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

DELIVERABLE D1.7

Tunable continuous-wave Tm-doped fibre Master-Oscillator Power-Amplifier (MOPA)

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CONTENTS

Pages :

1. INTRODUCTION

Following the demonstration and delivery of a relatively high-power single-frequency Tm-doped fibre master-oscillator power-amplifier (MOPA) (Deliverable D1.2) to HHUD, much of the effort in Work Package WP1 has focussed on improving overall performance with regard to the output power, stability and wavelength tunability. Earlier versions of the Tm fibre MOPA were based on a DFB laser oscillator with two orthogonally-polarised axial modes. Thus, to obtain a single-frequency linearly-polarized output from the MOPA system it was necessary to remove one of the modes using a polarizer immediately before the final amplifier stage. However, this approach was found to have a number of shortcomings. The main issue was competition between the orthogonally-polarised modes in the DFB. This resulted in poor power stability for the selected mode and on a few occasions resulted in damage to the isolator due to parasitic lasing in the final amplifier when the seed power was too low. The need for a polarizer and hence free-space optics between the pre-amplifier and power amplifier stages exacerbated the power-stability problem by virtue of the launched power into the final amplifier stage being very sensitive to alignment and hence mechanical vibrations and temperature fluctuations. To remedy this problem it is necessary to fabricate a DFB laser with internal discrimination between orthogonally-polarised modes. Work aimed at achieving this goal is ongoing. In the meantime, we have also pursued an alternative strategy for achieving a linearly-polarised single-frequency output based on a distributed-Bragg-reflector (DBR) cavity configuration. In this scheme, fibre-Bragg-gratings (FBGs) are written into polarisation-maintaining (PM) and non-PM Tm-doped fibres with slightly different periods selected so that reflectivity peak for the non-PM FBG occurs at the same wavelength as the reflectivity peak for one polarisation direction for the PM FBG. The two fibres are then spliced together to form a simple laser resonator with a short section of Tm fibre with out a grating between the two FBGs. This approach has the drawback that the wavelength tuning range is less than for a DFB laser, but nevertheless has proved to be a good temporary solution allowing the construction of Deliverable D1.7.

2. MASTER-OSCILLATOR POWER-AMPLIFIER PROTOTYPE DESCRIPTION

2.1. Tunable DBR laser with single amplifier stage

The Tm-doped fibre DBR laser was constructed from photosensitive polarization-maintaining (PM) and non-PM Tm fibre. Both fibres were fabricated in-house starting with the same perform to give nearly identical core composition in the two fibres. Each fibre had a Tm-Ge co-doped alumino-silicate core with a core diameter of ~10 µm and a numerical aperture (NA) of ~0.17. A relatively high Tm concentration (~ 1 wt.%) was used to allow efficient absorption of pump light at 1565 nm in a short length of fibre. Fig. 1(a) shows the Tm fibre DBR laser structure. A 3cm long high reflector (HR) fibre Bragg grating (FBG) was written in the non-PM Tm fibre, with a 3dB bandwidth of ~6GHz (see Fig.1(b)), and a 2cm long output coupler (OC) FBG was written in the PM Tm fibre. The transmission spectra for the two gratings are shown in Fig. 1(b). The OC grating has two transmission dips corresponding to orthogonal polarisations and the centre wavelengths of the HR and OC gratings were slightly different. The HR and OC gratings were fusion spliced together with a ~1cm long length of Tm fibre between the gratings. The total length of the DBR structure was 6 cm, corresponding to a longitudinal-mode-spacing >1.6 GHz. Hence, the DBR cavity could support no more than three longitudinal modes. A linearly-polarised single-longitudinal-mode output could be selected by simply adjusting the temperature of either grating (see Fig. 2).

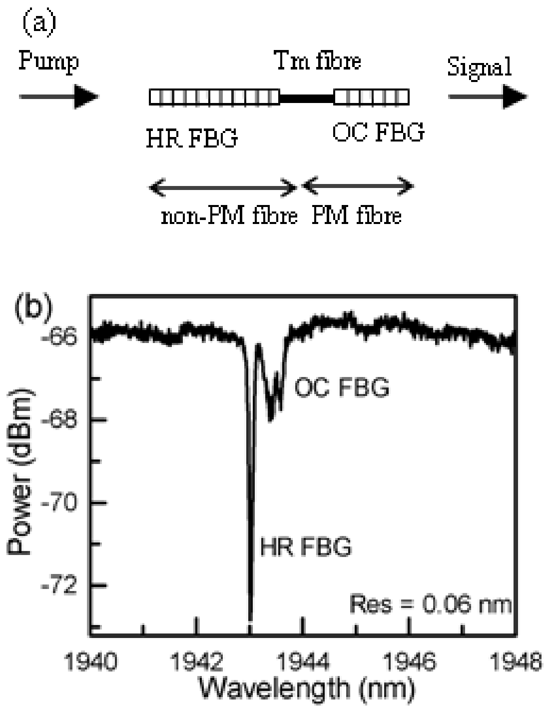

Fig. 1 (a): Tm DBR fibre laser structure, (b) Measured transmission spectra of the HR and OC FBGs.

