IN THE WAKE OF THE ERBIUM-DOPED FIBER AMPLIFIER – FUNCTIONAL FIBERS AND THEIR IMPACT

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Abstract: *There have been a number of laser developments in recent years that are quite staggering in their simplicity, that are so powerful in their operation that engineers and scientist have to rethink the laser future. One such is the high power fibre laser, born out of the optical telecoms revolution. It challenges currently held views on how to make things, how to repair things, and how to destroy things. With small size, maintenance-free operation, high thermal and electrical efficiency and outstanding beam quality, it has the potential to change every industry and discipline it encounters.*

1. Introduction

The extraordinary progress of optical communications over the last decade or so has led some commentators to suggest that the photonics community has done too good a job in satisfying the demand for bandwidth. In hindsight, historians and economists will point out that a glut of any commodity, in this case bandwidth, inevitably results in a crash in the market. While this may be so at present, the underlying growth in optical telecommunication remains firm and the market will surely eventually stabilise.

The huge investment made by the telecommunications community in advancing photonics over the last three decades brings a considerable opportunity to disrupt other markets with new optical technology. The extraordinary level of optical control coupled with the extended reliability that is routine in telecoms is regarded as revolutionary in, for example, lasers for industrial processing or the life sciences.

Exploiting the wealth of devices and techniques developed for telecoms in other areas of technology requires a clear view of the advantages which optical techniques can bring, most notably the high multiplexed data rate, immunity from electromagnetic interference and low invasion. Examples where these attributes are making an impact are in high-power lasers, sensing in oil wells, and in the biosciences. Photonics also brings unprecedented opportunities for signal processing, molecular manipulation and even industrial welding and cutting applications. Remarkably, the milliwatts of telecommunications can be scaled to powers as high as kilowatts in fibre amplifiers.

The talk will explore prospects for building new ‘cross-over’ technologies and applications through harnessing light in unexpected ways. Security, defence and manufacturing will benefit from novel remote sensors, intruder detection, X-ray generation and rapid laser cutting and prototyping. In addition, the demands of these new applications are identifying shortcomings in our existing arsenal of photonics devices and their performance.

2. High power fiber lasers

An excellent example of a cross-over technology is the high power fiber laser, born out of the optical telecoms revolution. With small size, maintenance-free operation, high thermal and electrical efficiency and outstanding (diffraction-limited) beam quality, it has the potential to change every industry and discipline it encounters. It challenges currently held views on how to make things, how to repair things, and how to destroy things.

Unique among high power lasers, the fiber laser is monolithic, the light being entirely confined to the fiber core. This gives immunity to thermal distortion of the beam, almost instant startup, very high stability and protection from the environment. Maintenance is minimal, since no realignment or cleaning of components is necessary.

One of the key attributes of fiber lasers is their very high gain (30dB) which results from their extended length. This allows the use of amplifiers as the preferred configuration, rather than oscillators, as used in most conventional lasers, giving far greater design freedom. As an indication of the extraordinary range of performance available from fiber lasers in c.w., pulse or single frequency regimes, the following results have been obtained recently in our laboratories:

3. Results

3.1 Oscillator Configuration

- 1.4kW 1070nm ytterbium-doped fiber laser (M^2=1.4)
- 600W polarized (PM) ytterbium-doped fiber laser
- 120W Q-switched ytterbium-doped fiber laser (0.6/8.4 mJ/pulse)
- 200W 1550 nm Er/Yb co-doped fiber laser
- 75W ytterbium-sensitized 2µm thulium-doped fiber laser

3.2 Master Oscillator/Power Amp Configuration (MOPA)

- 633W PM Yb fiber amplifier
- 511W single-frequency Yb fiber amplifier
- 150W 1550 nm single-frequency Er/Yb fiber amplifier
- 321W 20ps 1GHz Er/Yb amplifier (1550nm)
- 25W 100fs 5MW (peak) compressed-pulse amplifier (1060nm)

While this selection of results serves to highlight the performance envelope, records are tumbling at every conference, leading to the question of what are the limits. Most noteworthy in the table above are the results for single frequency (~20kHz linewidth), polarized laser output in a master oscillator/power amplifier (MOPA) configuration. Multiple amplifiers fed from a single seed source can be coherently beam combined provided they are polarized and narrow-linewidth. This provides a means of scaling fiber lasers from the current diffraction-limited record of 2.5kW reported by IPG [5] to perhaps beyond 100kW by stacking kW fiber lasers in beam-combined arrays with near-perfect beam quality. Moreover, the beam can be steered over a wide arc by phase controlling the outputs from each laser through, for example, fiber stretchers.

4. The MOPA configuration

The MOPA configuration offers further advantages for pulsed lasers, as required in many processing applications. Under the operator's control and using a low-power diode laser seed, the output pulse from a multi-stage pulsed MOPA laser can be carefully shaped to optimize peak power and processing parameters. In fact, there is little need to use the traditional and often fragile Q-switching or mode-locking techniques, when better control can be obtained through amplification to the kW regime. This revolutionary concept has led, for example to a recent report of a 321W Er:Yb MOPA operating at 1550nm and giving 20ps pulses at 1GHz [6]. At a commercial level, lasers giving ~1mJ, 100ns pulse width at 10kHz prf are available.

5. Conclusions

Despite these impressive results, fibre laser development is still in its infancy. We can expect perhaps 10kW output from a single diffraction-limited fibre, with several combining options for power-scaling to 100's of kW. Numerous pulse schemes are also available, giving pulses from 10's of fs to 20's of ns. Pulse energies up to 100mJ can be obtained from large core designs. In pulse mode as well, scaling by beam combination should give at least a tenfold increase in energy/pulse and peak power. Finally, wavelengths from 800nm to 2.1µ and beyond are seamlessly available through appropriate choice of rare-earth dopant or through Raman shifting.

All of the above impressive results have employed components originally developed for fiber telecommunications. Couplers, holey fibers, mode filters, DWM splitters, pump and signal diodes – all owe their existence to the telecom boom. The telecoms culture of reliability and consistent performance is also making an impact and is now recreating a mini-boomlet of its own in laser processing for manufacturing. Perhaps the next step will be to employ telecoms planar optical circuitry to laser design.

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