RARE-EARTH DOPED FIBRE LASERS AND AMPLIFIERS

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ABSTRACT

Rare-earth doped single-mode fibre lasers and amplifiers will form the basis of all-fibre optical circuits. Recent advances in the field and some possible applications will be described.

INTRODUCTION

The incorporation of rare-earth dopants into the core of single-mode optical fibres has led to a new class of both active and passive fibre devices including lasers, in-line optical amplifiers, absorption filters and distributed sensors. Several of these devices have reached a state of development where they are finding uses in telecommunication and fibre sensor applications. Most importantly, they will form the basis of an all-fibre approach to optical fibre circuitry.

Several techniques are available for incorporating a wide variety of dopants into single-mode fibres at levels from a few ppm to several percent [1-3]. These fibres are characterised by strong absorption bands in the visible region of the spectrum (typically >10dB/m) with low losses in the near-infrared region more typical of telecommunication fibres (~1dB/km). The small core size ensures that high pump light intensities are maintained, enabling low-threshold operation of the laser to be obtained [4]. It has also been possible to demonstrate, for the first time, low-threshold, CW operation of a three-level glass laser (Er^{3+})[5] and operation on a transition never before observed in glass (Pr^{3+})[6].

The absorption and fluorescence bands of the dopants are considerably broadened due to the nature of the glass host. This enables a wide variety of pump sources to be used, the most convenient of which is the GaAlAs diode laser. The wavelength tolerance on these diode lasers is greatly relaxed compared to those required for crystal laser pumping. As an example, the Nd^{3+}-doped single-mode fibre laser can be pumped by any CW diode laser operating between 770nm and 830nm. It is also possible to tune the laser over a large part of the fluorescence band[7].

These versatile lasers can also be Q-switched [4,5,8] and mode-locked[9] by inserting an acousto-optic modulator into the cavity, thus enabling the generation of short, high peak-power pulses for use in fibre sensors, OTDR and the study of nonlinear effects in fibres.

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The general operating characteristics of the rare-earth doped single-mode fibre lasers obtained to date are outlined in Table 1 [5-7,10,11].

	PUMP WAVELENGTH	OPERATING WAVELENGTH	OUTPUT POWER	TUNING RANGE
Nd^{3+}	823nm	0.94μm	3mW	—
	823nm	1.09μm	6mW	92nm
Er^{3+}	650nm	1.55μm	30mW	35nm
Pr^{3+}	590nm	1.06μm	3mW	61nm

Table 1. Fibre laser characteristics

The quoted specifications for the Nd^{3+}-doped fibre laser refer to GaAlAs diode laser pumped operation. It is particularly notable that the 940nm emission is obtained on the ${}^4F_{3/2}$ -${}^4I_{9/2}$ three-level transition of Nd^{3+} with none of the problems normally associated with this mode of operation. A Q-switched and tunable version of this laser will find immediate use as a source for fibre sensors due to the availability of cheap silicon photodiodes at this wavelength.

It is possible to fabricate an all-fibre laser using either resonant[12] or anti-resonant[13] ring cavities. By using a pigtailed diode laser as the pump source, this leads to the concept of a rugged monolithic fibre laser which may be spliced into additional fibre circuitry.

In normal, free-running mode of operation, the linewidth of the laser can exceed ten nanometres. The low temporal coherence and excellent temperature stability of the fibre laser operating either in this mode or as a superfluorescent device make it ideal as a power source for the optical fibre gyroscope. It is also possible to decrease the linewidth considerably by introducing wavelength selective feedback. This can be done using a diffraction grating[7], and a tuning range of 92nm from 1062nm - 1154nm has been demonstrated using this technique. Ultimately however, a monolithic device is preferable in order to ensure long-term, maintenance-free operation. This has been done by incorporating a fibre grating into the cavity (Fig. 1). The grating is etched directly into a short (51mm) length of highly doped fibre (Fig.2), the input of which is butted against a high reflectivity mirror in the usual manner. The free spectral range of the cavity is such that only one longitudinal mode is able to oscillate due to the narrow reflection bandwidth of the fibre grating and a linewidth of 1.3MHz is obtained at 1082nm. A similar device operating at 1.55μm will find immediate applications in coherent communication systems.

