Wavelength modulation of fibre lasers - a direct comparison with DFB lasers and extended cavity lasers.

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ABSTRACT

A strain modulated fibre laser is compared with a DFB laser and an extended cavity laser by studying the same absorption line in CO_2 at 1578.222 nm in second harmonic spectroscopy.

1. INTRODUCTION

As a spin-off from telecommunication the availability of small, robust semiconductor diode lasers oscillating in the near-infrared spectral region, combined with low-loss optical fibres, has opened for a range of sensor applications. In particular the use of molecular overtone and combination transitions for gas sensing with high sensitivity and selectivity profits from the spectral purity and wavelength modulation properties of such lasers. A semiconductor laser of the Fabry-Perot type is intrinsically a multimode oscillator, but the spectrum can be narrowed through optical feedback from an external diffraction grating. Such an extended cavity laser (ECL) can be tuned single mode over up to 100 nm by rotating the external grating, and is therefore an ideal tool for spectroscopic investigations. However, the technical complexity and added cost associated with the external cavity somewhat limits the applicability of the ECL for sensing, in particular if cost is of major concern. In addition, the output beam is coupled into free space, and optical components are needed in order to couple the radiation into a fibre.

An alternative to the ECL is provided by the semiconductor DFB laser. Owing to the frequency selective character of the distributed feedback structure this laser oscillates single mode without external optics, and it can be tuned over about 3 nm by changing the temperature. In a DFB laser the selection of wavelength is an integral part of the manufacturing process, and although inexpensive DFB lasers are available in the wavelength regions favored by the telecommunication sector, the picture changes radically when non-standard wavelengths are required. Also, the beam emitted from a DFB laser is not well adapted to coupling into a single mode fibre.

Over recent years the the advent of Er^{3+} doped fibre amplifiers combined with the development of techniques for UV writing of gratings in photosensitized fibres has paved the way for fibre DFB lasers in the wavelength range 1520 - 1610 nm. Compared with semiconductor lasers the fibre lasers have numerous advantages. The most striking of these is that the process of selecting the wavelength is distinct from the process providing the gain. All that is needed for choosing a particular wavelength is a so-called phase mask which allows for UV exposure of the fibre in a pattern providing the appropriate grating constant. With state-of-the-art technology the wavelength can be preselected to within a fraction of a nm, and the wavelength tuning provided by changing the temperature is similar to that of semiconductor DFB lasers. An additional advantage is that a single pump laser oscillating at 1480 nm for pure Er^{3+} doped fibres, or at 980 nm for fibres which are codoped with Yb^{3+}, can pump several fibre lasers, and since the radiation is created inside the fibre, the problems associated with coupling radiation from a semiconductor laser into a fibre, are non-existant.

In gas sensing it is standard practise to use wavelength modulation and synchronous detection at the first or second harmonic of the modulation frequency in order to improve the signal-to-noise ratio. It is therefore necessary to modulate the laser wavelength, and in this repect fibre lasers are at a disadvantage with repect to semiconductor lasers. A semiconductor DFB laser can be wavelength modulated at GHz frequencies throught the current. For an ECL this feature is lost since the wavelength is controlled by the external cavity configuration, and here wavelength modulation is restricted to a few kHz, implemented by dithering the external grating. For a fibre laser the wavelength can be modulated by modulating either the period of the grating, or the refractive index of the fibre. Both of these parameters are affected by the strain of the fibre, and the simplest way of wavelength modulating a fibre laser is therefore to mount it in such a way that the strain can be controlled with a piezoelectric transducer [1].

In this paper we compare the performance of a strain modulated fibre laser with that of an ECL and that of a semiconductor DFB laser by recording wavelength modulation spectra of the same absorption line in CO_2, the P14 line of the (22^01 - 00^00) combination band at 6348 cm^{-1}, located at 1578.222 nm.

