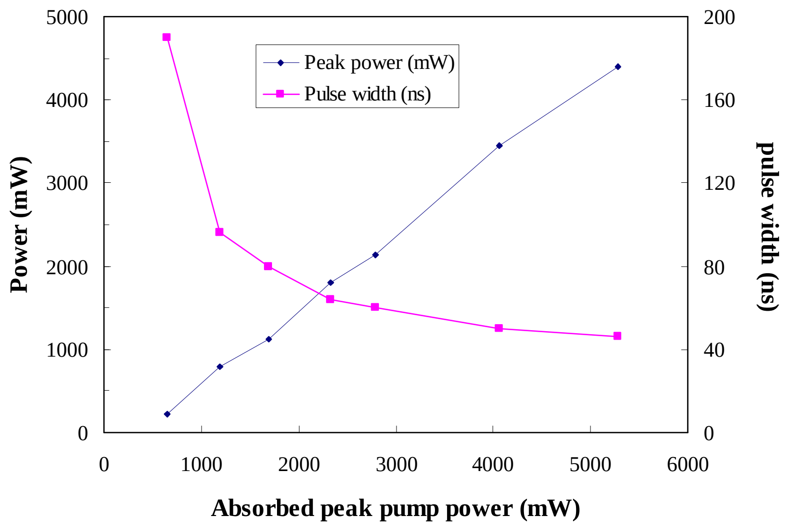

Figure 4: Gain-switched peak power and pulse width versus absorbed pump power

3. GAIN-SWITCHED DFB FIBRE LASER WITH SINGLE AMPLIFIER STAGE

A further increase in peak power can be achieved using a simple Tm fibre amplifier stage directly spliced to the DFB fibre and pumped by the zero-order pump beam (see figure 5). This approach exploits the relatively long energy storage time in the Tm fibre amplifier compared to the pump pulse duration required for gain-switching the DFB laser. At the maximum pump power, we obtained a peak power of ~30 W. A second amplifier stage should allow scaling of peak power to the kilowatt regime.

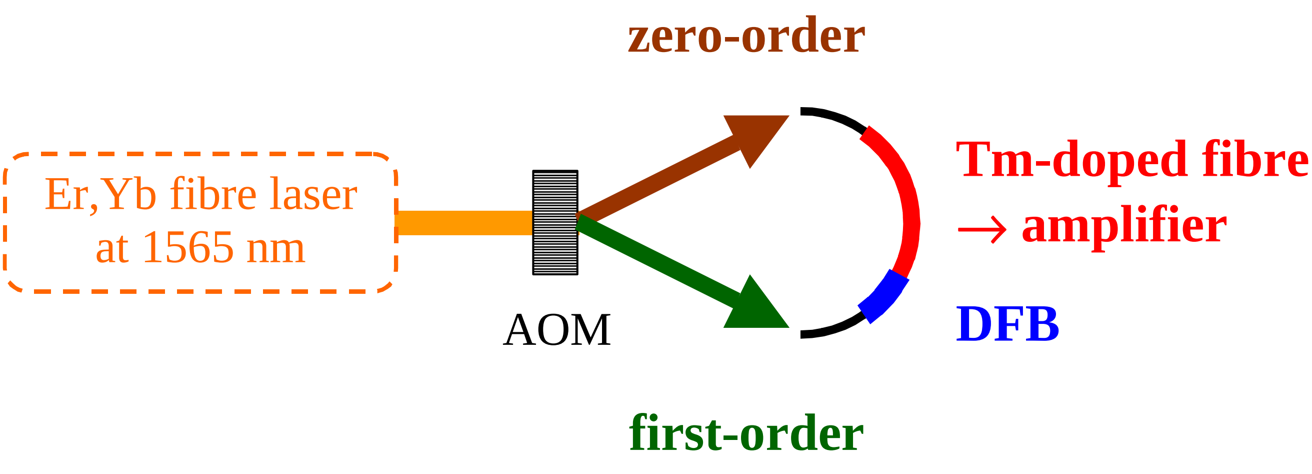

Figure 5: DFG fibre master-oscillator power-amplifier

4. STRATEGIES FOR IMPROVING PERFORMANCE

The peak power obtained from the gain-switched DFB MOPA is more or less in-line with expectations and with the provision of an additional power amplifier stage could be increased to a power level well beyond the threshold pump power for a quasi-cw SRO based on OP-GaAs. However, the pulse duration at the highest available pump power is much shorter than required to for quasi-cw operation. Hence delivery of the pulsed DFB MOPA was postponed and further studies to remedy this problem are ongoing.