In normal operation, the fibre laser emits on two orthogonal polarisation eigenmodes corresponding to the birefringent axes of the fibre. By incorporating a high extinction ratio single-mode fibre polariser in the laser cavity, it is possible to obtain single polarisation operation by introducing a large loss for one of these modes. A laser has been fabricated from a D-fibre incorporating a 2mm length of gallium near to the core (Fig.3)[14]. Using this technique, an exceedingly high extinction ration of 37dB between the two orthogonal eigenmodes was obtained.

Er^{3+}-DOPED FIBRE LASERS

Er^{3+}-ions in glass lase around 1.54μm[5]. This coincides with the low loss window of silica/germania fibres used in telecommunications and as such is of great practical interest. The transition is three-level in nature and therefore the absorption at the lasing wavelength must be bleached before lasing can occur. Er^{3+}-doped fibres have several absorption bands in the visible and near infrared which can be used for pumping. Most of the work has been carried out using a CW DCM dye laser operating at 650nm as the pump source, although recently laser operation using a 807nm pump source has been demonstrated.

A CW output power in excess of 20mW has been obtained for a modest input power of 70mW [15]. This approaches the theoretical maximum power obtainable for this device and is remarkable in view of the three-level nature of the laser.

By increasing the length of a three-level laser fibre and taking advantage of the longitudinal pumping arrangement, it becomes possible to obtain a region of unsaturated absorption at the output end of the fibre. Due to the high pump light intensity in the core, this absorption is readily bleached and, under certain conditions, it is possible to observe optical bistability [16]. Such a device has been constructed using a modified CW Er3+-doped fibre laser. The width and switching thresholds of the hysteresis loops obtained can be varied extensively by tuning the pump laser wavelength. Rise- and fall-times of several microseconds have been measured, limited by the switch-on and off times of the laser.

Q-switching has been achieved in a similar manner to that described previously. Pulses having a peak power of 120W with a duration of 32ns have been obtained at a repetition rate of 800Hz [15]. Tunable operation of the laser is also possible over a 35nm range from 1530nm - 1565nm.

Fibre gratings have also been used to control the spectral output of the Er3+-doped fibre laser [17]. The grating used in this experiment was characterised by a peak reflectivity at 1551nm of approximately 40% and a FWHM of 1nm. This grating, however, was fabricated using standard Corning fibre, incurring a butt loss of 3.1dB. This limited the slope efficiency of the laser to 5% and a threshold of 13mW was obtained. The spectral output had an approximately Gaussian profile with a FWHM of 0.04nm.

OPTICAL AMPLIFICATION

An Er3+-doped single-mode fibre amplifier operating at 1536nm has been fabricated [18]. The pump source used was a CW DCM dye laser operating at 650nm. The amplifier consisted of a 3m length of Er3+-doped fibre (150ppm Er3+) with a cut-off wavelength of 1150nm. The fibre absorption at the pump wavelength was 5dB/m. In order to prevent the onset of laser action at high amplifier gain, the optical feedback resulting from Fresnel reflections was reduced by index matching one end of the fibre (Fig.4). In practice, splicing the fibre into a fibre system would be sufficient to largely eliminate etalon effects, since low reflectivity splices are readily achievable. A 140 MHz sinusoidally modulated signal from a InGaAsP DCBH laser operating at 1536nm, the peak of the Er3+-doped fibre gain profile, was coupled into the fibre. A gain of 26dB was measured up to an input power of 10μW.

CONCLUSIONS

Rare-earth doped single-mode fibre lasers have been shown to be efficient, compact and versatile sources of laser radiation. These devices will be used in a wide variety of systems applications in the near future.