2. EXPERIMENT

The fibre laser is produced by IONAS A/S [2], and the layout of the experiment is shown in Fig.1. The unpacked fibre 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. The threshold pump power of the 980 nm laser was 40 mW, and the 1578 nm power increased linearly with pump power up to 1.3 mW at a pump power of 100 mW. Diagnostics of the laser was perfomed with a Burleigh WA-1500 wavemeter with 7 digit resolution, a 2 GHz scanning Fabry-Perot interferometer, and a fibre coupled power meter. The output of the fibre laser is collimated by a spherical lens, and split by a pellicle beam splitter. One beam passes through a 100 cm absorption cell provided with Brewster windows to one input of a New Focus model 2017 auto balanced detector. The other beam, which provides the reference for the detector, can be attenuated by a rotatable polarising cube in order to provide the optimum ratio between signal channel and reference channel. The fibre laser is strain modulated at 555 Hz, and the second harmonic component from the detector is recovered by a lock-in amplifier.

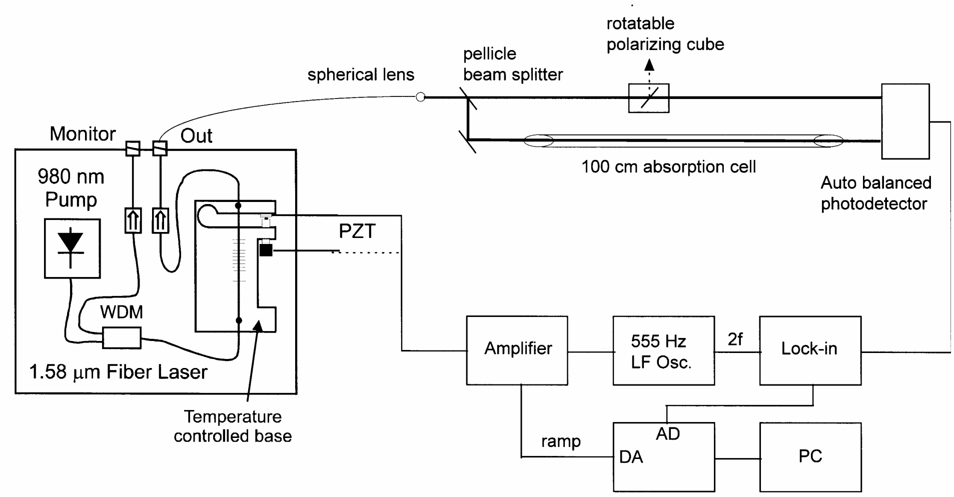

Fig. 1 Experimental arrangement with fibre laser

3. FIBRE LASER TUNING AND MODULATION

Coarse tuning 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. 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,

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 displacement of approximately 0.9 µm at 150 V. The frequency response of both piezos as given in Fig.2 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.

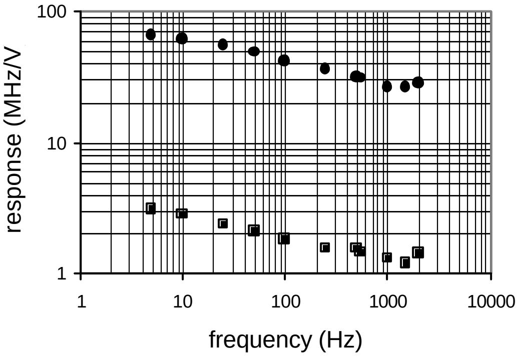

Fig. 2 Frequency response of coarse PZT (circles) and fine PZT (squares).