The first stage of this work was to establish a theoretical model for gain-switched DFB laser performance to see if the experimental results are in agreement with theory and to allow the formulation of a strategy for increasing pulse duration and pulse energy. Figure 6 shows the peak power as a function of absorbed pump power for a typical gain-switched DFB laser. It can be seen that the predicted values for peak power are in very close agreement with the measured values confirming the validity of the model. Figure 7 shows predicted and measured values for the pulse duration as a function of absorbed power. Once again, it cab be seen that there is reasonable agreement although the predicted values for pulse duration are just under a factor-of-two shorter than the measured values.

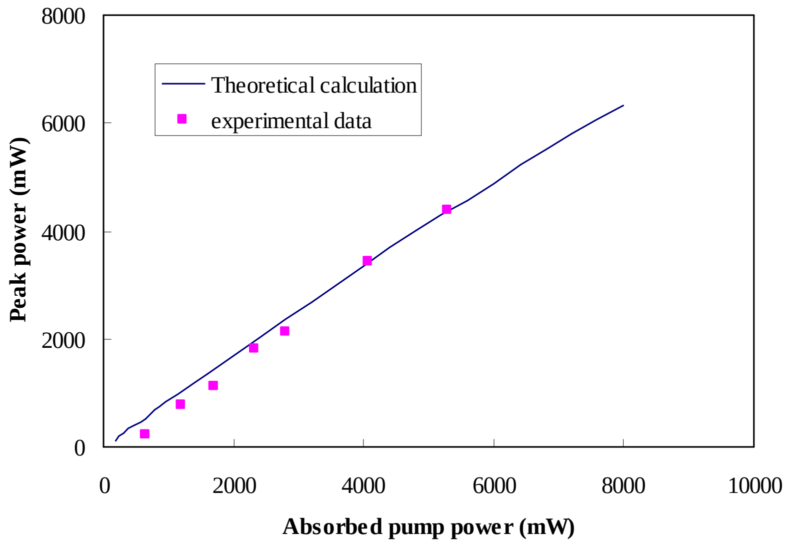

Figure 6: Peak power versus absorbed pump power for a gain-switched Tm DFB laser.

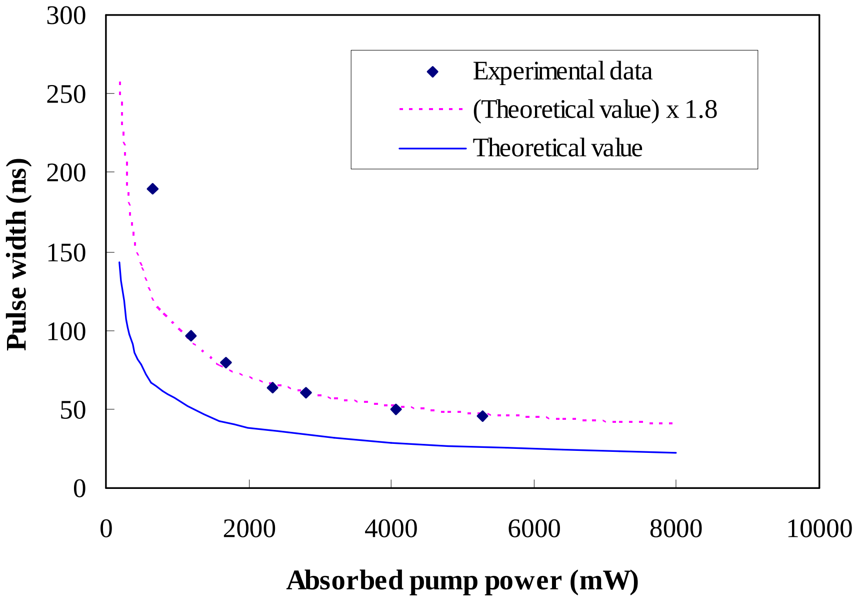

Figure 7: Pulse width versus absorbed pump power for a gain-switched Tm DFB laser.

