All-Fibre Bragg Grating Filters and Lasers for Future Optical Networks

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Introduction

Bragg gratings in optical fibre waveguides have now been around for 25years [1] and they were soon after being realised, identified as one of the most significant fibre-optic inventions with potentials in a wide variety of areas among telecommunications equivalent to that of the erbium doped fibre amplifier. Following their creation a plurality of in-fibre functions were thought possible with low or no insertion-loss. Although fabrication and control of vital grating parameters was limited in the early stages of their life, initially a number of filtering functions were identified for obvious demonstrations. It soon became apparent though that not just standard filtering manipulation was possible. Identifying the true potential of the devices has let to considerable effort being concentrated on their full exploitation implying building an infrastructure supported by theoretical design [2] and manufacturing techniques [3,4] around them. These techniques combined have let to a scenario where currently it is the imagination more than the actual design and manufacturing capabilities that imposes a limitation to what is being demonstrated and now they find applications in most of the modern telecommunications network.

Cladding-pumped fibre technology has revolutionised fibre lasers over the last decade, increasing output power from less than 1 W with traditional core-pumping to well over 100 W [5], [6], [7]. Even 1 kW of power has been reached in multi-mode designs [8], when several devices have been arranged in series or in parallel. For output powers below 100W, a few diode bars or multi-emitter laser diode assemblies are adequate pump sources. However, for powers beyond the 100 W level, diode stacks seem to be a better choice. The increasing availability of suitable diode stacks and the possibility of efficient fibre launch make them very attractive for pumping of high-power fibre-lasers. At the same time, while fibres proved very reliable at powers up to ~100 W, it is clear that further power-scaling to the kW level with diode stack pumping requires significant fibre optimisation in terms of fibre composition, pump coupling, and/or overall device layout. This is especially true when a single-mode output is required.

We will in this presentation discuss and highlight some of the most recent advances in Bragg grating devices and applications in advanced components together with the most recent advances in the area of high power fibre lasers. In particular we will show examples of the latest in Bragg gratings for dispersion-control, short pulse-manipulation, advanced filtering applications together with some of our latest results on lasers operating with powers approaching 1kW and speculate into what the future holds for Bragg gratings and high-power lasers and amplifiers.

1. Bragg gratings

On a number of occations it has been discussed how uniform apodised Bragg gratings exhibit near ideal spectral characteristics for application in dropping and adding channels when using a wavelength division multiplexing (WDM) transmission format [9]. This because they can be made to have near square-filter characteristics with very low side-lobe levels for very high spectral bandwidth utilisation. However, despite the near ideal spectral performance of the apodised filters it has also been discussed how these filters suffer from a non-constant time-delay and thus dispersion both outside and inside the stop-band [10,11]. With the evolution of grating manufacturing and design techniques [2] it is now possible though to control both the phase and amplitude of the grating manufacturing process and therefore nearly any filter shape can be made.

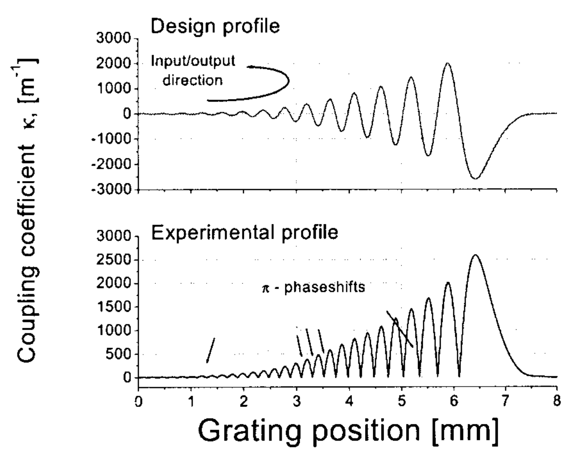

***Fig. 1.** Refractive index-profile of a Bragg grating designed to compensate third-order (slope) dispersion only, a) design profile b) profile as written into the fibre.*

As the bit-rates in systems continue to increase and therefore the sensitivity to dispersion is increased together with channel-separations that continue to decrease, a filter that has attracted much attention to cope with dense channel de-multiplication at is the square-filter linear-phase or dispersion-free Bragg grating [12]. Being designed using inverse-scattering techniques [2], its performance enhancement has been confirmed from directly comparing it with standard apodised Bragg grating filters in systems of 10Gbit/s down to 25GHz spacing [13]. Recent experiments confirm that up to 75% bandwidth utilisation is possible at bit-rates up to 40Gbit/s for 100GHz channel separations using these gratings [14]. At higher bit-rates dispersion-slope becomes an issue to address, using inverse-scattering, designing a Bragg gratings that can compensate this is possible aswell (Fig. 1) [15].

