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Reconstruction of coherence matrix in x-representation using nonclassical Hartmann sensor

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Abstract: We show the coherence properties of a signal can be measured by a Hartmann wavefront sensor in a nonclassical regime. Recasting the detection theory of the classical Hartmann sensor in the sense of quantum tomography enables to measure the coherence function, which is an analogy to the density matrix of mixed quantum states. Two methods were tested for the reconstruction of the coherence matrix from the intensity scan in the nonclassical mode of the Hartmann sensor. The reconstruction was performed in a classic way using the POVM matrix and using data pattern tomography.

Introduction

Excimer lasers with an unstable resonator play a crucial role in DUV lithography applications. These laser sources provide a partial spatial coherent signal, and the wavefront description is not applicable in this case. The wrong signal description can lead to errors in production, where these lasers are used. Therefore, it is beneficial to have an experimental tool in hand able to characterize the coherence properties of the signal. Hartmann sensor is a standard technique allowing to test the quality of optical systems. Traditional wavefront sensors deal with fully spatially coherent signals. Going out of this assumption provided data are carefully reconstructed the coherence properties can be retrieved [1].

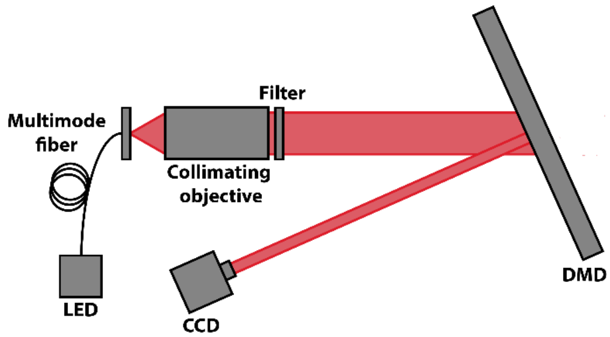
In cases a measurement apparatus is difficult to characterize and calibrate data pattern tomography can be preferably used. The method was proposed by J.Rehacek, D. Mogilevtsev, and Z. Hradil [2] as a tool for quantum state reconstruction without a priori knowledge of the measurement apparatus. The method was further developed by describing the efficient algorithm [3] and analyzed in different regimes together with the detector tomography [4,5].

Experiment

The key element of our experimental setup: Hartmann sensor is a standard technique allowing to test the quality of optical systems provided the measurement geometry separates the signal from the individual Hartmann mask apertures sufficiently. Hartmann mask can be realized via a digital micromirror device (DMD).

In the nonclassical approach the charge-coupled device (CCD) is placed behind the Hartmann mask in such a way the signal from the individual sub-apertures of the mask interferes mutually. In this case the information about coherence properties is encoded in the experimental data and can be reconstructed.

Fig. 1. DMD wavefront sensor based on Hartmann mask. The signal from the end of the optical fiber is collimated and measured.



Tomography reconstruction

The state reconstruction can be performed via complete characterization of the measurement based on POVM matrices and careful detector calibration. Alternatively, data pattern tomography can be used provided the calibration states (probes) are measured in the same experimental apparatus.

In the case of DMD wavefront sensor based on Hartmann mask the calibration states can be generated directly using DMD chip by addressing the suitable set of the Hartmann masks within one exposition time.

In the experimental setup the end of the optical fiber was collimated and measured by the way described in the previous paragraph (see Fig. 1). The corresponding degree of coherence generally depends on the optical fiber core diameter, collimator focal length, wavelength and separation of the measured points. Theoretically derived values are depicted in the Fig. 2 together with the measured degree of coherence.

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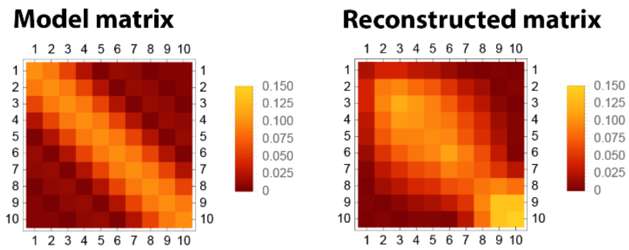
Fig. 2. True and measured coherence matrix of the collimated signal from the optical fiber (core diameter = 105μm).



Conclusion

We have experimentally performed measurement of the coherence properties of the partly coherent signal. The key element is DMD wavefront sensor based on Hartmann mask operating in the nonclassical regime where the standard reconstruction approaches are not applicable. In case the interfering signal comes from spatial points we get the x-representation of the coherence matrix directly.

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