As a rough guide the pulse duration for a gain-switched fibre laser varies with core diameter, D and resonator length, L according to:

$$\tau_p \propto D\sqrt{\frac{L}{P_p}}$$

where P_p is the absorbed pump power. Thus, to increase the pulse duration we need to employ a longer resonator and/or a Tm fibre with a larger core diameter. In the case of a DFB laser configuration it is extremely difficult to increase the cavity length whilst maintaining robust single-frequency operation, so the only practical solution worth pursuing is to increase the core diameter. Figure 8 shows the calculated pulse width as a function of core diameter for the Tm DFB laser. It can be seen that core diameters ~100 µm would probably be needed to achieve pulse durations 500 ns. This would require a special large-mode-area fibre design with carefully tailored refractive index, Tm and Ge doping profiles to provide adequate suppression of higher-order modes. The development of such fibres would require a significant fibre fabrication effort and hence may not be achievable within the timescale of the Village project.

An alternative approach is to use a Distributed Bragg Reflector (DBR) cavity configuration with a very long resonator length. In this approach feedback for lasing would be provided by the 3.6% refraction from a perpendicularly-cleaved fibre end fact at one end of the fibre and, at the opposite end, by a relatively long fibre Bragg grating (> 20 cm) to give the required output spectral characteristics.

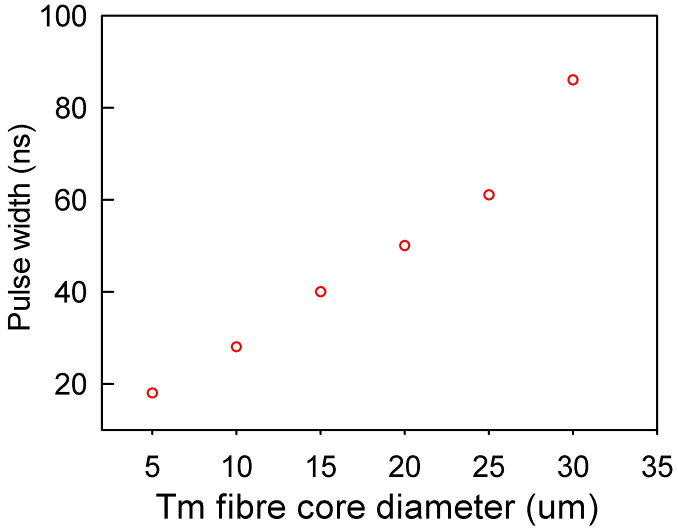

Figure 8: Calculated pulse width as a function of fibre core diameter for a Tm DFB laser.

5. PRELIMINARY RESULTS

A preliminary investigation of this approach has been conducted using a simple fibre laser configuration comprising 30 cm of Tm doped fibre spliced to a longer length of undoped fibre with feedback for lasing provided by a perpendicularly-cleaved facet at the output end (adjacent to the Tm doped fibre) and a simple external feedback cavity containing a high reflectivity mirror at the opposite end of the fibre. The laser was pumped using the same pump source and pumping arrangement as was used for the Tm DFB laser (shown in figure 1). Figure 9 shows the pulse shape for a 28 m long undoped fibre as a function of pump power. It can be seen that pulse durations ~1 μs can be achieved even at the highest available pump power.

