Self-healing of Bessel beams

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Overview

The electric field of ideal Bessel beams is proportional to the zeroth order Bessel function and their intensity profile is unaltered by propagation in free space. The beams can reconstruct themselves after being disturbed by an obstruction, which is referred to as “self-healing-effect”. Approximations of ideal Bessel beams can be generated, which approximately have the same properties as ideal Bessel beams along a finite range. Due to the self-healing effect the beams are advantageous for micro drilling of (transparent) materials, or for optical tweezing, for example. In order to analyze the self-healing effect of Bessel beams, a set-up was built, which visualizes the process of reconstruction of the beam behind an obstacle.

Experimental setup

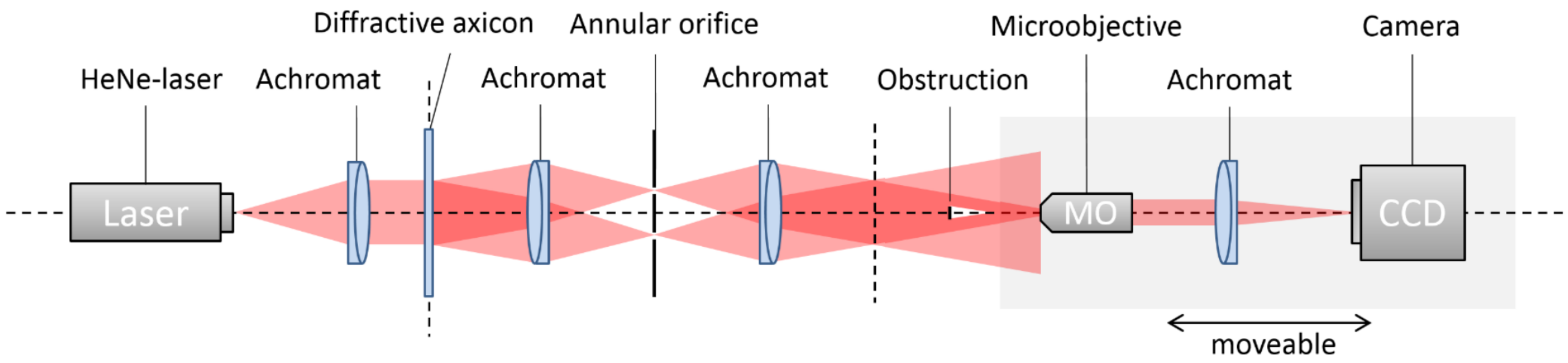

Figure 1: *Experimental set-up*

Behind the diffractive axicon a $4F$-system transmits only one diffraction order. An aperture is placed behind the $4F$-system in order to obstruct the Bessel beam. Using a combination of microobjective, (tube-) lens and CCD-camera, which are firmly connected together on a slider, the area behind the obstruction is analyzed and the self-healing process becomes observable. A Bessel beam can be considered as ’healed’ when: [1]

$$f_O\left(x,y,z\right) \approx \lambda_0 f\left(x,y,z\right) \tag{1}$$

Here, $f_O\left(x,y,z\right)$ is the obstructed field, $f\left(x,y,z\right)$ the unobstructed field and $\lambda_0 = \sqrt{\frac{I(f_O)}{I(f)}}$ is a scaling factor that accounts for the intensity reduction due to the obstacle.

