Investigation of the geometrical depth of focus of focal spots obtained by scattering lenses operating in the transversal and lateral direction

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The combination of scattering media with spatial light modulators has paved the way to imaging around corners [1] and beyond diffuse media as well as focusing light below the diffraction limit (see ref [2] and refs therein). Here we present for the first time, to the best of our knowledge, experimental results on focusing laterally through a scattering medium. We investigate quantitatively the focal spot by measuring the focal width and the geometrical depth of focus (DOF) for both transversal and lateral scattering lens configurations.

An experimental set-up based on the design of Vellekoop, with the stepwise sequential algorithm [3], was used to modulate the spatial light modulator (SLM) to focus light through a 2 mm thick Teflon sample (Fig. 1a). In the first experiment the focus was found in the conventional transverse direction. After the focus was obtained, images were taken from the focal spot while translating the imaging system through the focal length in steps of 5 micron. The maximum intensity of the focal spot was measured from these images (see Fig. 1b). In the second experiment we employ a novel lateral experimental configuration as shown in Fig. 2a. The focus was found in the lateral direction, where the spatially modulated light propagates through the sample and focuses around a corner (see Fig. 2b).

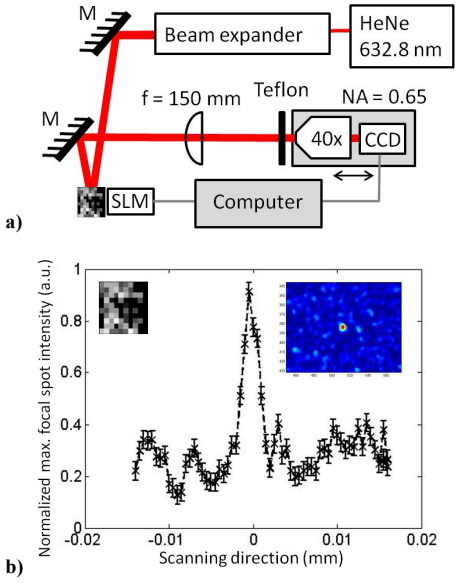

Fig. 1 (a) Experimental setup for focusing transversally; (b) maximum intensity of focal spot while scanning through the focal length. Insets show phase mask SLM and focus.

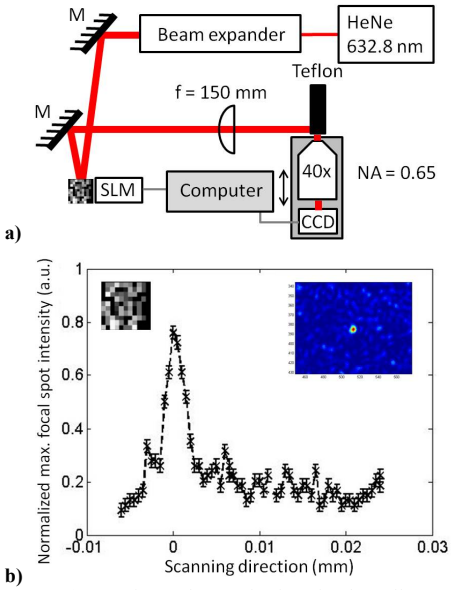

Fig. 2 (a) Experimental setup for focusing laterally; (b) maximum intensity of focal spot while scanning through the focal length. Insets show phase mask SLM and focus.

The focal widths are determined from the focal spot images from the insets in Fig. 1b-2b and are 2.5 µm and 2.7 mm for the transverse and lateral obtained foci, respectively. The intensity plots in Fig. 1b-2b show clear peaks on top of the background speckle modulation. The DOF is obtained by measuring the length over which the focal intensity is higher than half of the full intensity at z = 0 µm, i.e. the FWHM. The obtained DOF is 2.0 µm and 2.5 µm for the transverse and lateral obtained foci, respectively. Both the focal width and the DOF of the two foci are smaller than what one would expect from the size of the beam impinging the sample.

We have demonstrated, for the first time, lateral focusing of light through scattering media. In addition we have demonstrated that the quality of scattering lenses, besides of having a focal width below the diffraction limit, is that of having a very short DOF, which makes scattering lenses good candidates for precise energy delivery in 3D.

References

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978-1-4673-7475-0/15/$31.00 ©2015 IEEE