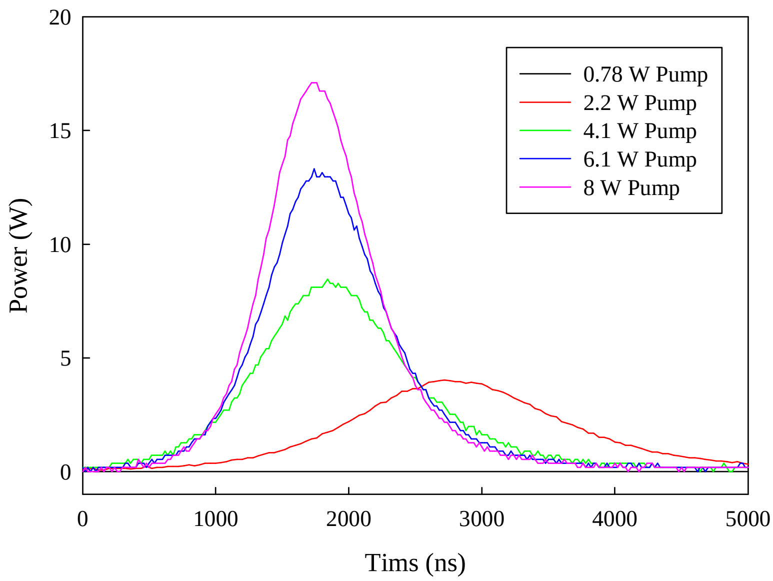

Figure 9: Gain-switched pulse shape for different absorbed pump powers.

Figure 10 shows the pulse width and peak power as a function of fibre length at the highest available pump power. The maximum pulse width of ~900 ns (FWHM) was obtained for the longest fibre length (i.e. 28 m) and the peak power was ~17 W. Thus, this approach does appear to offer a route to the longer pulse durations required for quasi-cw pumping of an OP-GaAs SRO. The next stage of this work will investigate the effect of FBG length on linewidth and investigate wavelength tuning. The results of this study will be used to help formulate a design strategy for the DBR laser.

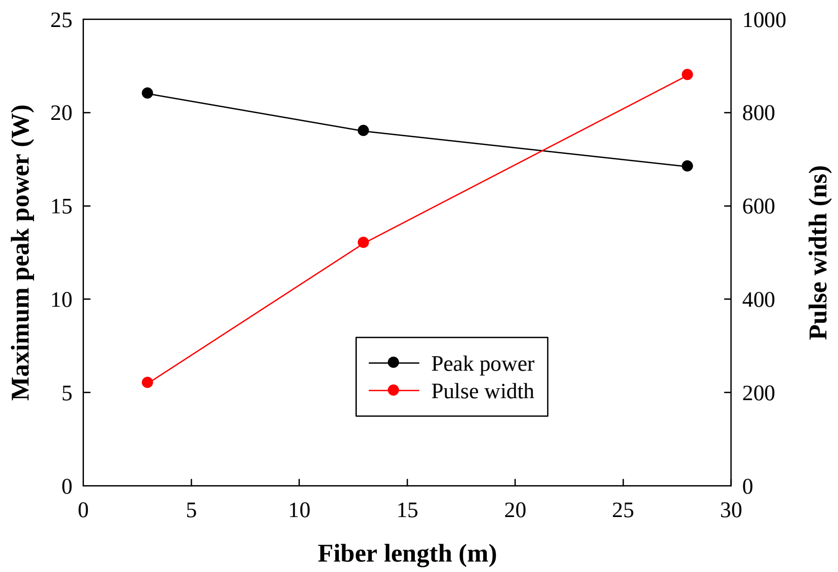

Figure 11: Peak power and pulse width versus fibre length for gain-switched Tm fibre laser.

6. PLANNING UPDATE

Gain-switched operation of a Tm DFB fibre laser offers an attractive route to higher peak powers than can be achieved in cw mode, but the pulse durations are much smaller than required for quasi-cw pumping of an SRO based on OP-GaAs. For this reason, an alternative laser design based on a long DBR laser configuration is being pursued. Preliminary experiments have already confirmed that pulse durations ~ 1 µs can be obtained via this approach. However, achieving narrow-linewidth (< 50 MHz), as required by the Village project, may prove to quite challenging so further work is needed to confirm the viability via this approach.