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

DELIVERABLE D1.1

CW Tm-doped DFB single-frequency fibre laser

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University of Southampton	ORC	United Kingdom
Universidad de Valladolid	UVA	Spain

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1. INTRODUCTION

Following the preliminary analysis carried out during the first six months of the project (see Deliverable D3.1), two prototypes have been planned at T0+9 to enable the implementation of the first mid-infrared source, based on DFG, expected at T0+12 from Work Package WP3:

- A first continuous wave Tm-doped DFB single frequency fiber laser from Work Package WP1, which is discussed in the present report.
- A first orientation-patterned GaAs (OP-GaAs) crystal from Work Package WP2, described in Deliverable D2.1.

2. PROTOTYPE DESCRIPTION

The first DFG experiment, targeting a methane absorption line in the vicinity of 7.67 µm, requires a Tm-doped DFB single frequency fiber laser with limited tunability (~ 1nm) around 1943 nm. The fiber required for this DFB laser was fabricated in-house via the modified chemical vapour deposition and solution doping technique. The resulting fiber had a Tm-doping concentration of ~ 1wt.% and a core diameter of ~ 10 µm. The core was co-doped with germanium to make it photosensitive to allow UV writing of the Bragg grating. The fiber was initially tested in a simple laser configuration with a high reflectivity mirror butted to one end of a 20 cm length of fiber and a perpendicularly-cleaved facet at the opposite end to form the laser resonator. The fiber laser was pumped in-band by an Er,Yb fiber laser at 1565 nm and generated multi-watt output power with a slope efficiency of ~ 80%. These results were in-line with our best expectations. The photosensitivity of the fiber was measured and found to be at the lower limit of that necessary for fabricating DFB fiber lasers.

2.1. First prototype DFB fiber laser

The Tm-doped DFB fiber laser set-up used in our experiments is shown schematically in Fig. 1. Pump light was provided by an Er,Yb-doped fiber laser with up to 10 W of output in a diffraction-limited single-spatial-mode (M^2 < 1.1) beam at 1565 nm with an emission bandwidth of < 2 nm (FWHM) supplied by SPI Lasers Ltd. The DFB grating was written directly into the core of the fiber using a phase-mask technique and a phase mask of period 1340 nm. The resulting DFB grating was ~ 8 cm in length with a π-phase-shift located 5 mm from the mid-point of the grating to achieve a predominantly single-ended output from the fiber end closer to the π-phase-shift. After writing, the grating was annealed for 24 hours at 100°C to stabilise the refractive index modulation, and the final grating strength (κL) was estimated to be ~ 8. Pump light from the Er,Yb fiber laser was launched into the core of Tm-doped DFB fiber laser via a standard single mode delivery fiber (core diameter ~ 9 µm and NA ~ 0.14) which was spliced to the Tm-doped DFB laser at the end opposite the main output. Launching of pump light into the core of the delivery fiber was achieved with aid of a simple two-lens focusing arrangement (shown in Fig. 1) yielding a launch efficiency of over 82%. The pump input end of the delivery fiber and the signal output end of the DFB Tm fiber were angle polished at ~ 10° to reduce unwanted feedback from the fiber end facets due to Fresnel reflection to prevent parasitic broadband lasing from the end-facets. To facilitate heat removal and minimise the risk of thermally-induced damage, the entire length of the Tm fiber was embedded in a V-groove of an aluminium heat-sink with the aid of thermally-conducting grease.

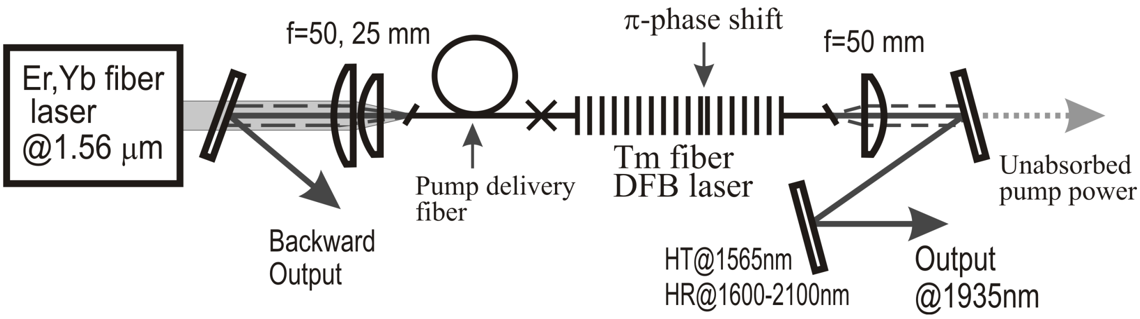

Fig. 1. Experimental set-up for the single frequency DFB Tm-doped fiber laser.

The output power from the Tm DFB fibre laser in the main output (forward) direction, reverse direction and the total (combined) output power as a function of absorbed pump power are shown in Fig 2 (a). The laser reached threshold at an absorbed pump power of ~50 mW and generated 318 mW of output in the forward direction for ~ 1.7 W of absorbed pump power, corresponding to an average slope efficiency of 21%. It can be seen that the output power increases linearly with the pump power at low power levels with a higher slope efficiency of ~ 24%, but begins to 'roll-over' when the pump power exceeds 1.5 W. Preliminary studies suggest that this behaviour is related to the non-uniform temperature distribution along the fiber (due to the non-uniform pump deposition density and quantum defect heating) and its impact on the grating feedback characteristics. Further studies to establish the physical mechanism and ways to alleviate the problem are on going. The maximum output power in the reverse direction was ~107 mW for 1.7 W of absorbed pump power. Further optimisation of the DFB design and position of the π-phase-shift should yield a further reduction in the reverse direction power in favour of increased output power in the forward direction.