On-axis obstruction

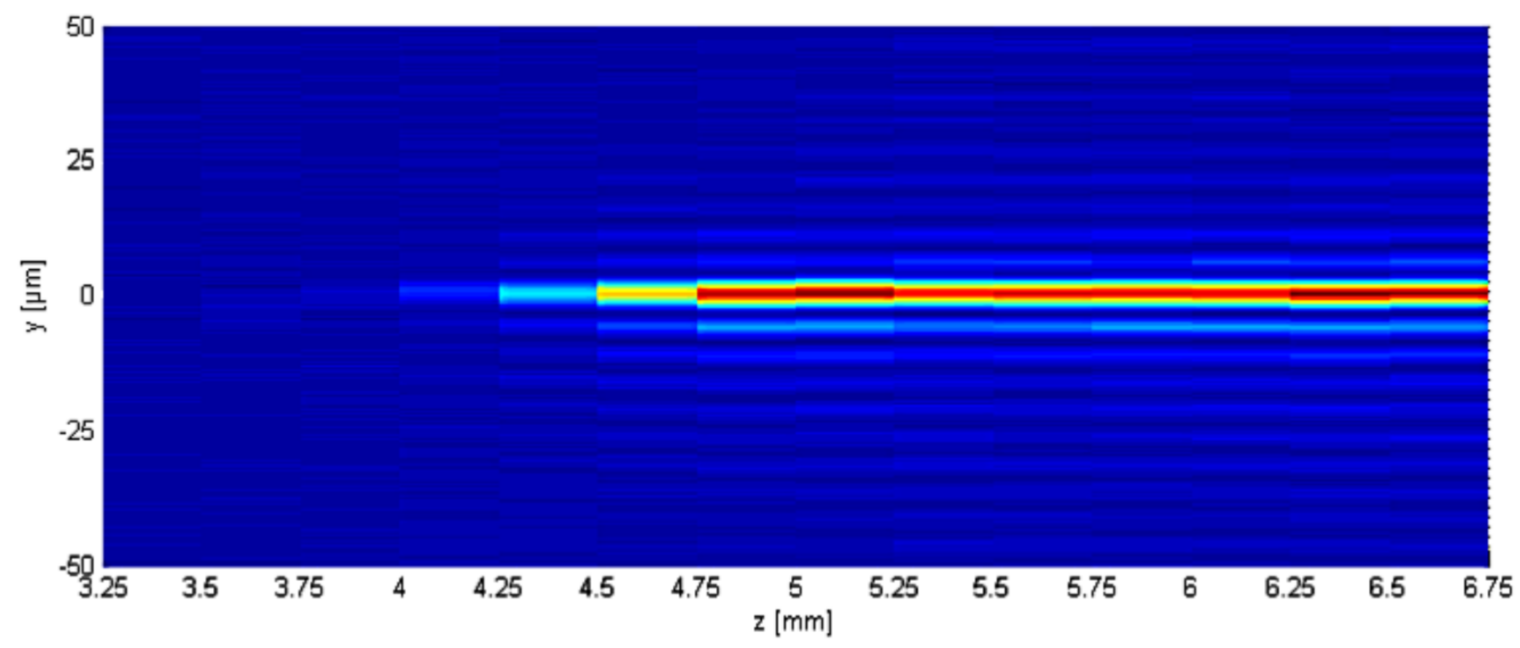

Figure 2: *Distribution measured with setup: Bessel beam in y-z-plane (y=lateral-, z=axial direction), wavelength $633nm$, diffractive axicon of $10\mu m$ lattice spacing, circular on-axis obstruction of $0.55mm$ diameter at $z = 0mm$*

Figure 2: cross-section of a Bessel beam along the optical axis (y-z-plane) behind an on-axis obstruction. Due to geometrical optics, the first interference rings should occur at $z = 4.34mm$ from the obstruction. However, the beam recovers earlier due to diffraction at the obstacle.

Figure 3: correlation coefficient of the obstructed beam with the corresponding unobstructed field. The beam has restored its intensity profile for the most part before reaching the ’geometrical self-healing distance’ (green line). The self-healing process can be considered completed before the shadow of the obstruction leaves the area used for correlation (red line).

