Tunable Fibre Laser Source for Methane Detection at 1.68μm

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Abstract

A tunable fibre laser for spectroscopic gas detection is reported for the first time. The laser is based on a single-mode thulium doped fibre, which can operate at a wavelength around 1.684μm, corresponding to a significant absorption line for methane. The fibre laser was pumped at 786nm, a wavelength which is readily available with AlGaAs laser diodes and an optical threshold power of 43mW was observed. An in-fibre photorefractive grating was used as the wavelength-selective output coupler for the laser. Simultaneous straining and heating of the grating induced a change in lasing wavelength, and a tuning range of up to 2nm was demonstrated.

This new tunable light source was configured within a methane detector and absorption spectra were recorded which demonstrate the presence of this gas. The large tuning range of the thulium fibre laser should allow the detection of many gas species with absorption bands in the wavelength region 1.65μm to 2.05μm.

1. Introduction

A tunable laser source is an attractive high-intensity source for high resolution spectroscopy. Such a source can be employed for the optical detection of gases by scanning it through one or more absorption lines of the gas. Previously, semiconductor diode lasers have been demonstrated as possible sources for this application [1], but it has generally proved difficult to achieve high-yield manufacture of semiconductor lasers having a precise emission wavelength. In this letter we report the development of a fibre laser and demonstrate its suitability as a tunable source for methane gas sensing.

Fibre lasers are a relatively new class of solid state laser [2], and are ideally suited to gas sensing applications owing to their stable behaviour and wide tuning range. Rare-earth ions may be incorporated into the core of an optical fibre by solution doping [3], thereby making the fibre core the active region of the laser. This technique combines the advantages of fibre geometry; namely high optical intensities and single transverse mode guidance, with the broad absorption and stable emission spectra associated with rare-earth ions in glass hosts. Many types of optical fibre laser can be operated using low-power, diode-laser pump sources, making them practical for incorporation into industrial systems and even into portable equipment. The broad fluorescence spectrum of the material allows the laser operating wavelength to be tuned over a wide range; typically 300nm for Tm^{3+} [4].

2. The Tunable Thulium-Doped Fibre Laser

Our tunable fibre laser was designed with an operating wavelength close to 1.68μm. This is a useful, near IR wavelength for methane detection, coinciding with the P-branch in the $2\upsilon_3$ absorption spectrum of the methane molecule. This is at the short wavelength end of the range available using Tm^{3+} doped SiO_2-GeO_2 fibre [4]. The Tm^{3+} fibre laser conveniently possesses a pump band at 780nm, matching the output of commercially available laser diodes. This is readily seen in Figure 1, where the dependence of pump power required to reach laser threshold, using a Ti^{3+} sapphire laser as a laboratory pump source for diagnostic purposes, is plotted as a function of pump wavelength. The optimum pump wavelength was found to be 787nm, with only a small penalty in pump power of 10% incurred in deviating up to 4nm from this value. As a consequence, the wavelength (temperature) control required of the diode laser pump source is not critical.

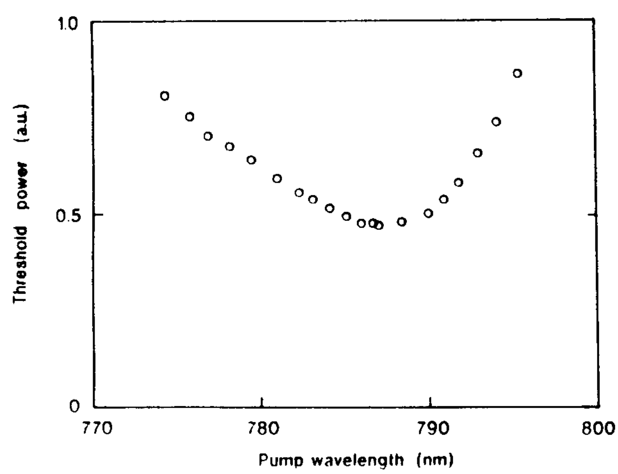

Figure 1 Pump threshold power versus wavelength for the thulium doped laser

The cavity for the Tm^{3+} fibre laser consisted of a dichroic mirror butted to one end of the active fibre and a photorefractive grating at the output end (see Figure 2). The photorefractive grating is a distributed feedback element made by periodically modifying the index of the fibre core along its length. The grating is formed holographically, using converging optical beams of ultraviolet light to produce a stable, photorefractively-induced, periodic variation of refractive index along the illuminated section [5]. The grating pitch constrains the operating wavelength of the laser to be close to the peak reflectively wavelength of the grating.

