Effects of fill factor of fiber combiner on the all-fiber coherent combining

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A new approach for an all-fiber coherent beam combining by active phasing a fiber combiner is presented, and effect of fill factor of the fiber combiner on the all-fiber coherent combining is also numerical analyzed. Experimental results show that the power in the bucket (PIB) increases more than a factor of 2.35. The results validate the feasibility of coherent combining using a fiber combiner. The PIBs with different fill factors are calculated and the results show that the coherent combining is reduced with the increasing fill factor.
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Fiber laser has been attracting much attention, mainly because of its ability to provide good beam quality, high efficiency, compactness, and high reliability[1−3]. At present, a commercial single mode fiber (SMF) laser with 10-kW output power has been developed by IPG[1]. However, due to the fiber damage and nonlinearity in a single diffraction-limited fiber laser chain that operates in fundamental mode, further scaling the output power to a higher level is a challenging task. Coherent beam combining (CBC) technology is an effective solution to not only scale the output power but also maintain high beam quality[4−7]. The main configurations for CBC can include two categories: the free-space configuration and the all-fiber configuration. In free-space configuration, kilowatt level output power together with high beam quality has been reported[4,5]. However, beam combining in all-fiber configuration, which is a desirable path for reliable, compact, rugged, and efficient high power laser systems[6−8], is by far lagged. Fiber combiner is also a popular alternative to scale the output power in all-fiber form. And a laser system with 50-kW output power has become commercially available by IPG in 2010[9]. Nevertheless, the brightness is not increased and the $M^2$ factor of the output beam is 32.7, far from the near-diffraction-limited beam[10]. In many laser application fields, especially for the long-distance delivering, a laser with poor beam quality will become quickly inadequate, even if it has sufficient power. How to scale power while simultaneously preserving brightness by a fiber combiner is a challenge for us. In this letter, we will demonstrate an all-fiber and all-active coherent combing using a fiber combiner. This approach is assisted with active phase control and beam cleanup technology. In addition, the effect of fill factor on the coherent combining is also discussed.

For a better understanding, we firstly compare two schemes of beam combining with tapered fused bundles (TFBs) when input lasers are combined incoherently and coherently as shown in Fig. 1. Figure 2 illustrates the end face of a 7×1 TFB tip with full fusion degree. The claddings are fused and merged into unity one, leaving the seven cores alone. The simulated outputs results are shown in Fig. 3. Figure 1(a) shows that $N$ laser sources are launched into respective SMFs, and the output is combined incoherently (Fig. 2(a)). The total output power scales with the number of lasers without brightness improvement. However, if one laser source is split into $N$ SMFs, as shown in Fig. 1(b), all the fiber elements operate with the same wavelength and the relative phases of the elements are controlled. The coherent combining output is satisfied. Both output power and brightness are up-

![Fig. 1. Two schemes of beam combining with TFB (a) incoherently and (b) coherently.](image1)

![Fig. 2. End-view image of 7×1 TFB with full fusion degree.](image2)
Fig. 3. Simulated outputs of a 7×1 TFB launched (a) incoherently and (b) coherently.

It is possible to achieve coherent combining in all-fiber via an appropriately designed fiber combiner.

Fig. 4. Schematic of the experimental system.

Fig. 5. Experimental results. Captured image of far-field intensity distribution (a) before and (b) after cleanup; (c) evaluation function curve.
Fig. 6. Array distribution of the TFB tip.

Fig. 7. Intensity distribution of the respective far-field with different $v$ in the $x$ direction.

Fig. 8. Relationship between the PIB values and fill factor $v$.

the beam quality is reduced with the increasing $v$. The results are consistent with that of the free-space coherent combining laser arrays.

In conclusion, a new all-fiber coherent combining configuration is presented. Using active control and beam cleanup technology, a high power output maintaining good brightness is realized by the fiber combiner. Meanwhile, the effect of the fill factor of the fiber combiner on the coherent combining is studied numerically.

Results show that a fiber combiner with a smaller fill factor is more efficient for the all-fiber coherent combing. In order to decrease fill factor, the fiber cladding, which does not carry power, should be reduced. Hydrofluoric acid is an effective way to etch away the fiber cladding, and therefore the taper ration can be minimized. This conclusion offers a guide for designing and manufacturing the fiber combiner used for coherent combining.

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References