The resultant complex field, $g=|g|e^{i\xi}$, is then Fourier transformed again, and, the four-step sequence of operations repeats, until a predetermined convergence condition is satisfied. As an example, the convergence condition can entail that the correlation of the complex field (at a given plane) upon iteration n and upon iteration n+1 be greater than a specified threshold, the value of which is dependent on the end-user application. Throughout the iterative process, the phase functions **315** and **335** (ξ and ϕ, respectively) are unconstrained, with the converged phase functions determining the required phase plate spatial profiles for DOE-**1** and DOE-**2**, respectively.

Note that the G-S algorithm can proceed in a different order of steps, depending upon the end-user's preference. As an example, to design a mode converter that transforms the HOM of a ribbon fiber to a fundamental mode (e.g., TEM_{00}), the sequence of operations depicted in FIG. **3** would become ordered as Steps 3-4-1-2. That is, initially, in Step 3, the HOM constraint ($|G|$) **330** is first specified; followed by a Fourier transform, resulting in Step 4; at which point, the seed fiber oscillator amplitude constraint ($|g|$) **310** replaces the transformed amplitude ($|g'|$) **340** as depicted in Step 1. This is followed by a Fourier transform, resulting in Step 2; at which point, the HOM amplitude constraint ($|G|$) **330** replaces the transformed amplitude ($|G'|$) **320**, completing the first iteration, with the sequence repeating. As before, the phase functions **315** and **335** (ξ and ϕ, respectively) are unconstrained, with the converged phase functions determining the required phase plate spatial profiles, DOE-**1** and DOE-**2**, respectively. In the experiments discussed below, the threshold condition was set to 97%, implying that the normalized overlap integral that characterizes the goodness of the iterative process is close to unity.

5. Mode-Converter Design and Simulation

Returning to FIG. **1**, the input plane (corresponding to the location of DOE-**1**) of the mode conversion system is assumed to be situated at the near-field plane (or, an image relay plane thereof) of the seed laser output beam, whereas the output port of the mode conversion system is situated at the near-field plane of the input to the ribbon fiber (or, an image relay plane thereof). Without loss of generality, we assume that the optical beams are monochromatic and possess a single polarization state. Hence, a scalar representation of the optical fields can be utilized. Moreover, we assume that the ribbon fiber is of a single-mode in the orthogonal direction, thereby reducing the system design to a one-dimensional model.

As discussed above, a mode converter that transforms a TEM_{00} (or, a LP_{01}) mode to a given multi-lobed higher-order-mode (HOM) must redistribute the energy from a Gaussian profile (typical of a fundamental mode) to a HOM profile with multiple-lobes in the transverse direction. Another necessary condition is that the phase-front of the HOM is characterized by a spatial phase profile that alternates between 0 and π radians that correlates with the multi-lobe amplitude profile. Accomplishing these two tasks necessitates two diffractive-optic-elements (i.e., phase-only plates; one for each task) as illustrated in FIG. **1**. The first phase plate, DOE-**1 110**, steers and reshapes the input Gaussian profile **140** to generate an appropriately scaled, multi-lobed amplitude profile **150** that corresponds to a given higher-order guided-mode of the ribbon fiber, which is positioned at the plane of the second phase plate, DOE-**2 120**. The second phase plate, in turn, imposes the requisite amount of phase shift across the wavefront, **155**, to achieve multiple lobes whose phase alternates between 0 and π.

By placing the first phase plate (DOE-**1**) **110** at the waist of the input mode, we ensure that incident beam's phase-front is flat, which is characteristic of the fundamental mode of the seed fiber oscillator. The second phase plate (DOE-**2**) **120**, in turn, is placed in the conjugate Fourier plane with respect to the first phase plate. As noted above, the system is configured so that the location of second phase plate (DOE **2**) along the optical axis coincides with the near-field of the ribbon fiber amplifier input plane.

Turning now to FIG. **4**, a single-pass MOPA system implementation is shown in which a mode converter module is used to enable efficient coupling of a low-power master oscillator into a high-power ribbon fiber amplifier. The basic system is comprised of a single-mode fiber seed laser **460**, which is assumed to provide a diffraction-limited LP_{01} output beam. The power amplifier stage, in this example, is comprised of a ribbon-fiber amplifier **470**. For this simulation, the fiber amplifier cross section is similar to that depicted in FIG. **2**. The ribbon-fiber is oriented in FIG. **4** so that the y-axis lies in the plane. The laser beam propagates along the z-axis, corresponding to the optical axis of the system. The same coordinate system convention is employed in all subsequent system diagrams herein.

A mode converter module **400** is used to efficiently convert the LP_{01} input beam into a desired higher order mode (HOM), which is launched into the ribbon amplifier **470**. The amplified output beam **480** exits from the downstream facet of the fiber amplifier.

The basic mode converter module **400** is comprised of a pair of DOEs, **410** and **420**, separated along the optic axis by a distance, $2f_1$, with a Fourier transform lens **430** placed at the mid-plane. This triplet is similar to the basic module shown in FIG. **1**, with the respective elements **110**, **120** and **130**.

The system **400** is further comprised of a pair of relay lenses, **440** and **450**, of focal lengths, f_2 and f_3, respectively. Relay lens **440** is used to image the near-field of the seed laser output plane to the upstream diffractive element DOE-**1 410**, whereas relay lens **450** is used to image the downstream diffractive element DOE-**2 420** (which also corresponds to the far-field of the seed laser output plane) to the near-field input plane of the ribbon-fiber amplifier **470**.

Recall, from FIG. **2**, we use the 7th eigenmode of the ribbon fiber i.e., a rectangular 5 μm×50 μm silica core with 0.1 NA and circular cladding), which has 7 lobes along the width of the core. As is well-known for this HOM, the phase of each lobe is 0 or π. Since the rectangular effective waveguide is designed to possess a single mode in the x-direction, in this dimension, the eigenmode can be transformed to the appropriate size using cylindrical lenses. Using the G-S algorithm in 1-D, we solve the phase profiles of the two DOEs that transform a diffraction-limited Gaussian profile to the ribbon fiber's higher-order eigenmode.

FIGS. **5**A through **5**D show results of the G-S algorithm, subject to the constraints noted above. Specifically, one constraint, is the near-field amplitude ($|g|$) of the seed laser output **510**, as shown in FIG. **5**A, whereas, the second constraint is the near-field amplitude ($|G|$) of the 7^{th} order HOM of the ribbon-fiber amplifier **520**, as shown in FIG. **5**B. These amplitudes correspond to the magnitude of the EM fields incident on DOE-**1** and DOE-**2**, respectively. The G-S result for the phase-unwrapped profile (ξ) **530** for the field incident on DOE-**1** is shown in FIG. **5**C, whereas, the phase-unwrapped profile (ϕ) **540** for the field incident on DOE-**2** is shown in FIG. **5**D. Note that DOE-**1** has a phase-excursion that spans approximately 1.5 waves. This phase plate essentially steers and reshapes the Gaussian input profile to achieve multiple-lobes in the plane of DOE-**2**. On the other hand, DOE-**2**