3663

The Diversity of Fibre Laser Technology

D. J. Richardson
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK

High power fibre laser technology has come of age over the past five years or so, due primarily to developments in fibre design and fabrication and semiconductor pump lasers. Fibre is now emerging as the technology of choice for a wide range of laser applications. Nowhere has the progress been more striking than in terms of the maximum continuous wave output power achievable from a single-mode fibre laser. Up until the start of 2001 the maximum reported output power from such a laser was ~110W. However, since then the reported power levels have risen rapidly and steadily such that by late 2006 values as high as 2.5kW were achieved with great prospects for further extension to the 10kW regime. Far higher power levels than this should be achievable in due course using beam combination technology. Fibre lasers are thus consequently now strong competitors to KW-class 'bulk' and thin-disk solid state lasers (for example, Nd:YAG and Yb:YAG) and CO_2 lasers for a wide range of industrial applications including materials processing, aerospace and defense. Relative to these competing technologies fibre lasers benefit from the advantages of compactness, efficiency, beam quality and arguably most importantly ready thermal management due to the large surface-area to volume ratio of the fibre geometry. The fibre laser is thus seen to have the potential to revolutionize both the range of uses and economics of high power laser systems.

Equally impressive as the advances in average power scaling, and perhaps just as, if not more important, from an end application perspective, have been the developments with regard to extending the versatility and diversity of the format of the output radiation, both in terms of temporal and frequency characteristics. Central to this has been the onward development of the fibre MOPA concept which allows the faithful and ready power scaling of the output from stable, high performance but generally low power seed lasers. Due to the excellent gain characteristics of fibres it is straightforward to achieve net signal gains in excess of 60dB using just a few simple amplification stages, with even higher gains possible when employing techniques such as in-line filtering and time-gating to reduce the build up of ASE through the system. For example, using this approach, fibre systems providing >400W of single frequency output in a single polarization, and single transverse mode have been achieved. Such MOPAs represent a suitable fundamental building block for the construction of even higher power coherently combined systems. Progress in the pulsed regime is equally striking. Femtosecond systems incorporating nonlinearity management techniques such as chirped pulse amplification (CPA) and Parabolic Pulse Amplification (PPA) can now be operated in the multi-10 W to multi-100 W regime. Moreover, pulse energies approaching 1mJ for CPA, and 1μJ for PPA have been reached, opening a host of potential further applications as diverse as materials processing through to X-ray generation. Likewise, the use of pulsed diode seed lasers operating in the GHz regime has enabled the development of picosecond systems operating at multi-100W power levels. These represent excellent sources for frequency conversion using external frequency converters and have been used for example to obtain power levels of nearly 100W in the visible regions of the spectrum. In the nanosecond regime multi-100W systems have also been achieved with single mode pulse energies as high as 10mJ, and by relaxing the mode quality pulse energies approaching 100mJ are possible. The above examples, which in most instances can be achieved simply by changing the seed laser, or by adding additional components to a suitable MOPA chain, emphasize the inherent flexibility, versatility and real power of the fibre approach.

To date most high power fibre laser work has focused on the Yb-doped system which operates at wavelengths around 1.1μm. This is mainly due to its high efficiency, and the availability of high power semiconductor pump sources at the pump wavelengths of 915 and 976nm. Indeed, essentially all of the results referred to above were achieved with Yb-based systems. However, high-power fibre lasers operating in the eye-safe region (1.5 – 2 μm) are also now attracting a lot of attention for use in important free-space applications such as remote optical sensing, range-finding, and free-space optical communications. Eye-safe lasers are significantly less efficient than Yb-doped fibre lasers at 1.1 μm. Nevertheless output powers around 300 W have been reported recently at 1.57 μm from an erbium-ytterbium co-doped fibre laser (EYDFL), and 200W around 2μm using Thulium. Power levels will undoubtedly also scale further in due course.

In summary, fibre lasers are now competitive in pure average output power performance terms relative to the more conventional bulk and disk high power laser systems with potential for yet higher powers. However, there is far more to this technology than raw power as the performance specifications above show. The versatility and flexibility of the fibre approach is truly unique and as a consequence fibre lasers have a very bright future indeed.