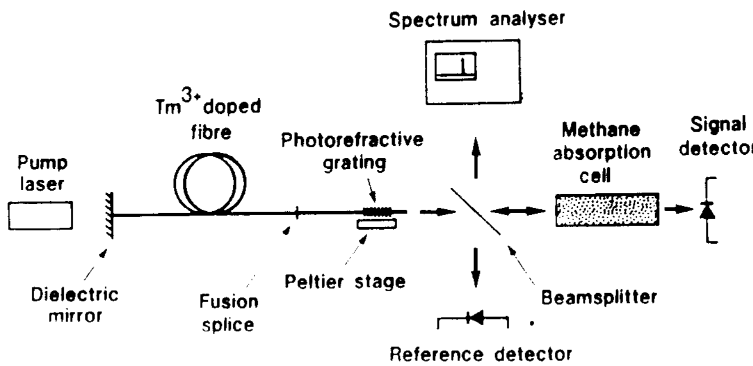

Figure 2 The thulium doped fibre laser

The fibre can be stretched to tune the grating reflection, and hence the laser. The grating acts as both the output coupler and tuning element, thus greatly reducing complexity compared to other tuning methods, and also minimizing the cavity loss. Ideally, with a state-of-the-art device, the grating could have a reflectivity of ~ 90%, and could be produced directly in the doped fibre. However, fabrication of photorefractive gratings for this application is still in the research stage. As a result, our own grating was one produced in a section of undoped fibre, and had a reflectivity of only 60%. Although this is less than the best reported results, it was nonetheless quite adequate to demonstrate the potential of the fibre laser source. For simplicity of tuning, the fibre was simultaneously stretched and heated by cementing it into a metal tube of higher expansion coefficient. This tube was placed in thermal contact with a peltier heating/cooling element and could be heated to cause simultaneous temperature rise and expansion. The tunable laser output, as a function of tube temperature, is shown in Figure 3. The linewidth of the laser was measured to be less than 0.1nm, (see inset of Figure 3).

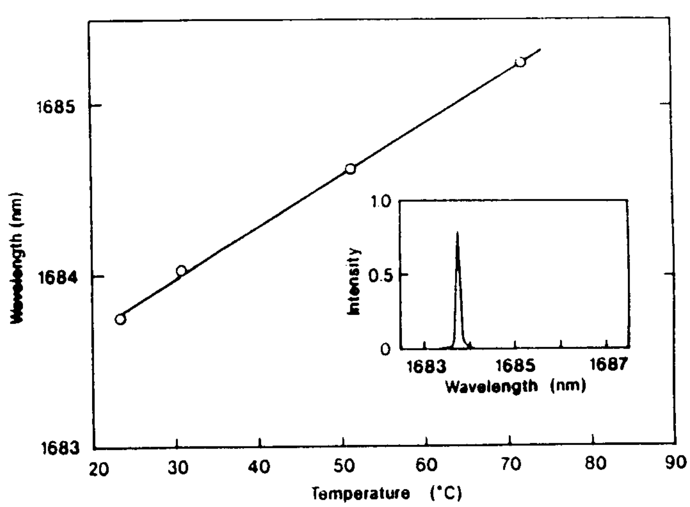

Figure 3 Laser emission wavelength showing temperature tuning

The launched pump power required to reach threshold at 1.684μm was 43mW; obtained using the diagnostic Ti^{3+} sapphire laser. This pump power is too high to allow operation with currently available laser diodes. However, many improvements to the laser cavity could be made. The main areas for improvement are elimination of the (1dB) splice loss between the doped fibre and the grating, and an increase in the grating reflectivity, from the current value of 60% to 90%. These improvements should reduce the threshold to 10mW, or less, and would therefore allow diode pumped operation.

3. The Methane Sensor

To demonstrate the laser in a methane sensor configuration, the laser output was collimated through a gas cell containing a methane-air mixture, and focused onto a photodetector, as shown in Figure 2. An 80cm cell containing methane at a concentration of 2.5% was employed. Prior to entering the gas cell, a fraction of the incident beam was deflected onto a reference detector, which, when used with a divider circuit, compensated for laser amplitude fluctuations. The normalised transmitted signal was recorded as the laser wavelength was swept through a methane absorption line. Subsequently, a zero-methane reference level was obtained by flushing the cell with nitrogen. A graph of results obtained in this way is shown in Figure 4, where the transmission is shown over a wavelength range of approximately 0.7nm. The absorption at 1.6847μm is a line of the P branch of the $2v_3$ band, which is characteristic of the presence of methane in the gas cell.

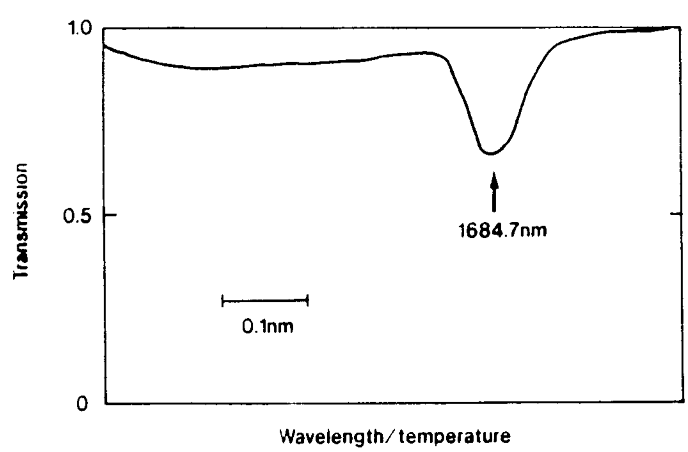

Figure 4 Laser output scanned through a methane absorption line

4. Conclusion

We have successfully demonstrated the use of a tunable Tm^{3+} fibre laser as a source for methane gas sensing. We believe this is the first demonstration of a tunable fibre laser for high-resolution spectroscopy. The design of the laser is both compact and practical for this application. Further improvements, notably in the reflectivity and location of the photorefractive grating are expected to allow this sensor source to be diode pumped.

5. References

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