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ADVANCES IN FIBRE DEVICES

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Optical fibre devices are assemblies of fibre components, often incorporating special fibre designs, to form functional optical fibre circuits with a complexity which increases annually. Fibre circuits can be thought of as a discrete technology which can exceed the complexity of integrated optics and which has a number of important attributes. These are: low intrinsic losses, low interconnection losses, polarisation independence and relatively-low manufacturing and assembly costs. However, it should be recognised that optical fibre devices are relatively large (ie long), they cannot easily be modulated, they have small electro-, acousto- and magneto-optic interactions, and a small third-order and a negligible second- order non-linearity. Notwithstanding these disadvantages, a number of successes have been achieved, notably four-port fused-taper couplers, photorefractive Bragg grating filters and the erbium-doped fibre amplifier (EDFA). It is the purpose of this review to provide a critical appraisal of current optical fibre device work and to examine future prospects for the technology in the light of a number of recent developments (eg new glasses). Fibre amplifiers will be covered elsewhere in the Conference.

Fibre Gratings

Since the first report of transversely-written photorefractive gratings by transverse holographic illumination using 264nm ultra-violet light [1], rapid progress has been achieved in the production of practical Bragg grating filters. Today fibre gratings with a reflectivity of greater than 99.8% can be holographically written into the core of a germania-doped optical fibre with a single 20nsec pulse of uv light [2]. Spectral filters have been demonstrated with optical bandwidths in the range 6-920GHz, making them ideal for channel-drop filters in future WDM systems. The filters have limited tunability (2nm) using temperature or strain and are potentially very inexpensive. Future applications seem assured as EDFA ASE filters, narrowband feedback elements for single-frequency diode and fibre lasers, embedded sensors in GRF composites and for spectral analysis. As the technology progresses, shaped and chirped filters, multi-filter arrays, dispersion compensators and long gratings (greater than 10cm) will emerge, as well as grating fabrication during the fibre draw at rates perhaps of hundreds of gratings per second.

Fibre Lasers

Unlike the EDFA, the fibre laser has yet to make a significant impact on optical communications technology, largely because of its requirement for an external diode pump and modulator. Nonetheless, it has some unique attributes which have been recognised in the traditional laser field. Fibre lasers are essentially diode-laser light convertors, able to turn the poorly-specified but high-power output from, for example, a multi-stripe diode pump laser into a widely-tunable, narrow-linewidth, quiet, single-frequency light source with output powers up to 1W cw [3]. Perhaps one of their main attributes is their ability to give much higher pulse power outputs than can be obtained from diode lasers and a pulse power up to 111kW has been reported [4]. Figure 1 shows the extraordinarily-wide range of wavelengths which have now been reported from fibre lasers, spanning the range from 400nm (upconvertors) to 3.4μm. Fibre lasers at both 1.3μm (Nd^{3+}) and 1.55μm (Er^{3+}) can be constructed in combination with fibre photorefractive gratings [5] to give single-frequency cw output for telecommunications applications, although at present it is difficult to avoid either mode-hopping or relaxation oscillation. This problem is expected to be solved by the use of very short fibre lasers, perhaps even a DFB fibre laser.

Fibre Soliton Generators

These fall into two classes, namely mode-locked fibre lasers and dispersion-tapered fibres. Mode-locked fibre lasers have received much attention in the literature, both by the ultra-short pulse community and the soliton communications area. Being all-fibre devices, fibre lasers tend to produce high-quality solitons which are well-matched to communications requirements. However, some difficulty is experienced in obtaining high bit-rates, since the fundamental mode-locking frequency is usually around 100MHz. Since gain-switched diode lasers and the use of electro-absorption modulators are also able to produce pulses close to the required $sech^2$ shape, the mode-locked fibre laser may well be better suited as an inexpensive source of ultra-short (30fsec) pulses for use in diagnostics and photochemistry. On the other hand, the dispersion-tapered fibre [6] has the remarkable ability to convert even sinusoidally amplitude-modulated light into extremely high-quality solitons at rates up to 200GHz. It can also be used to compress soliton pulses by as much as a factor of 16, thereby making this device very attractive for generating and manipulating the soliton pulses of future telecommunications systems.

Non-Linear Fibre Devices

As is well known, glass possesses an inversion symmetry and therefore lacks the second-order optical non-linearity found, for example, in lithium-niobate. However, in recent years it has been shown that a high $\chi^{(2)}$ can be induced in glass and fibres by all-optical, electric-field or electron-implantation poling [7]. A number of theories exist to explain the relatively-high (1 pm/V) non-linearity which ensues, but the mechanism has yet to be adequately clarified. Nonetheless, the quest to obtain $LiNb0_3$-like properties in glass continues with the aim of producing electro-optic modulation and parametric effects in both fibre and planar configurations. In this respect the most attractive route is by electron-implantation, since it provides the ability to write quasi-phase-matched structures with 10nm spatial resolution and depths up to at least tens of microns. Considerable research in glass technology will be necessary before these devices become a reality.