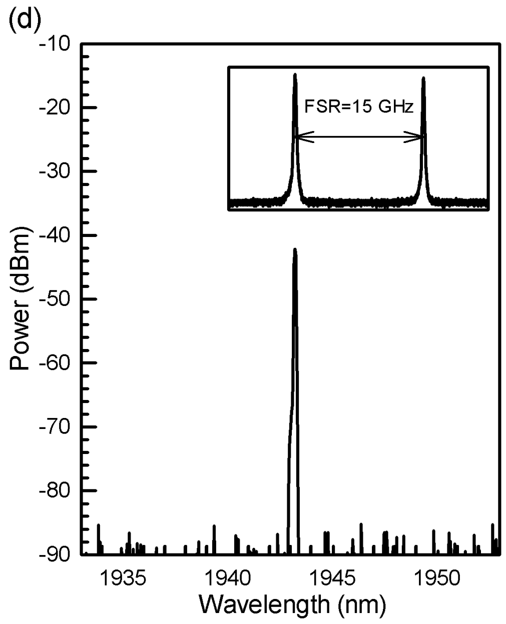

Fig. 2: Typical emission spectrum for DBR laser (Inset: a scanning Fabry-Perot interferometer trace).

The DBR laser was pumped by an Er,Yb co-doped single-transverse-mode fibre laser with a maximum output power of 10 W at ~1565 nm. Pump light was coupled into the DBR laser with the aid of a WDM coupler designed to eliminate feedback to the Er,Yb fibre pump laser at ~ 1.06 µm and hence suppress parasitic lasing on the Yb^{3+} transition at ~ 1 µm. This all-fibre arrangement avoids the need for free-space optical components and hence is more robust than earlier DFB and DBR lasers. Approximately half of the available pump power was absorbed in the DFB laser. The remaining (unabsorbed) pump power was absorbed in a 60 cm long section of PM Tm-doped fibre spliced after the OC FBG serving as a simple pre-amplifier stage. Temperature stabilisation of the DBR laser and limited wavelength tuning were achieved using a simple arrangement comprising a thermoelectic cooler and a piezo-driven stage as shown in Fig. 3.

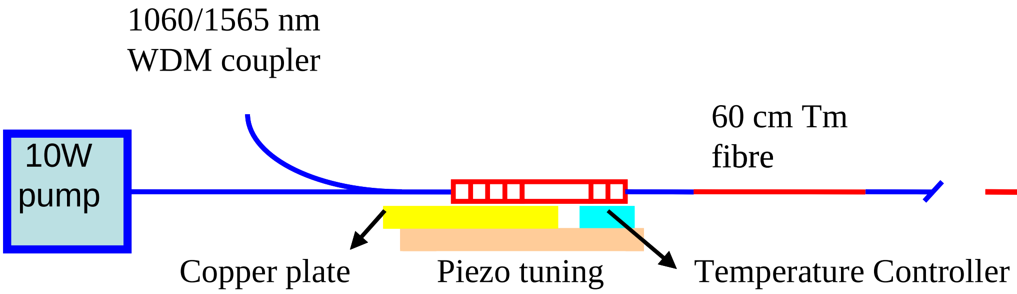

Fig. 3: Schematic diagram of Tunable DBR laser with a single amplifier stage.

Figure 4 shows the output power for the DBR MOPA as a function of pump power. The DBR laser had a threshold pump power of 1.2 W (absorbed) corresponding to a launched pump power of 2 W. At the maximum available pump power of 8.2 W the DBR MOPA yielded 2 W of linearly-polarised single frequency output with a corresponding slope efficiency of ~32 %. The polarisation extinction ratio was measured to be >16 dB.