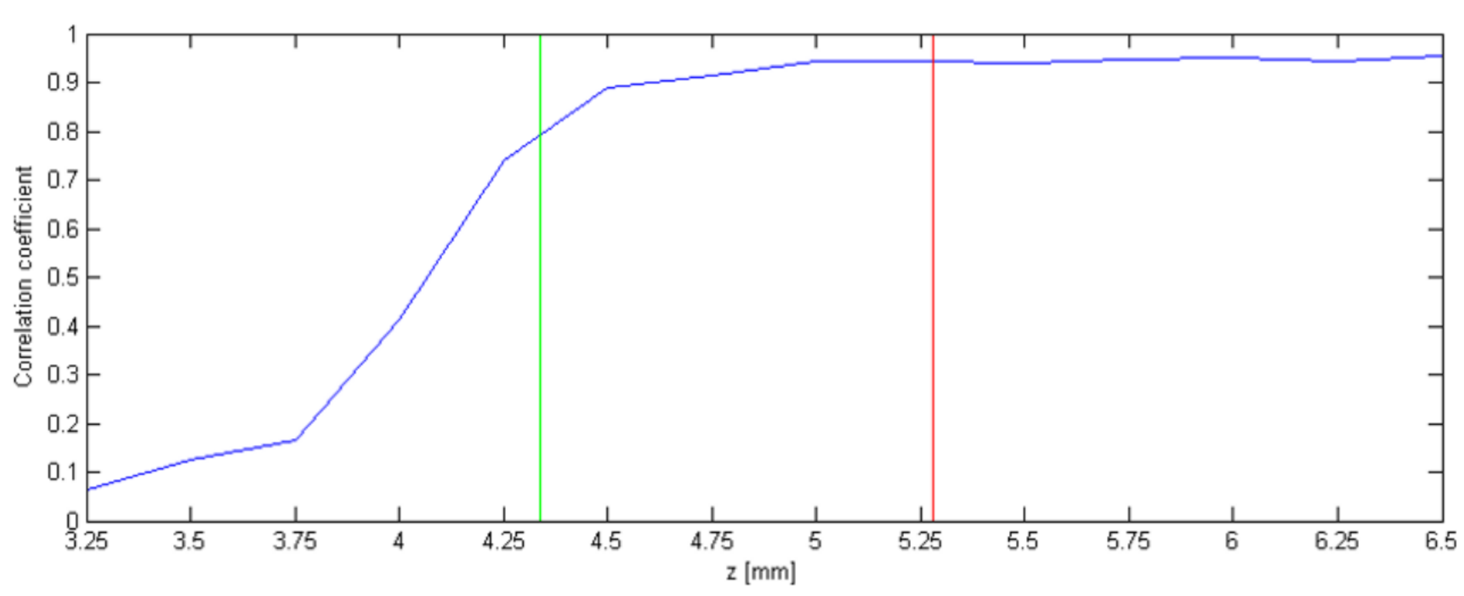

Figure 3: *Correlation coefficient of obstructed Bessel beam with unobstructed beam, green line: self-healing should start here according to geometrical optics, red line: shadow of obstruction leaving area of correlation*

Off-axis obstruction

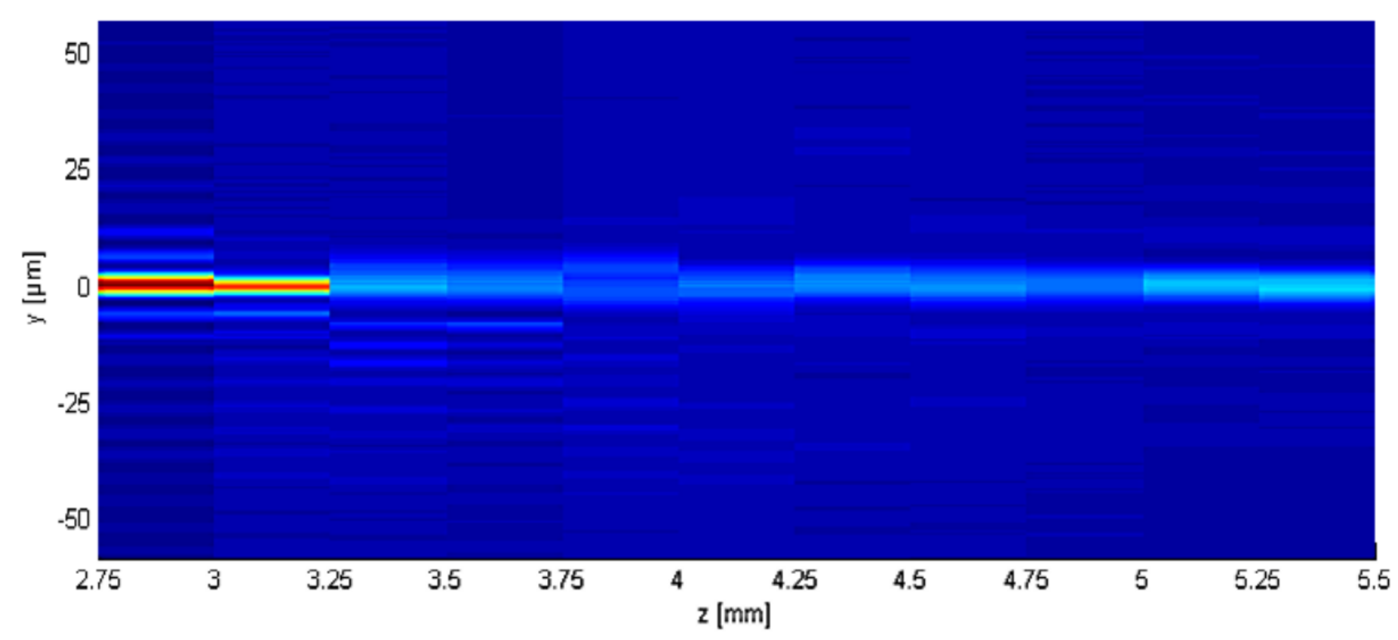

Figure 4: *Distribution measured with setup: Bessel beam in y-z-plane (y=lateral-, z=axial direction), wavelength $633nm$, diffractive axicon of $10\mu m$ lattice spacing, circular off-axis obstruction of $0.55mm$ diameter at $z = 3mm$ shifted by $y = 0.28mm$ from optical axis*

