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AN OVERVIEW OF FIBRE LASERS

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ABSTRACT

A review of the current status of rare-earth doped fibre lasers is presented. Their properties and possible relevance to 'real-world' applications will be discussed.

To a large extent, the runaway success of the erbium-doped fibre amplifier (EDFA) has overshadowed the large body of research which has been carried out on rare-earth doped fibre lasers. This success was due largely to the opportune appearance of the EDFA at a time when long-haul telecommunication links were on the verge of being constrained by bottlenecks in the electronic signal regenerators in common use at the time. Such a commercial force did not then exist which could focus the fibre laser research, and therefore much of the early work was driven by curiosity rather than applications. In addition , high power diode lasers were being made available over a wide range of wavelengths, and research into other types of diode laser pumped solid-state lasers, *e.g.* Nd:YAG, was increasing in popularity. This made it all the more difficult for the fibre laser to find possible niche markets in which it could excel. An additional problem which beset early fibre laser research was the absence of suitable pump lasers and fibre components. Much of the early work was carried out using bulk components and unwieldy, inefficient pump sources which greatly limited the usefulness of the fibre laser outside of the laboratory.

The commercial need for more efficient lasers has largely solved the problem of the pump source, with reasonable power ($\sim$100mW) single-mode fibre pigtailed lasers available at a number of wavelengths. There is also a growing need for all-fibre components driven by the fibre telecommunications and sensor markets, and these are finding their way into fibre lasers. These same markets are also the main potential users of fibre lasers.

In general, fibre laser research can be split into two broad areas; that involving silica based glass and that involving the so-called 'soft glasses', which is generally taken to mean any glass other than silica. This latter area encompasses research into glasses such as chalcogenides, chalcohalides, sulphides and, most commonly, heavy metal fluoride glasses such as ZBLAN [1]. The vast bulk of published research is concerned with silica optical fibre, in part due to the maturity of the technology, but also due to the difficulties which are still encountered when trying to fabricate single-mode fibre using some of the more exotic glasses. Such glasses have markedly different properties from silica, with extended infrared transmission being the most prominent. The low phonon energy environment of these materials radically alters the radiative and non-radiative decay mechanisms of incorporated rare-earth ions, leading to amplification and lasing operation using transitions not accessible in silica. This allows for laser operation out to $\lambda \approx 3.5\mu m$ [2], and visible wavelength operation using multi-step upconversion.

Most installed telecommunication systems operate either at the zero-dispersion wavelength of $1.3\mu m$, or the minimum attenuation wavelength of $1.55\mu m$, the so-called second and third windows of silica optical fibre. The $1.3\mu m$ window has generally proved troublesome as far as silica fibre lasers are concerned, since the most promising transition, that from $^4F_{3/2}$ - $^4I_{13/2}$ in Nd^{3+} is severely curtailed by excited state absorption (ESA). This effect serves to increase the loss in the doped fibre as the pump power is increased. For this reason, alternative hosts have been sought which minimise or eliminate the ESA by modifying the crystal field around the rare-earth ion, allowing gain to be observed. Promising results have been obtained using Nd^{3+}- and Pr^{3+}-doped fluoride fibres [1], and other low phonon energy hosts are being actively sought. However, compatibility problems with silica fibre still need to be overcome. Most research is aimed at producing an optical amplifier, rather than seeking a replacement for the diode laser.

Operation of silica fibre lasers in the region of the third window has been much more fruitful, with the only radiative transition of Er^{3+} lying in the region of $1.53\mu m$ to $1.56\mu m$. With almost unit quantum efficiency and an exceptionally long fluorescent lifetime ($\sim$ 12ms), low threshold lasers and high gain amplifiers [3] are exceedingly practicable. In particular, much current research is aimed at replacing the ubiquitous diode laser as a source for future telecommunication systems. Two areas are being targeted: single frequency lasers and soliton sources. Single frequency lasers rely on the incorporation of photorefractive fibre gratings into the core of the doped fibre [4]. These act as narrowband reflectors which serve to define the operating wavelength and reduce the operating linewidth of the laser. By employing short laser cavities and thus increasing the mode spacing, single longitudinal mode operation is possible with linewidth and wavelength stability vastly superior to that of the traditional distributed feedback (DFB) diode laser. Recently, a continuous mode-hop free tuning range of 32nm was obtained using a compression tuned Er^{3+}-doped fibre laser [5]. This used a master oscillator-power amplifier (MOPA) configuration in which a short section of lasing fibre was followed by an EDFA. By using Er^{3+}-doped fibre co-doped with Yb^{3+}-ions, it is possible to drastically increase the absorption of the pump power without sacrificing device efficiency.

Using this type of fibre, the first DFB fibre laser was demonstrated [6], giving a diode laser pumped output power of 3mW with a linewidth of 60kHz in a far from optimised device. The lack of a direct modulation capability should not present a problem, due to the ready availability of external modulators at multi-gigabit frequencies. Also, there is the very real prospect of future high bit rate systems employing soliton technology as a means of increasing the data rate and circumventing the problem of fibre dispersion. Several soliton sources have been demonstrated using Er^{3+}-doped fibre lasers, although diode lasers still remain a viable competitor.

The long fluorescence lifetime of the rare-earth ion in glass lends the fibre excellent energy storage capabilities, a characteristic which diode lasers do not share due to the rapid recombination time of the charge carriers. This property leads to good Q-switched performance with kilowatt peak powers being possible for only a few tens of milliwatts pump power. In addition, the Er^{3+}-doped fibre laser operates in a wavelength region which is generally regarded as 'eye-safe', rendering the device eminently suitable for the task of laser rangefinding [7]. It may also be used as a source for an OTDR in order to carry out loss and length measurements in an optical fibre. A rather specialised demonstration of this technique has been the development of a commercially available distributed fibre temperature sensor based on a Nd^{3+}-doped Q-switched fibre laser. This device is capable of accurately measuring temperature over many kilometres of fibre with excellent spatial resolution, a task which would be impossible by any other means. Such a laser is the ideal source for many distributed or quasi-distributed fibre sensors, where strain or temperature need to be measured in real time at many points.

Many other opportunities remain to be exploited. High-power cladding pumped fibre lasers may find use in the medical field, where the wide range of available wavelengths and broad tunability would allow for optimum wavelength selection for a given task, *e.g.* photodynamic therapy and tissue ablation. Superfluorescent fibre sources are an attractive alternative to ELEDs due to their superior wavelength stability, making them excellent sources for fibre gyroscopes. Clearly, the fibre laser has a bright future.

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