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High power fiber lasers and amplifiers/Lasers et amplificateurs à fibre de puissance

Foreword

Initiated in the field of optical communication systems, fiber technology development has been continuously drawn by emerging scientific, industrial and defence applications. Compared to conventional industrial lasers, fiber lasers are versatile, compact and robust solid-state sources that have intrinsically high beam quality. The Cladding-pumped fiber technology has revolutionized the last decade in the domain of solid-state lasers, increasing output power levels from less than 1 W with traditional core-pumping in the kW range. The recent technological breakthroughs were preceded by a long history of research and development: the first rare-earth-doped fiber laser was demonstrated in the early 1960s, the first practical erbium-doped fiber suitable for single-mode diode pumping in 1986, successful operation of a double-clad fiber structure with high-power broad stripe multimode laser diode pumping in 1988. Combining double-clad doped fibers with broad-area high-power semiconductor pump laser diodes has allowed the development of high brightness optical sources. The pump beam is launched into the double-clad fiber through multimode couplers and absorbed in the doped core during propagation. It allows signal amplification with possible diffraction-limited beam quality. The core diameter ranges from 6 μm for standard single-mode fibers to more than 40 μm for large mode area fibers. The Cladding-pumped fiber technology has led to a dramatically increase in fiber laser power: 35 watts was reported in 1998, 110 watts in 1999, 485 watts in 2003. Single-mode lasers and multi-core multimode Yb^{3+} fiber lasers have reached output powers above 2 kW and 50 kW respectively. The high beam quality of these lasers means that they compete directly with the established Nd:YAG lasers in many high-power industrial applications. The medical and biotech markets are driving a much development in femtosecond laser technology for optical diagnostics using fluorescence spectroscopy, whereas high-power fiber laser applications in nanosecond to microsecond duration regime focus on aerospace lidar applications, laser marking, laser welding, ... The high level of technical papers presented in prestigious conferences (CLEO, OFC, ECOC, ...) illustrates the research investment of many laboratories and the potentialities opened by theses technologies. The special issue "*Lasers et amplificateurs à fibre de puissance*" of the *Comptes rendus de physique de l'Académie des sciences* provides an overview of state-of-the-art and emerging technologies for fiber lasers and amplifiers. The principles, technologies and applications of fiber lasers will be presented through various contributions from various research institutes in France and Europe.

Fibre lasers are based on the fiber technology initially devoted to optical communications applications. The first article "*Fibres for high-power lasers and amplifiers*" by H.R. Müller et al. from IPHT (Germany) presents state-of-the-art on double clad fiber technology and design (cladding geometries, Large-Mode-Area fibers developed in order to increase the energy storage and reduce nonlinear effects). Fiber material and preparation, characterization of the most important fiber properties are outlined in this first communication. Nonlinear effects such as optical Kerr effect, Stimulated Raman Scattering (SRS) or Stimulated Brillouin Scattering (SBS) can be observed in high-power fiber amplifiers as short as a few meters. The second article "*Power limitations induced by non-linear effects in pulsed high-power fiber amplifiers*" by Y. Jaouën et al. from GET/Telecom Paris (France) analyses the non-linear dynamics for optical pulse amplification versus temporal pulse duration (picosecond, nanosecond and microsecond regimes).

Three articles focus on the performances and limitations of high-power fiber sources. The first "*Millijoule, high-peak power, narrow-linewidth, sub-hundred nanosecond pulsed fibre MOPA at 1.55 μm*" by C. Codemard et al. from University of Southampton (United Kingdom) reviews the challenges associated with power-scaling and the necessary design considerations for high-energy, narrow-linewidth fiber amplifiers. Up to 1 mJ and 6.6 kW peak power pulses have been obtained using a 90 μm core diameter fiber last stage MOPA ($M^2 \sim 5$). The article entitled "*Performances*

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and limitations of high brightness Er^{3+}–Yb^{3+} fiber sources" by G. Canat et al. from ONERA (France) balances the increase of the SBS threshold and beam quality when using LMA fibers under quasi-singlemode excitation. Pulse energies up to 100 µJ have been obtained from an-all fiber source operating close to the diffraction limit ($M^2 < 1.5$). The last contribution "*Ultrafast high-power fiber laser systems*" by J. Limpert et al. from Friedrich Shiller University Jena (Germany) reports on two different ways for generating diffraction-limited pulses in the MW range at 1040 nm: combined interaction of normal dispersion, gain and nonlinearity for generation of linearly chirped parabolic pulse and chirped-pulse amplification system.

The next two papers focus on high-power fiber laser applications. The Fibre-Injection System of the "Laser Méga-Joule" (LMJ) program facilities uses an arborescent architecture starting from a unique all-fiber oscillator onto a large number of synchronous independent amplifying beam sections. A. Jolly et al. from CEA (France) present in "*Fiber lasers integration for LMJ*" the current technological options for the design of the fibre injection system. Fiber lasers are becoming new effective sources for coherent lidars due to their spatial and spectral properties. In the article entitled "*Laser source requirements for coherent lidars based on fiber technology*", J.-P. Cariou et al. from ONERA (France) discuss on the performance enhancement offered by high-power fiber lidars for various lidar families (ground-based or airborne lidars, atmospheric or hard targets). Some potential applications for operational systems are presented.

The final contributions are dedicated to more advanced technologies and concepts for high-brightness optical sources. The first article "*Photonic crystal fibres for lasers and amplifiers*" by P. Roy et al. from IRCOM (France) presents a brief overview on photonic crystal properties in the field of amplifiers and lasers applications such as strong mode confinement, very large doped core with singlemode amplification and increasing of nonlinear power threshold. The second article "*Non-linear mode cleaning for high-power fibers*" by L. Lombard et al. from Thales TRT (France) describes original approaches to convert the multimode and depolarised output beam issued from a very large core fiber highly multimode Yb^{3+}-doped amplifier into a Gaussian beam: beam clean-up methods based on nonlinear two-wave mixing in photorefractive crystal, optical phase conjugation mirror using the SBS effect in a multimode optical fiber. In order to increase the nonlinear threshold, LMA fiber lasers have been developed. The last article of this journal entitled "*Coherent combining of fibre lasers*" by A. Desfarges et al. from IRCOM (France) presents an overview of alternative ways offered by coherent combining of several moderate power lasers which permits to extend the use of an available technology.

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