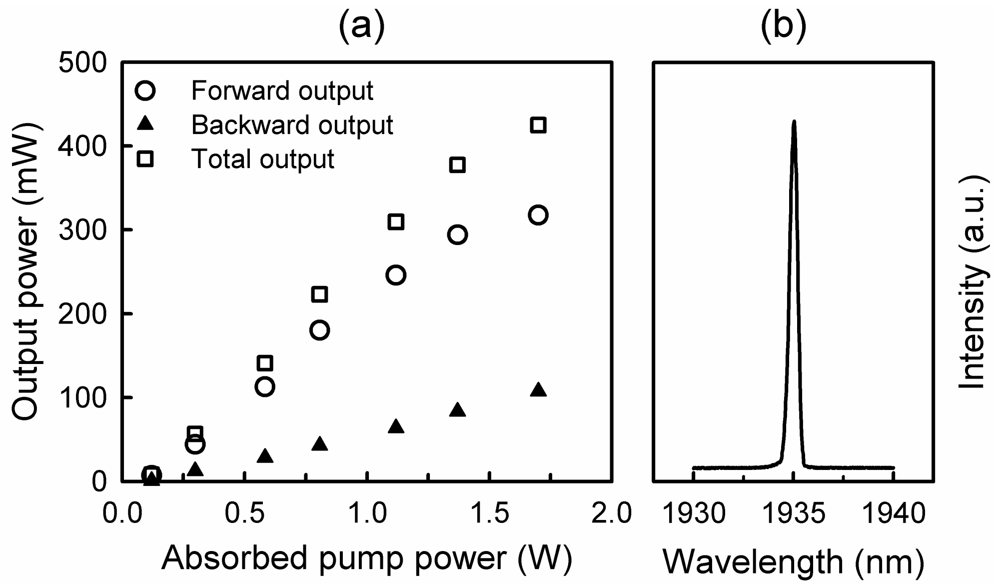

Fig. 2. Performance of the DFB Tm fiber laser:
(a) output power as a function of absorbed pump power; (b) output spectrum.

The lasing wavelength was measured with the aid of a scanning monochromator to be 1935 nm (as shown in Fig. 2(b) and narrow linewidth operation was confirmed with the aid of a scanning Fabry-Perot interferometer with a free spectral range (FSR) of 7.5 GHz and finesse of 100.

Careful inspection of the frequency spectrum revealed that the DFB fiber laser was oscillating on two orthogonally-polarised modes with a relatively small frequency spacing of ~ 660 MHz. This behaviour can be attributed to the residual birefringence in the fiber and the absence of any polarisation discrimination.

2.2. Second prototype DFB fiber laser

A second prototype DFB laser was fabricated using the information gained from the first device to allow the grating pitch to be optimised for operation at the target wavelength of 1943 nm. The experimental set-up was very similar to that shown in Fig. 1.

The resulting DFB was tested and was found to operate at the correct wavelength (i.e. 1943 nm) and yielded a much higher output power (> 600mW) than the first prototype (see Fig. 3). This is the highest output power that has so far been demonstrated from a Tm-doped DFB laser in this wavelength regime. The laser has now been completely characterized and will now be incorporated in the package designed for delivery to HHUD, as discussed in the next paragraph.

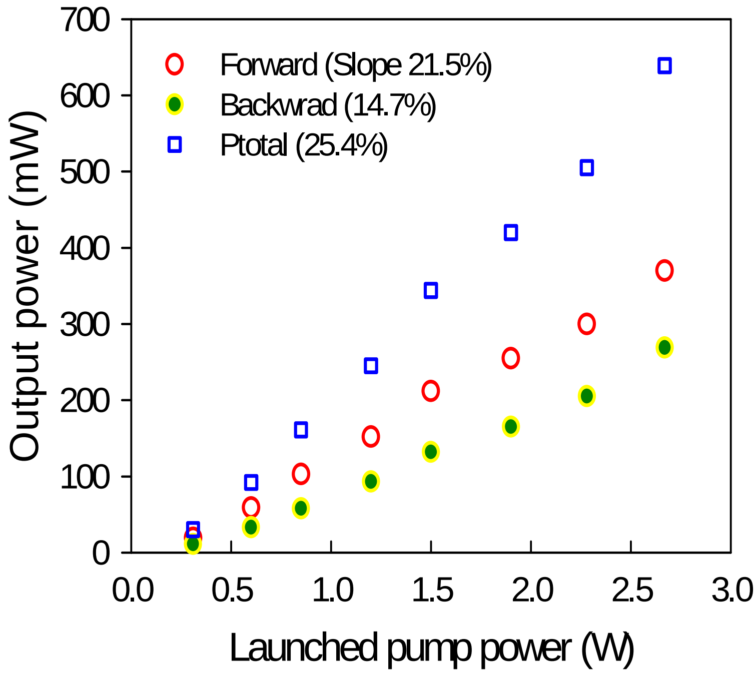

Fig. 2. Output power as a function of pump power from the second prototype DFB fiber laser.

3. CONCLUSION

The Tm-doped DFB single-frequency laser from Work Package 1 has been assembled in a test configuration and tested. Its performance is in-line with our best expectations and the device is currently being re-packaged for HHUD.