Figure 4: cross-section of the Bessel beam along the optical axis (y-z-plane) behind a circular off-axis obstruction at $z = 3mm$ (it covers the upper half of the beam). It takes a longer distance for the Bessel beam to recover behind the off-axis obstruction than behind the same on-axis obstruction (see Figure 5). The self-healing process can be considered completed before the geometrical shadow of the obstruction vanishes from the area of correlation (red line, Figure 5).

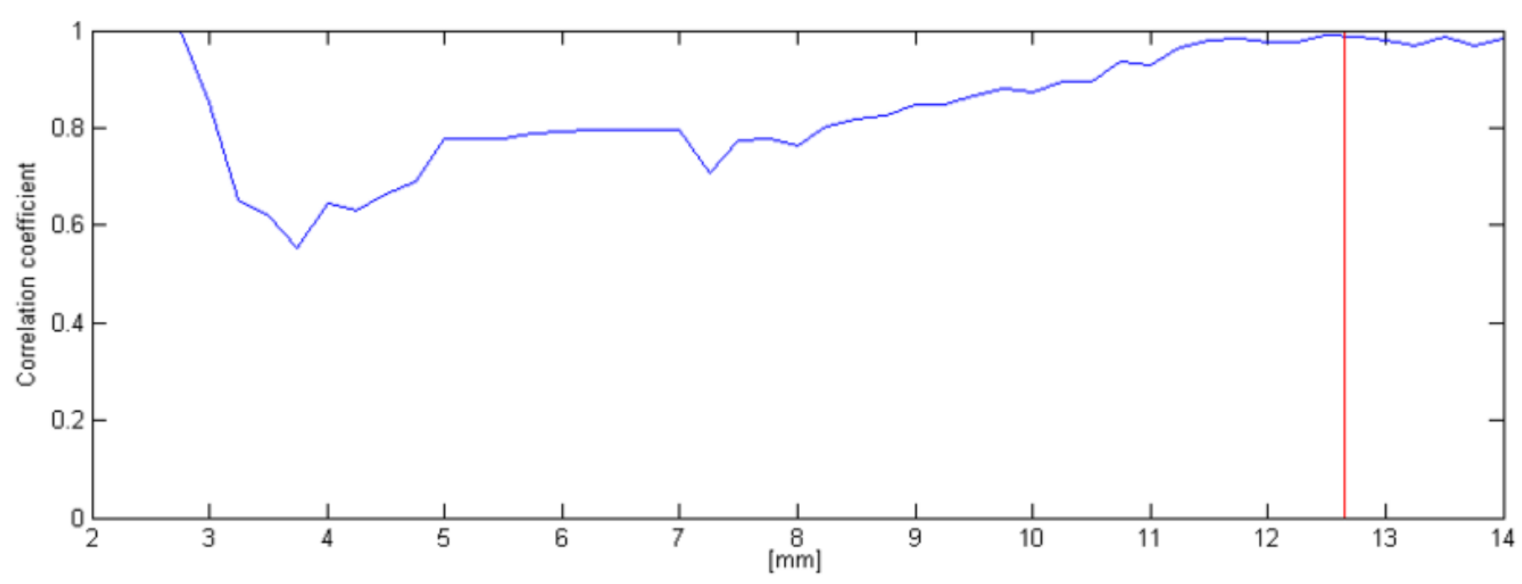

Figure 5: *Correlation coefficient of obstructed Bessel beam with unobstructed beam, red line: shadow of obstruction leaving area of correlation*

SUMMARY OF RESULTS: Diffraction plays an important role in the self-healing process of Bessel beams. Off-axis obstructions perturb the Bessel beam more strongly than on-axis obstructions. Both, for on- and off-axis obstructions, the Bessel beam reconstructs its initial intensity profile almost completely.

[1] A.Aiello and G.S.Agarwal. Wave-optics description of self-healing mechanism in bessel beams., *Opt. Lett.*, 39(24):6819–6822, Dec 2014.

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