Scatter-plate microscopy with coherent illumination and moving scattering media

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Scatter-plate microscopy is a lensless technique for high-resolution microscopic imaging through light-scattering media. We used the method with spatially coherent sample illumination and further realized imaging through moving scatter-plates.

1 Introduction

Scatter-plate microscopy (SPM) exploits the optical memory effect of light-scattering layers to realize microscopic imaging with variable numerical aperture (*NA*) and variable magnification [1]. In SPM images are retrieved from random intensity patterns generated by positioning a thin scattering medium between the object and the recording plane. Image retrieval is realized by cross-correlating these patterns with the speckle pattern of the previously recorded point spread function (PSF) of the scattering medium. The magnification of SPM is given by the distance between the scattering layer and the recording plane over the distance between the scattering layer and the object plane.

It has been predicted that the method should work with coherent sample illumination [2]. However, so far the method was just realized with temporal coherent, but spatially incoherent sample illumination. For the first time we realized now SPM with both temporally and spatially coherent sample illumination. Moreover we could demonstrate that SPM is also possible with a non-static temporal modulated scatter-plate.

2 Methods

It turns out that for imaging with spatially coherent sample illumination by cross-correlating a single pattern with the PSF, the extend of the pattern must be quite large. However, alternatively we found out that the image can be retrieved by averaging results acquired with many different scatter-plates [3]. Following this approach, we decided to place a coherently illuminated sample and a point-source-like light source at the same time in the object plane and recorded the resulting pattern (Fig. 1). While SPM is commonly a two-shot technique (sample pattern and PSF are recorded separately and the image is retrieved via cross-correlation), with this single-shot approach, the image is now retrieved from the autocorrelation of a single pattern [4]. It is essential in this imaging configuration that the intensity irradiated by the sample is approximately the same as the intensity of the point source. Therefore, two polarizers were installed to adjust the illumination intensity. Instead of using different scatter-plates, we used a single ground glass diffuser, which we rotated between two pattern acquisitions. The single-shot approach opens up new possibilities to SPM, for both spatially incoherent and spatially coherent sample illumination. It allows imaging through a scatter-plate which change its scattering behaviour during the pattern recording. The possibilty of image retrieval is in this case guaranteed as long as the local phase changes an incoming light beam undergoes on the scatter-plate are continuously and independently from the phase changes at other locations. Further it must be ensured, that the recording device can record a high-contrast pattern.

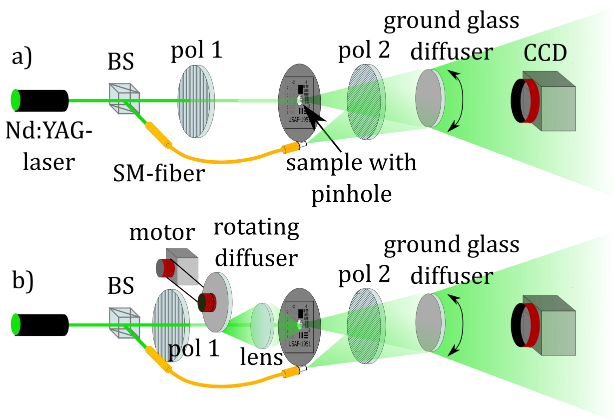

Fig. 1 *Experimental setup of scatter-plate microscopy. In the single shot configuration the PSF and the pattern generated by the sample are recorded at once. a) Coherent sample illumination. A laser (wavelength 532nm) illuminates the sample. A pair of polarizers are used to adjust the laser beam intensity. The point source is approximated by a SM-fiber. A ground glass diffuser, which can rotate both stepwise and continuously is used as the scatter-plate. Images are recorded with a CCD-Camera (6576 x 4384 pixels, 5.5 µm x 5.5 µm pixel size). b) To realize spatially incoherent sample illumination, a rotating diffuser and a collimating lens are inserted in the beam path.*

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3 Results

To realize SPM with spatially coherent sample illumination we averaged over images acquired with different orientations of a single ground glass diffuser. In Fig. 2 we demonstrate the capability of the SPM-setup shown in Fig. 1 with both spatially coherent and spatially incoherent sample illumination. Fig. 3 show results for imaging through a continuously rotating ground glass diffuser. The diffuser rotated during the recording of the pattern with $4.2\,°\mathrm{s}^{-1}$. It is obvious that in the case of spatially incoherent sample illumination less images have to be averaged to acquire good image quality.