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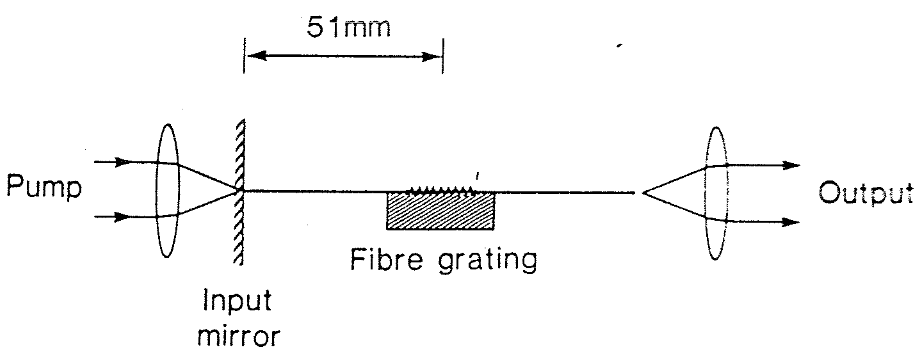

Fig.1 Experimental configuration of single longitudinal mode fibre laser

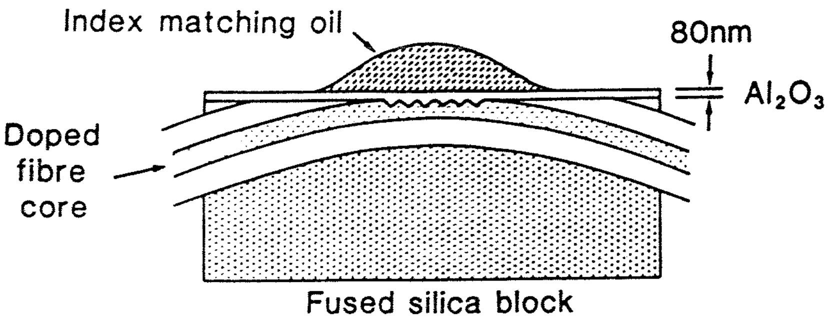

Fig.2 Schematic of doped fibre grating

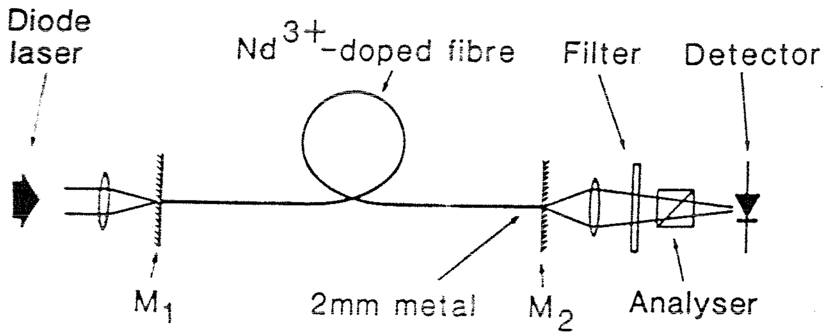

Fig.3 Experimental configuration of single polarisation fibre laser

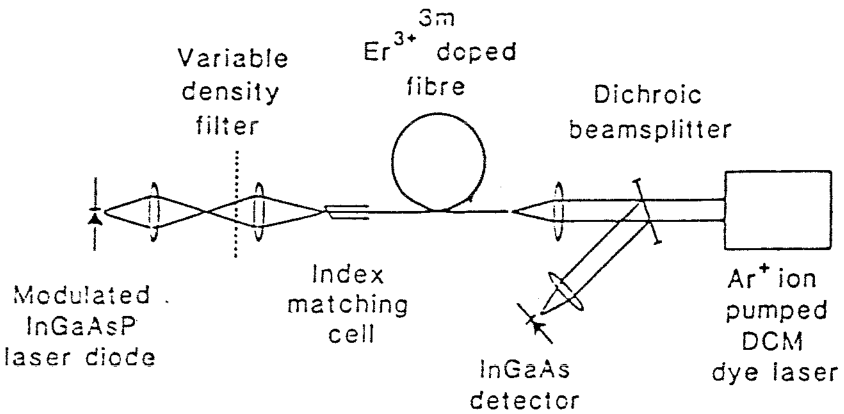

Fig.4 Experimental configuration of fibre amplifier