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FULL-OPTICAL TWO-CHANNEL ADAPTIVE SYSTEM FOR DETECTING MICROCANTILEVER VIBRATIONS

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Abstract

We demonstrate a full-optical two-channel system for measuring mechanical vibrations of microoscillators, which is based on adaptive holographic interferometer using multiwave mixing in a photorefractive crystal. The orthogonal geometry of dynamic hologram recording makes possible independent operation of the measurement channels. The absolute detection limit of the system to cantilever vibrations in a channel amounted to $2.6{\cdot}10^{-6}$ nm$\cdot$W$^{1/2}\cdot$Hz$^{-1/2}$. We tested the system in simultaneous detection of vibrations of two cantilevers with dimensions $215{\times}40{\times}15$ μm.

Keywords: adaptive interferometer, photorefractive crystal, vibration detection, cantilever, multichannel.

1. Introduction

The development of micro- and electromechanical system (MEMS) devices gave rise to the emergence of a variety of microcantilever-based sensors (MBS) and finding ways to use them [1]. The integration of piezoelectric layer with silicon MEMS with good actuation and sensing capabilities has led to development of a wide variety of devices, such as accelerometers, force sensors, pressure sensors, acoustic sensors, ultrasonic transducers, etc. [2]. Another extensive area of applying MBS is the creation of microbiosensors [3]. In particular, microcantilever-based sensors have emerged as a promising label-free detection technique, which are used to measure different quantities [4, 5].

To develop cantilever-based devices, one should solve two major problems: actuate the cantilever motions and detect them. There are a lot of methods for actuating or sensing cantilever motion (mechanical, optical, electrostatic, and electromagnetic), from which the most common is optical techniques [4,6]. They are noncontact, nondestructive, and broadband. Apart from contact techniques, the optical method of excitation of cantilever vibration does not affect its parameters, including natural frequency. Optical techniques for vibration detection fall under two broad categories: near-field and interferometric methods [7]. Near-field optical techniques [8, 9] rely on the interaction between evanescent waves, e.g., from weakly guided modes in an optical fiber, and a vibrating nanomechanical structure. Interferometric methods [10–12] are based on the interference between the probe beam reflected from the vibrating structure and reference beam, which converts the phase modulation of the probe beam into intensity change.

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The increase in sensitivity of cantilever-based devices is inseparably linked with the necessity to reduce the microoscillator size. The sizes of modern microoscillators are comparable with the transverse dimensions of the probing (object) laser beam in the focal plane, and their further miniaturization leads to significant distortions of the object wave front in the interferometer. In turn, the mismatch of the wave fronts of the interfering beams leads to the reduction of the interferometer sensitivity up to the total failure of its working performance. The mentioned problem becomes particularly urgent in the case of using the oscillators of submicron and nanometer scale. Moreover, due to technological specificity, the microoscillator surface cannot be precisely manufactured as mirror-smooth, which also introduces additional wave front distortions. This problem can be solved if an adaptive interferometer based on the use of two-wave mixing at dynamic hologram continuously recorded in a photorefractive crystal (PRC) is used instead of the classical interferometer [13, 14]. Due to the adaptive properties of the dynamic hologram, such an interferometer can stably operate with light waves having arbitrary wave fronts.

As was shown in [15], such an interferometer allows one to detect vibrations of submicrometer-size cantilevers. In particular, the adaptive interferometer has a low detection limit $2.4 \cdot 10^{-8}$ rad$\cdot$(W/Hz)$^{1/2}$ even in the case of using cantilever with dimensions of $180\times40\times15$ μm. However, this system has been implemented with only one measurement channel. Meanwhile, there are some applications where multiple measurement channels are necessary. For example, a multichannel measurement system can provide improvement in the accuracy and reliability of measurements. Simultaneous measurement of different physical parameters or even their spatial distribution can be done using a multichannel system [16]. The six-channel adaptive interferometer was proposed in [17]. It was used for processing light waves having both low divergence and relatively high intensity, which were coming from multimode optical fibers. The detection limit for small phase fluctuations in the channels of the interferometer was determined to be $2.1\cdot10^{-8}$ rad$\cdot$(W/Hz)$^{1/2}$. However, the light scattered by microcantilevers has very low intensity distributed in a wide solid angle of scattering.

In this relation, the purpose of this work is to design and study the performances of a full-optical two-channel adaptive system based on multiplexed adaptive holographic interferometer for excitation and detection of microcantilevers vibrations.

2. Experimental Setup and Results

The scheme of the measurement system is shown in Fig. 1. Two conventional AFM silicon semicontact cantilevers with dimensions $215\times40\times15$ μm (cantilevers A and B) were used in the system. Laser light pulses at a wavelength of 532 nm with an energy of 0.5 mJ and a duration of 7 ns were used to excite the cantilevers. The out-of-plane mechanical vibrations of the cantilevers with amplitude about 40 nm caused by the laser pulse were measured by an adaptive interferometer. In the latter, IR light at a wavelength of 1064 nm and a power of 20 mW coming from a cw Nd:YAG laser was split into the object and the reference beams with the intensity ratio 1:5. The object beam was focused onto the free ends of the cantilevers by means of a short-focus lens, as it is shown in Fig. 2. Being reflected from the cantilevers, the object beam arrives at the photorefractive crystal CdTe, where it interacts with the reference beam. The power of each of the two object beams at the crystal input face was about 80 μW, while the reference beam power was 16 mW. The interaction of the reference and object beams at the dynamic hologram, which is recorded in the PRC, provides precise matching of the wave fronts of the mixed light beams, while the adaptive properties of the dynamic hologram provide stabilization of the interferometer operating point in the region of maximum sensitivity, where the quadrature conditions are