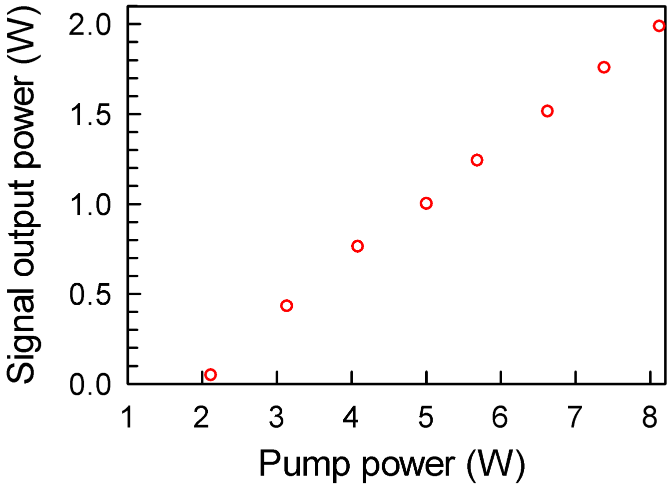

Fig. 4: DBR MOPA output power as a function of pump power.

Wavelength tuning by > 0.4 nm without mode-hopping was achieved by applying a voltage to the piezo stage to stretch the DBR gratings. The lasing wavelength as a function of applied voltage is shown in Fig. 5. This source is now ready for delivery to NEO.

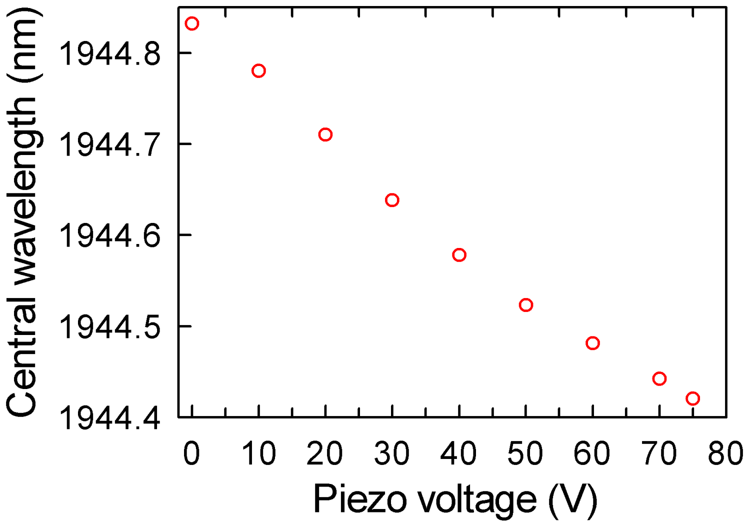

Fig. 5: DBR lasing wavelength versus applied voltage to piezo stage.

2.2. DBR laser with two amplifier stages

A more powerful version of the DBR MOPA with a second amplifier stage has also been constructed and delivered to HHUD. The MOPA design is shown in Fig. 6. This arrangement employed an earlier version of the DBR laser with a free-space launch arrangement for the Er,Yb fibre pump laser. The second amplifier stage employed a 60 cm long section of Tm-doped fibre pumped by a 20 W Er,Yb fibre laser at 1565 nm.

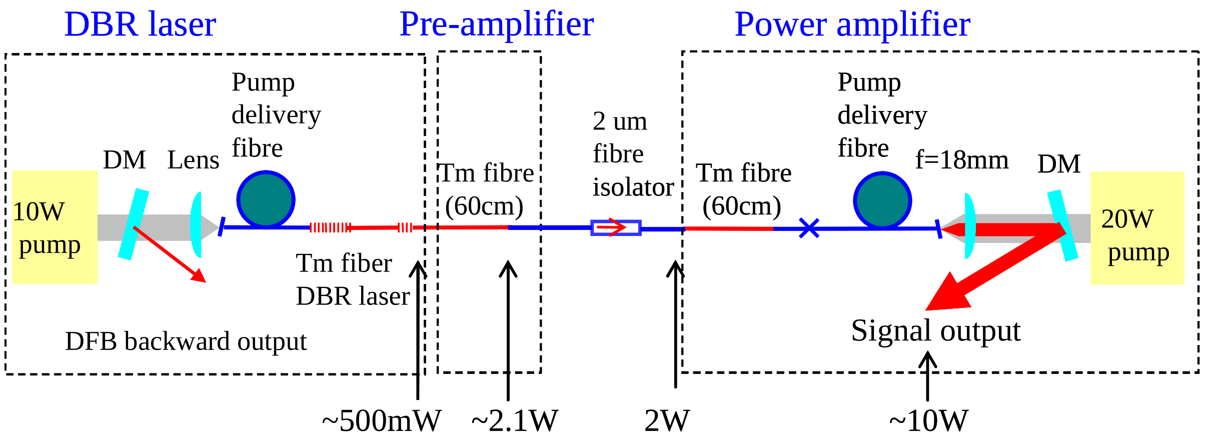

Fig. 6.: DBR MOPA configuration with two amplifier stages.

