CO_2 STABILISED ER^{3+}-DOPED FIBRE LASER AT 1578 NM

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ABSTRACT

A single-mode distributed feedback (DFB) fibre laser has been frequency locked to a CO_2 absorption line at 1578.665 nm. A mechanical lead screw provided coarse wavelength tuning, while wavelength modulation and fast frequency corrections were applied by straining the fibre laser with piezoelectric transducers. With a suitable choice of absorption line such a system may serve as absolute frequency reference for DWDM grids in telecommunication.

1. INTRODUCTION

Single frequency lasers with narrow line width are attractive for applications such as laser spectroscopy, for sensor systems, or as wavelength standards in optical communication. Distributed feedback (DFB) erbium doped fibre lasers meet the requirements, and with the excellent wavelength selectability throughout the telecommunication C and L bands ranging from 1525 to 1610 nm, they represent an interesting alternative to semiconductor lasers. The drawback of fibre lasers in connection with some of these applications is that tuning and modulation is less straightforward to implement than is the case for semiconductor DFB lasers. We here apply the strain approach which has recently been described by Wetjen et al. [1]. The laser is locked by the first derivative technique to an absorption line in CO_2, and the stability of the system is validated by heterodyning against an extended cavity laser (ECL), offset locked to the same line. One possible application of such a system is to serve as an absolute wavelength reference in DWDM grids used for telecommunication [2].

2. EXPERIMENTAL SETUP

The DFB fiber laser is fabricated by introducing a Bragg grating into the core of an Er^{3+} doped fiber [3]. The unpacked fiber laser is epoxy-bonded at two spots just outside the grating, and one end is adjustable by a lead screw and two piezoelectric transducers (PZT). The entire base of the aluminium mount is temperature controlled to ensure passive stability. Output powers up to 4 mW were achieved. The tuneable fibre system was characterised using a 2 GHz scanning Fabry-Perot interferometer, a Burleigh WA-1500 wave meter, and through beat frequency measurement, using a New Focus model 6262 extended cavity laser (ECL) tunable from 1510 - 1590 nm.

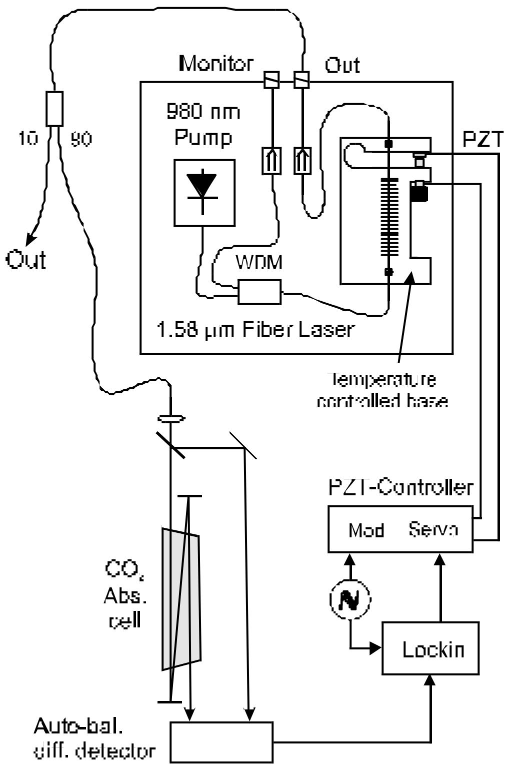

Fig. 1. Experimental setup for a fibre laser locked to a CO_2 absorption line.

3. TUNING AND MODULATION

Coarse tuning as illustrated in Fig.2 is accomplished with the lead screw at a rate of 6.8 nm/mm, referred to the displacement of the screw, corresponding to about 11 nm/mm referred to the stretching of the fibre. To avoid damage to the fibre, tuning was limited to 2.7 nm (325 GHz), corresponding to a relative length change of 0.0023. Based on geometrical considerations alone, this strain would imply a tuning of 3.6 nm, the difference reflecting the strain induced change of the refractive index.

