Full characterization of a semiconductor laser beam by simultaneous capture of the near- and far-field
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**INTRODUCTION**
- We present a new measurement method for fully characterizing a laser beam, i.e. determining the optical phase as well as the intensity.
- The method is based on the simultaneous capture of the near- and far-field, making this method very useful for laser beams with temporal variations in intensity and/or phase.
- A single plano-convex lens is used to create equally large images of the near- and far-field.
- Anti-reflectance coatings on the lens surfaces reduce the need for attenuating filters that disturb the phase, when measuring on high-power lasers.
- When the optical phase has been retrieved, the $M^2$-value can easily be determined by numerical propagation.

**METHOD**
- Phase retrieval is used to iteratively determine the phase distribution.
- A modified version of the Gerchberg-Saxton algorithm is used for the phase retrieval.
- The two-step method is used for numerical propagation of the optical fields, providing a free choice of sampling distance in the last plane common to both branches, i.e. just before the plano-convex lens.

**RESULTS – TEM10 CASE**
- The method can also handle higher order modes with rapid phase variations, for instance the TEM10 mode, see Fig. 4.
- The $M^2$-value was in this case found to be 3.3 in the $x$-direction and 1.3 in the $y$-direction.

**RESULTS – TEM00 CASE**
- Fig. 3 shows the results for a beam from an OP-SDL, (optically pumped semiconductor disk laser) operating in TEM00 mode.
- The retrieved intensity distributions match the measured distributions to a very high degree.
- The $M^2$-value was found to be 1.1 in both the $x$- and $y$-directions.

**SETUP**
- The main components in the experimental setup, see Fig. 1, are a plano-convex lens and a CCD camera.
- Light incident on the lens will be reflected both at the flat and at the curved surface of the lens, splitting the beam into two branches.
- Branch 1, created by the flat surface, will produce the far-field on the CCD camera, see Fig. 2.
- Branch 2, created by the curved surface, will produce a magnified image of the near-field on the CCD camera, see Fig. 2.
- When the CCD camera and the plano-convex lens are correctly aligned, the CCD camera will capture the intensity distributions of the near- and far-field.
- The capture will be simultaneous; the near- and far-field are part of the same beam and invariant to temporal variations.
- The fields can be made to fill equally large areas on the CCD camera, which makes the phase retrieval more stable.

**METHOD VALIDATION – INTRODUCTION OF KNOWN WAVEFRONT CURVATURE**
- For validation, a cylindrical lens was inserted in the beam.
- The resulting phase distribution was simulated in MATLAB.
- The phase distribution was also retrieved through our method.
- The retrieved and simulated phase distributions show a convincing agreement, see Fig. 5.

**Fig. 1.** A schematic view of the experimental setup. The near- and far-field images on the CCD camera are created by a single optical component: a plano-convex lens.

**Fig. 2.** The two optical branches in the setup, created by reflections at the flat and the curved surfaces of the plano-convex lens.

**Fig. 3.** Close match between the measured and retrieved intensity distributions of a TEM00 laser beam. The retrieved phase distribution is overlaid with intensity contours (50%, 10%, and 2% of peak).

**Fig. 4.** The measured and retrieved intensity distributions for a TEM10 mode laser closely resemble each other. The retrieved phase distribution shows that rapid phase variations can be handled.

**Fig. 5.** The good match between the retrieved and simulated phase shows the accuracy of the phase retrieval in this method.