2. All-fibre DFB-lasers

All-fibre DFB lasers have attracted much attention in recent years because they have inherent fibre compatibility, ultra-low relative intensity noise (RIN), high side-mode extinction-ratio and very high signal-to-noise ratio (SNR). Their simple design consisting of a phase-shifted Bragg grating written directly into a rare-earth doped fibre have facilitated powers of greater than 13dBm with single frequency, single polarisation and single sided outputs [16]. Furthermore keyed-axis output [17] (Fig. 2) has recently been achieved, strongly favouring these devices for alignment to for example external modulators and other polarisation sensitive components.

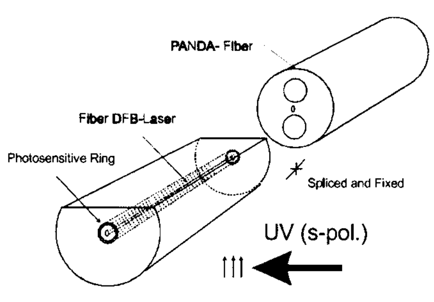

Fig. 2. Keyed axis all-fibre DFB-laser for easy alignment to external polarisation-keyed components.

We will in this section review the most recent advances in the area of all-fibre DFB-lasers and demonstrate how their performance in transmission-systems when operated as transmitter sources easily outperforming existing transmitter-sources [18]. Additionally we will demonstrate recent results that show how the 10-20mW of an all-fibre DFB-laser easily can be amplified with a high-power amplifier to powers in excess of 2W without any degradation to the line-width of ~15kHz or RIN to the laser.

3. High-power fibre-lasers

On the topic of higher power operation of fibre lasers, the case for cladding-pumped high-power fiber lasers is strong, made even stronger by recent results, enabled by developments in fibre and diode-pump technology. We will review some of our most recent high-power results with ytterbium doped fibres operating at ~1060 nm (Fig. 3) [19] and Erbium-ytterbium doped fibres operating at ~1550 nm [20]. At the time of writing the record for output power of a fibre-laser stands at 610W at 1090nm [21], with an output to pump power efficiency of 82% at a pump-wavelength of 975nm, but this number is rapidly changing with 1kW clearly in sight. Output powers of 120W with M^2 ~1.9 has recently been achieved in an Er/Yb doped fibre-laser operating at 1570nm and a tuneable version of this laser has with a fibre-grating been demonstrated with an output-power of >40W over 33nm bandwidth (1566-1533nm) [22].

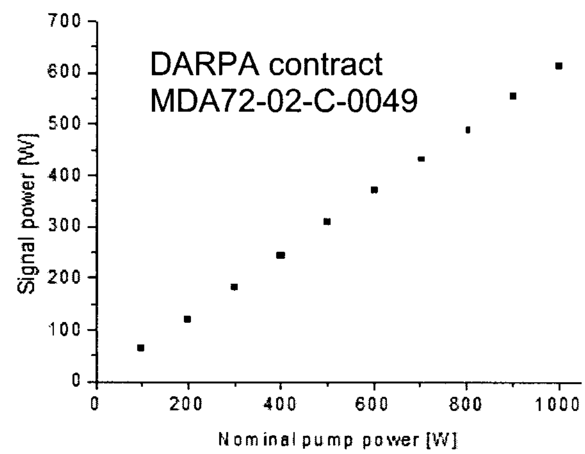

Fig. 3 Signal output power @ 1090nm against pump-power @975nm.

Conclusions

We have reviewed recent advances in the areas of Bragg gratings, fibre-DFB lasers and high-power fibre-lasers and discussed their applications in optical systems.

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