A particular feature of the laser used in these experiments is the presence of a marked 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. ABSORBANCE MEASUREMENTS

In Fig. 3 we show examples of second harmonic spectra recorded at a pressure of 100 mbar with an extended cavity laser with piezo modulation of the grating at 313 Hz (upper graph), a semiconductor DFB laser with current modulation at 313 Hz (middle graph), and the fibre laser with strain modulation at 555 Hz (lower graph). In all cases the modulation depth was chosen so as to maximise the second harmonic signal, corresponding to a modulation depth $b \equiv \nu_m/\Delta\nu \approx 3$, where ν_m is the modulation amplitude and $\Delta\nu$ is the HWHM linewidth [3]. Using a line strength of $1.535 \cdot 10^{-23}$ cm/mol and a pressure broadening coefficient of 3.019 MHz/mbar [4], the logarithmic absorbance for 100 cm cell length is calculated as 0.128, and a direct measurement of the absorbance yielded 0.124. In all three cases the signal-to-noise ratio corresponds to a minimum detectable absorbance of $1.5 \cdot 10^{-4}$. The qualitative difference between the three line profiles is a consequence of amplitude modulation. For the extended cavity laser, modulation of the grating yields essentially pure wavelength modulation, and the second harmonic profile is symmetric. In the limit of low modulation depth the profile is proportional to the second derivative of the Voigt line profile, but in our experiments the line is strongly overmodulated in order to optimise the signal-to-noise ratio. For the DFB laser modulation of the current will change both the wavelength and the amplitude, and as shown in Ref. [3] this leads to the observed asymmetry. For our fibre laser, strain modulation leads to an amplitude modulation which is significantly more pronounced than for the DFB laser, and the asymmetry is correspondingly stronger.

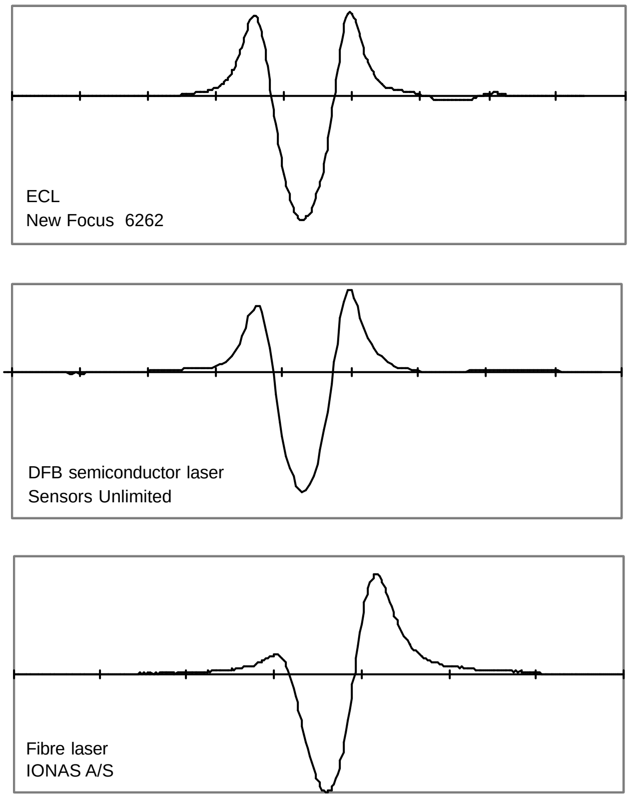

Fig. 3 Second harmonic spectra of the P14 line of CO_2 at 1578.222 nm recorded with three different lasers.

6. CONCLUSION

We have compared the performance of a strain modulated DFB fibre laser with that of a semiconductor DFB laser and that of an extended cavity diode laser, and found that they perform equally well in wavelength modulation spectroscopy with a minimum detectable absorbance of $1.5 \cdot 10^{-4}$. In all cases the attainable sensitivity is limited by slowly varying residual etalon effects in the background signal, and is not limited by laser noise. The main difference between the lasers relates to the amplitude modulation which is smallest for the extended cavity laser and strongest for the fibre laser. The presence of amplitude modulation has no effect on the signal-to-noise ratio, but it modifies the line shapes, and must be accounted for if the laser is used for line shape analysis.

REFERENCES

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