Signal light from the first amplifier was coupled into the second amplifier via a pig-tailed isolator to prevent feedback and hence suppress parasitic lasing in the amplifier stages. This 'all-fiber' arrangement for the MOPA benefits from improved mechanical stability and hence better power stability compared to earlier versions. Figure 7 shows the output power from the final amplifier as a function of launched pump power. The MOPA yielded just over 10 W of linearly-polarised single-frequency output at 1943.4 nm for ~15 W of launched pump power in the final amplifier stage corresponding to a slope efficiency of 62%. The polarisation extinction ratio was measured to be > 16 dB. This source has been delivered to HHUD.

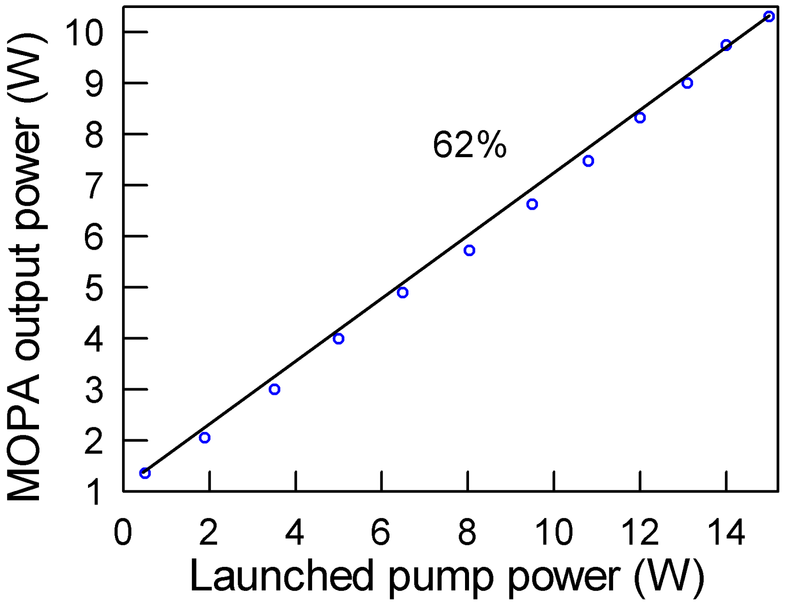

Fig. 7: Output power from DBR MOPA versus launched pump power to second amplifier stage.

3. CONCLUSION

The single-frequency DBR laser source described above has a rather limited tuning range (< 1 nm), since excessive stretching or compressing of the DBR structure would cause damage in the region of the splice where the fibre is weaker. Thus, for wide wavelength tuning a single-frequency DFB laser is needed. Further work on the development of a truly single-frequency DFB laser (i.e. with a single linearly-polarised mode) is progressing rapidly.

In addition, plans to move to an 'all-fibre' MOPA architecture (including pump coupling) are at an advanced stage. A schematic diagram of the intended design for future DFB/DBR MOPAs is shown in Fig. 9.

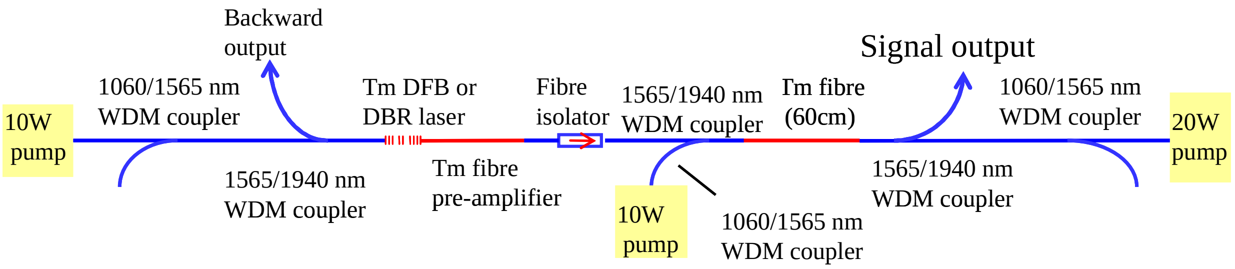

Fig. 9: All-fiber MOPA architecture

Further upgrades to existing MOPA's at HHUD and NEO to improve overall performance, power stability and the wavelength tuning range will be made available when a route to robust linearly-polarised operation of the DFB laser is established.