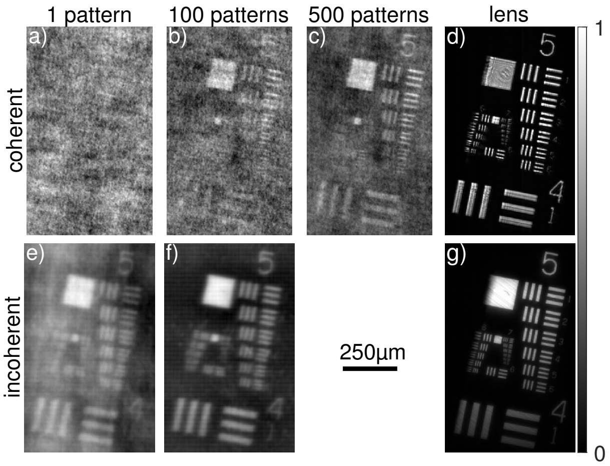

Fig. 2 *SPM with spatially coherent (a-c) and spatially incoherent (e-f) sample illumination. A ground glass diffuser served as scatter-plate. We recorded patterns with different diffuser orientations. The distance between diffuser and the CCD was* $320\,\mathrm{mm}$*, the distance between object-plane and diffuser* $104\,\mathrm{mm}$ *resulting in a magnification of* 3.07*. The NA was* 0.1*. (a) and (e) image retrieved from a single pattern, (b) and (f) result obtained by averaging over images retrieved with 100 different diffuser orientations, c) average of 500 images, (d) and (g) images obtained with a spherical lens, the same magnification and the same NA .*

4 Conclusion

We demonstrated that SPM with spatially coherent sample illumination is possible, if the spatial correlations of the patterns are accompanied by an averaging over images obtained with many different scatter-plates. Further, we demonstrated that SPM is possible even with moving or changing scattering media. This may open up new applications to the technique e.g. concerning the imaging through fog, smoke or turbid liquids.

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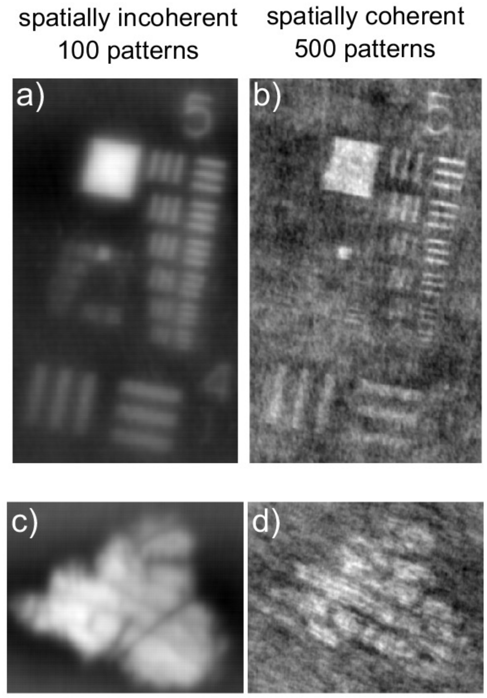

Fig. 3 *SPM with a continuously rotating ground glass diffuser and spatially incoherent (a and c) respectively spatially coherent (b and d) sample illumination. (a-b) were acquired with the same magnification and the same NA as the images shown in Fig. 2. (c-d) show images of a piece of onion tissue. The cell walls are visible. The magnification was set to* 2.02*, the NA was* 0.1*. (a) and (c) result obtained by averaging over images retrieved with 100 patterns, (b) and (d) average of 500 images.*

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