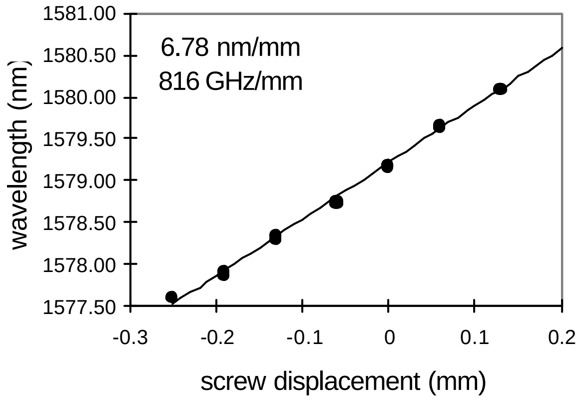

Fig.2 Coarse tuning by mechanical lead screw

Intermediate range tuning is possible by controlling the temperature of the base plate to which the fibre laser is thermally anchored. Over the range 20-30 °C the wavelength tunes linearly with a coefficient of 0.0326 nm/°C, as shown in Fig.3.

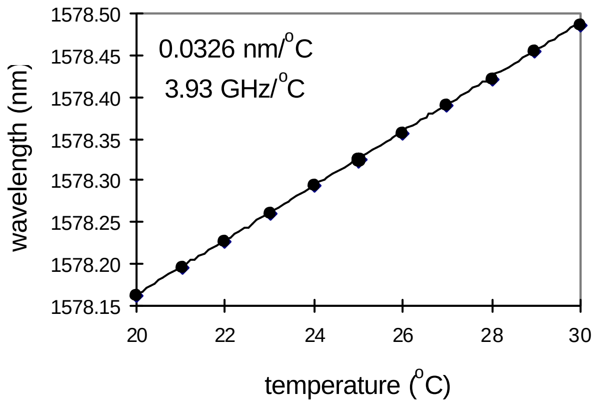

Fig.3 Temperature tuning of fibre laser

Modulation is induced through either of two piezoelectric transducers, a coarse PZT with a nominal displacement of 15 µm at 150 V, and a fine PZT with a displacementof approximately 0.9 µm at 150 V. The frequency response of both piezos as given in Fig.4 shows a uniform fall-off with frequency up to about 2 kHz, while several mechanical resonances were observed at higher frequencies. Maximum tuning was limited to 0.12 nm (14.4 GHz) for the coarse piezo and 0.0055 nm (660 MHz) for the fine piezo by the maximum voltage at the piezos.

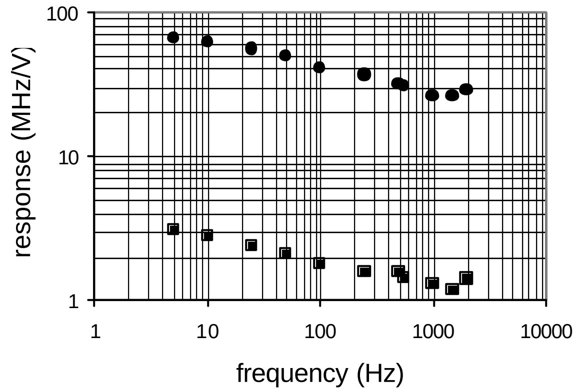

Fig. 4 Frequency response of coarse PZT (circles) and fine PZT (squares).

An undesirable feature of the laser used in these experiments is the presence of an unexpectedly strong dependence of output power on the fibre strain, and an associated strong amplitude modulation induced by strain modulation. Whether this is an inherent property of the fibre, or whether it is induced by the mounting of the laser, is not known at present.

4. FREQUENCY LOCKING

In order to enable locking to an absolute frequency reference, the fibre laser was designed to operate at 1578 nm, in the vicinity of absorption lines of the 30012 ← 00001 combination band of CO_2. For the present work we chose the P16 line at 1578.665 nm [4] with a line strength of $1.56 \cdot 10^{-23}$ cm/mol and a self broadening parameter of 2.96 MHz/mbar [5].

The fibre laser was locked to the line centre of the absorption dip produced by three passes through a 20 cm cell sealed with Brewster windows, and filled with CO_2 to a non-optimised pressure of about 200 mbar. Wavelength modulation was induced through the fine piezo at 555 Hz with a peak-to-peak modulation width of 130 MHz. The use of an auto-balanced photoreceiver (New Focus Nirvana) enabled elimination of the offset of the 1-f signal, created by the amplitude modulation (Fig.5). The origin of the residual etalon effects has not been identified so far.

