Aberration-Free, Rod-Based Amplifier-Modules for High Average-Power Lasers

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We show that the high average-power lasers with good beam quality can be built based on rod-shaped elements. The key concepts to achieve this breakthrough are radially polarized light, pump-chambers that produce no azimuthal aberrations and only controlled amounts of spherical aberration, and simple aberration correction elements. In this paper we show how to design multi-kW pump-chambers required in aberration-free amplifier modules.

Previously, good quality (BQ<10), multi-kW beams in rod-based lasers were achieved by combining radial-polarization's birefringence mitigation, together with spherical-optics based 1:(–)1 relay-telescopes that corrected third-order spherical (SA $\approx 5\lambda$) and odd-order azimuthal aberrations. Beam-quality was limited by azimuthal pump-inhomogeneities and by radial profiles that didn't account for temperature-dependent refractive-index and thermal-conductivity.

We here present simulation-results showing the possibility of "aberration-free" amplification, and describe rod-based pump-chambers designed to work with radial polarization and external third-order SA correction. Free-parameters were: shape, orientation, and location of light-guides coupled to horizontal diode-arrays, diffuse-reflector inner-diameters, and diode-array number.

Two-dimensional simulation tools included a Monte-Carlo ray-trace program to calculate absorption profiles, a heat-flow program with temperature dependent material properties to calculate temperature distributions, and a phase-front program with thermo-optical dependences to compute optical path differences (OPD) and Zernike coefficients.

The resulting design had no azimuthal pump variations throughout most of the rod. Peak-to-valley (PtV) azimuthal OPDs were 0.1λ and 0.05λ for single and dual (relay-imaged) pump-chambers ($P_{heat\_per\_rod}$=1100 W). Seven-sided pumping gave good results close to the asymptotic limit. The radial absorption-profile was optimized to minimize higher-order SA after subtraction of third-order SA. The resultant radial PtV OPD was 0.1λ and 0.2λ for single and dual (relay-imaged) amplifier-modules ($P_{heat\_per\_rod}$ =1100 W).

Beam-quality degradation for two relay-imaged pump-chambers was ΔBQ=2. Radial polarization remained pure. In saturation, this module contributes ~2300W laser power ($P_{heat\_2\_rods}$ = 2200 W).

Sensitivity analysis showed that the design was insensitive to mechanical misalignment. Standard mechanical tolerances suffice, and easy assembly is facilitated with alignment pins. Variations in the spectral properties of the diode-arrays are an issue, but it is one that can be dealt with by selection of arrays with matched spectral characteristics.

These design considerations have now been experimentally confirmed and our high-power, good beam-quality rod-based lasers are now based on this design. The synergistic combination of radial polarization, advanced pump-chamber design, and aspheric aberration correcting phase-plates is providing us with a renaissance in rod-based high-power lasers.

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