Research Progress on Beam Combining of Fiber Amplifiers in IOE, CAS

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Abstract—We report the most recent progress on beam combining (BC) of fiber amplifiers in IOE, CAS. Experiments of coherent and incoherent BC based on new-style correctors and novel tip/tilt control strategy have been demonstrated.

Keywords—coherent and incoherent beam combining; adaptive fiber-optics collimator; tip/tilt control; adaptive optics

Coherent and incoherent beam combining (BC) of fiber amplifiers via a master-oscillator-power-amplifier (MOPA) architecture is an outstanding way for brightness scaling with good beam quality. In recent years, BC researches based on new-style correctors and novel tip/tilt control strategy have been implemented in the Institute of Optics and Electronics (IOE), Chinese Academy of Sciences (CAS).

To compensate the piston-type aberrations, piezoelectric-ceramic-ring fiber-optic phase-modulator (PZT PM) has been developed with a half-wave voltage of 3.1-V and a frequency response of about 90-kHz. To correct tip/tilt-type aberrations, the adaptive fiber-optics collimator (AFOC) has been designed based on different fibers. One kind of AFOC employing PM-980 fiber from Nufern is used for low-power applications, where the deflection angle of collimated beam is in range ±0.5-mrad and the first resonance-frequency is about 1.85-kHz. Another kind of AFOC employing the 20/400 LMA double cladding fiber is used in high-power places with output power of 0.5-kW, where the deflection angle is in range ± 0.29-mrad.

The stochastic parallel gradient descent (SPGD) algorithm is used for phase-locking and tip/tilt control. A novel approach of tip/tilt control by using divergence cost-function in SPGD algorithm for BC is proposed and demonstrated for the first time to our best knowledge. Compared with the conventional power-in-the-bucket (PIB) cost-function for tip/tilt control, this method ensures wider correction range, automatic switching control of program, and freedom of camera’s intensity-saturation.

The aberration correctors mentioned above and the proposed tip/tilt control strategy have been demonstrated in the following BC experiments:

Coherent BC of a seven-channel 2-W fiber amplifier array with correcting both piston- and tip/tilt type phase errors simultaneously is achieved. The 37-second long-exposure far-field intensity distributions are shown in Fig. 1. In open loop, seven spots are visibly separate in the far-field, as shown in Fig. 1(a). When tip/tilt control is implemented, the dispersive spots overlap well, but the corresponding long-exposure pattern is an incoherent one with a fringe visibility of nearly zero, as depicted in Fig. 1(b). Fig. 1(c) describes the realized coherent BC result with intensity maximum in the centre. Fig. 1(d) is the partial enlarged view of Fig. 1(c) in the red square area. In this experiment, an average of 432-μrad of divergence metrics in open loop has decreased to 89-μrad when tip/tilt control implemented. In coherent BC, the power in the main lobe increases by 32 times, and the phase residual error is less than \( \lambda/15 \).

Another demonstration is the incoherent BC of four high-power single-mode fiber amplifiers. AFOCs of 0.5 kW-level are employed to correct tip/tilt-type phase errors among beamlets. Fig. 2 describes the snapshots of combined beams in the far-field under the output power of 1.5-kW, when tip/tilt control is off and on, respectively. In open loop, four spots are visibly separate in the far-field. When control on, the dispersive spots overlap well, which indicates the tip/tilt aberrations of beamlets are corrected and closed loop is achieved. Here, the average of metrics increased from 0.171 in open loop to 0.798 in closed loop.

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