New Glasses

A number of groups are currently researching low phonon-energy glasses for application in 1.3μm praseodymium fibre amplifiers, upconvertors for blue light generation and fibre lasers in the 3-5μm region. Candidate materials are chalcogenide (eg gallium-lanthanum-sulphide), mixed-halide (eg cadmium-fluoride/cadmium-chloride) and telluro-halide glasses. In addition to their ability when rare-earth-doped to give long fluorescent lifetimes for a number of unusual excited states, these glasses exhibit very high index (1.8-2.4) and consequently an excellent acousto-optic merit and third-order non-linearity. Provided fibres can be manufactured with losses in the region of 0.1dB/m, a number of new fibre devices should emerge, for example an all-fibre GAZ acousto-optic modulator and short, low-threshold non-linear switches.

Conclusions

Despite its maturity, the field of optical fibres continues to produce new and exciting components, the most important recent example being the photorefractive fibre grating. Many of these devices have been assembled into complex fibre circuits capable of switching, soliton generation, multiplexing and demultiplexing. The substantial research which currently exists on glasses for optical fibres undoubtedly will have a considerable impact on the performance of fibre devices in the future, leading to enhanced non-linearity, new fibre lasers and amplifiers and very large photorefractive changes.

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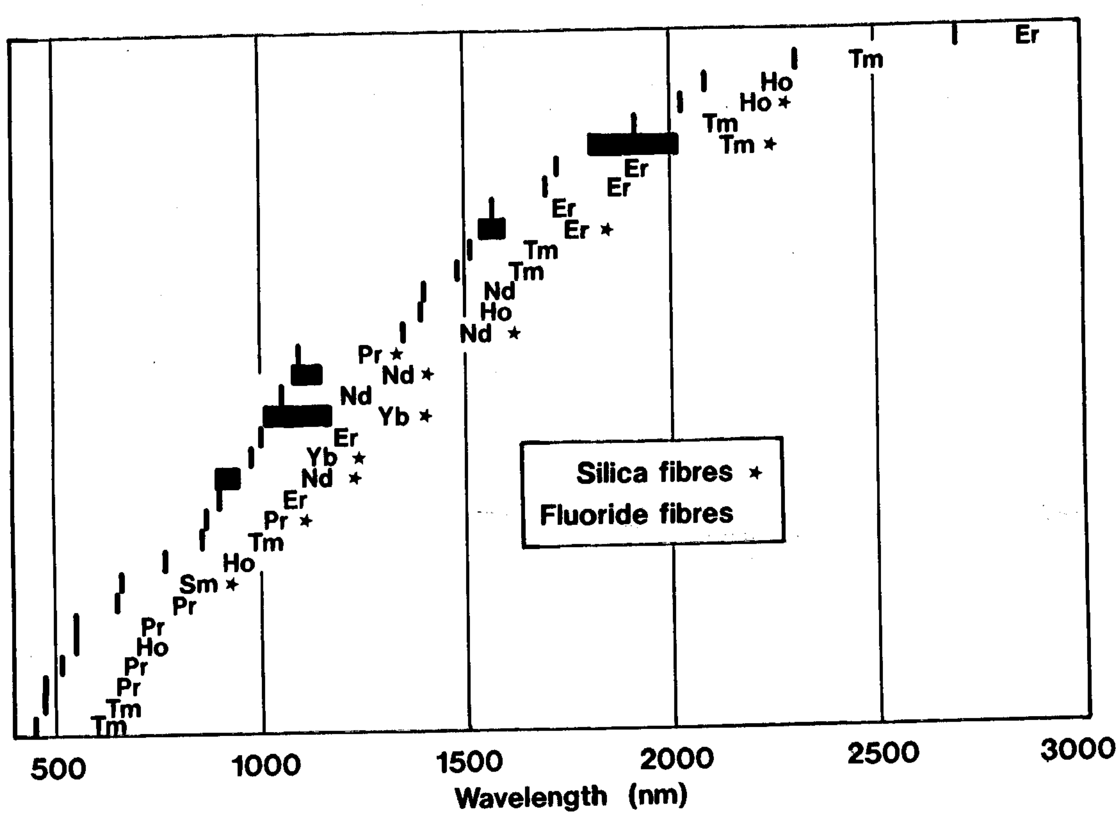

Fig 1 Fibre laser wavelengths