Fibre Lasers: The New Wave in Material Processing

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Abstract

In the last few years, fibre lasers have established themselves as the preferred laser source in many applications. The combination of small size, maintenance-free operation, thermal and electrical efficiency combined with outstanding (diffraction- limited) beam quality have made the fibre laser an attractive alternative to more established technologies. In fact, in some processes the fiber laser is the enabling technology.

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.

In this review paper, we will:

- Give a brief historical perspective of the invention and development of the fibre laser from its inception in the early 1960's, through the first end-pumped single-mode demonstration in the mid-1980's [1], to full commercial deployment [2].
- Describe a number of "state of the art" research results that not only demonstrate that the fibre laser can be scaled in power [3,4], but is also capable of operating in a number of advanced modes, such as single-frequency, pulsed or tunable, and at a variety of wavelengths.
- Give a view of the near-term commercial exploitation of these results, and finally
- Propose some future steps for both the technology and application of this unique technology platform.

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:

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

Master Oscillator/Power Amplifier 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 pk 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.

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.

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. This unique and powerful laser technology will increasingly be visible in the marketplace in coming years.

References

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