In order to produce a beat frequency suitable for counting, the ECL was locked to the side of the same absorption line, using a separate single pass cell of 127 cm length, also filled to a pressure of about 200 mbar. A reference signal was branched off in front of the cell and subtracted from the transmitted signal in a difference detector. By adjusting the magnitude of the reference signal, the zero crossing of the combined signal could be shifted relative to the line centre in order to produce an offset of about 650 MHz.

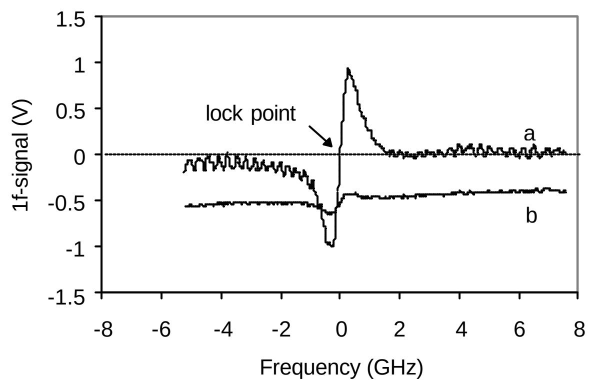

Fig. 5. First harmonic profile of the P16 line of CO_2 at 1578.665 nm obtained with a tuneable fibre laser and auto-balanced detection (a) or traditional balanced detection (b).

5. ALLAN VARIANCE

Signals from the two lasers were combined on a fast detector, and the beat frequency was displayed on a Tektronix 2756P spectrum analyser and counted. An Allan variance analysis of the countings indicates that the lock has no effect for integration times shorter than about 20 s, whereas for longer integration times the stability is improved by about one order of magnitude (Fig.6). The long-term beat frequency stability of around $5{\cdot}10^{-8}$, corresponding to 10 MHz, was limited by the sensitivity of the ECL lock to changes in the level of the signal transmitted through the 127 cm cell. It is therefore reasonable to take 10^{-8} or 2 MHz, as measured for integration times less than 20 s, as an upper limit of the fibre laser stability. From the beat note spectrum we could estimate the line width of the fibre laser to a few MHz. This is somewhat higher than reported for both the ECL and a packed fibre laser [5], and may be caused by acoustical noise in the laboratory as well as by the construction of the fibre laser mount. Another limitation at present may be caused by the significant power variation with frequency tuning of the fibre laser, and the associated amplitude modulation. These effects are under further investigation.

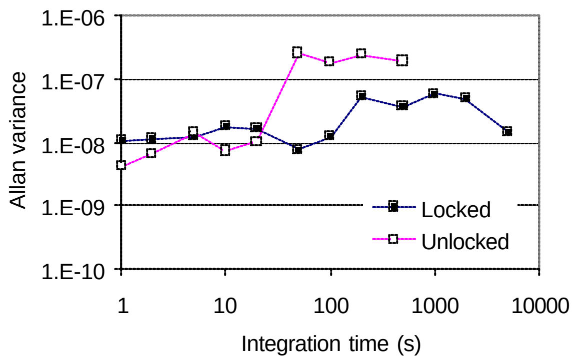

Fig.6 Allan variance analysis of the beat frequency between the fibre laser and the ECL.

6. SUMMARY

Due to the low noise and narrow line width, tuneable DFB fibre lasers are attractive sources for metrologic and spectroscopic applications. An absolute wavelength standard with 2 MHz stability, locked to a Doppler-broadened absorption line in CO_2 and suitable for DWDM applications in telecommunication, has been demonstrated. Other candidate molecules for operation in the 1520 to 1610 nm wavelength range include C_2H_2, HCN, H_2S, and CO. Improvement of the stability of the present wavelength standard may be achieved through optimisation of the absorption cells and reduction of the laser amplitude modulation, and a tighter limit on the stability may be obtained by a more sophisticated locking of the reference laser.

The use of Doppler free techniques would in principle lead to a significant improvement of the stability. However, in the context of present day DWDM grids with minimum channel widths of 50 GHz [2], locking to Doppler broadened lines is sufficient to meet the requirements of telecommunication.

ACKNOWLEDGEMENT

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