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PHASE MODULATION DETECTION AND VIBROMETRY WITH LIQUID CRYSTAL LIGHT VALVE AND DIGITAL HOLOGRAPHY

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Abstract. Self-adaptive interferometry allows the measurement of very small optical phase modulations even in noisy environments and with strongly distorted optical wavefronts. We review two techniques of self-adaptive interferometers based on liquid crystals spatial light modulators, one obtained by using an optically addressed light valve, the second one realized by adopting a digital holography CMOS-LCOS scheme. We report that the liquid crystal devices can be coupled with multimode optical fibers for sensing applications. The adaptive character of these two types of holographic interferometers will be analyzed and compared. They allow performing very efficient detection of phase modulations even with noisy signals. The detection limits are estimated and a multiplexing protocol is proposed for the spatial localization.

1. INTRODUCTION

Adaptive holography has been proposed as an interferometric method based on dynamical holographic recording in nonlinear media. It is based on the use of a medium able to react dynamically to low frequency fringe displacements, the adaptive hologram (AH), allowing to overcome the problems related to the active stabilization of the interferometers. This stabilization is required when dealing with complex interfering wavefronts, like in the case of speckles. The principle of adaptive holography was first demonstrated by using photorefractive nonlinear crystals illuminated by interference of a reference and signal beams. Since its early developments, dynamic holography has demonstrated great potentialities for applications in signal processing, and measurements of very small displacements or vibration amplitudes (fraction of picometer typical) [1–2]. As a general rule, the physical mechanisms rely on a two-wave mixing process in a Kerr-like medium. Because of the temporal response of the medium, the wave mixing process is associated to a frequency bandwidth, allowing to reject low frequency noise and environmental disturbances. In this paper we show that the adaptive holographic methods can be applied to realize the detection of very small amplitude phase modulations when using either a photoconductive liquid crystal light valve (LCLV) or a CCD – LCOS (liquid crystal on silicon) scheme as interferometric recording media.

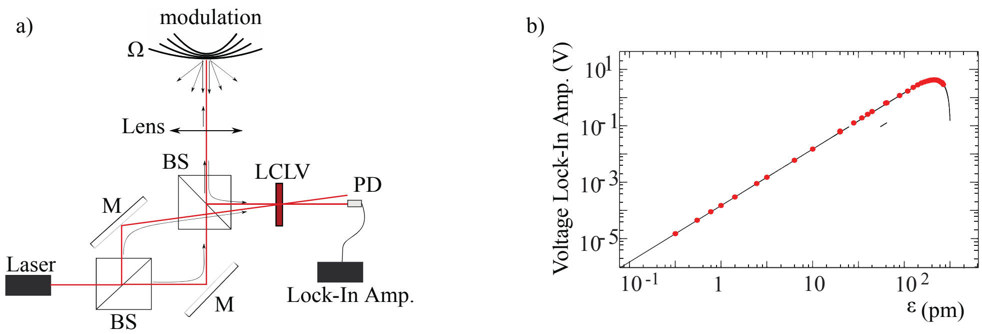

Fig. 1 – a) Adaptive holographic interferometer with LCLV. Reference and a signal beam interfere in the LCLV. The signal is a speckled beam resulting from the scattering from a vibrating object. The amplitude of the modulation is detected *via* a photodiode, PD; b) measured vibration amplitudes.

2. INTERFEROMETRY WITH A LIQUID CRYSTAL LIGHT VALVE

The LCLV, schematically depicted in Fig. 1 is made by associating a liquid crystal (LC) layer with a photoconductive $Bi_{12}SiO_{20}$ (BSO) crystal cut in the form of a thin plate (1 mm thickness, 20 × 20 mm²). The thickness of the LC layer with parallel alignment is typically of the order of 10 µm. While liquid crystals are used for their large birefringence, the BSO is used for its large photoconductivity and transparency in the visible range. Transparent electrodes (Indium Tin Oxide layers) deposited over the BSO and the glass wall, allow the application of an external a.c. voltage across the LC layer with a rms value from 2 to 20 V – frequency from 50 Hz to 20 kHz. Illumination of the BSO with interference fringes thus induces a photoinduced index modulation due to liquid crystal molecule orientation. This behaves like a highly nonlinear Kerr medium [3]. Two wave mixing adaptive interferometry in the green at 532 nm is thus realized with the setup shown in Fig. 1, where the detection of vibration amplitudes of a fraction of picometer is achieved at the shot noise limit. Beside interferometry, slow light experiment will also be analyzed and demonstrated with the LCLV.

3. INTERFEROMETRY WITH LCOS-CMOS DIGITAL HOLOGRAPHY

We highlight in this part a novel digital off-axis holographic recording setup shown in Fig. 2. It is based on a CMOS-LCOS scheme considered as a nonlinear two-beam coupling medium, where self-diffraction and energy exchange takes place between the incident interacting reference and signal waves [4]. In this scheme the intensity fringe pattern of the green laser is recorded by a CMOS matrix while the corresponding phase hologram is displayed in real time on a LCOS spatial light modulator (SLM), from which the two incident waves self-diffract in the Raman-Nath regime. The corresponding coupled wave equations will be detailed to achieve gain on the complex signal wavefront with speckle. This setup is used to realize a digital adaptive holographic interferometer. The two components, the CMOS camera and the phase only SLM with 8 μm pixel size, are symmetrically placed at 45° from a 50% beam splitter and precisely imaged one onto each other.

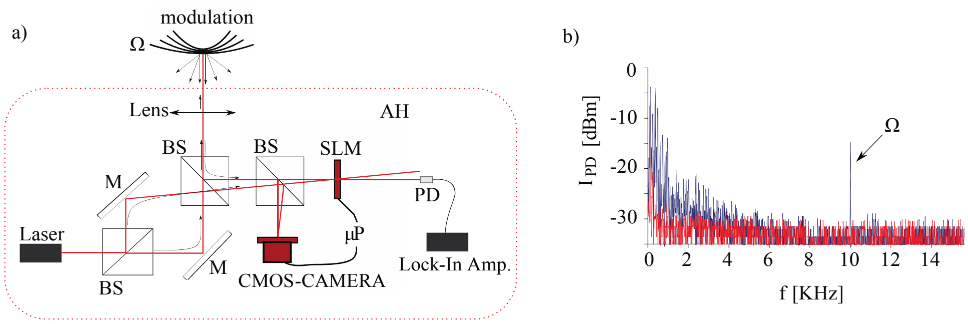

Fig. 2 – a) Setup of an CMOS-LCOS adaptive interferometer. The interference pattern is acquired by a CMOS camera and interferogram after signal processing, is sent to a LCOS-SLM. The light intensity diffracted by the the SLM is recorded by a photodiode; b) spectrum of the signal detected with a CMOS-LCOS at 10 KHz.

We outline that this configuration provides a substantial advance in comparison with conventional nonlinear media. Indeed the amplitude of the phase grating can be optimized through the signal processing module before fringe display on the LCOS. Thus the phase shift between the fringe and index patterns can be easily adjusted for linear detection of any time varying phase modulation. Also by using a balanced detection the signal to noise is increased due to the suppression of the zero frequency by the differential measurement.

In conclusion, adaptive holographic interferometry using liquid crystal devices like LCLV and LCOS, can be efficiently employed for performing wave mixing experiments and applications. We have shown that they realize adaptive interferometric systems able to detect very low amplitude phase modulations with a linear response and with complex speckled and distorted beams. The digital

CMOS-LCOS configuration is demonstrated in a simple and compact setup. It provides a large flexibility, with possible choice of the operating wavelengths and it may have attractive performances due to the new progress of the technologies of the spatial light modulators and of the photodetector arrays.

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