Real-Time Holographic Interferometry using Photorefractive $Bi_{12}SiO_{20}$ Crystals and their applications in Surfaces Analysis with Phase-Stepping Technique

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Abstract

This work searches to develop and to optimize a holographic interferometer that it uses the photorefractive Bi12SiO20 (BSO) crystals in diffusive regimen with configuration exhibiting diffraction anisotropy for Real-Time Holographic Interferometry (RTHI) and applications in surfaces analysis. In RTHI with photorefractive BSO crystals, the writing-reading hologram process is made in real-time in diffusive regimen, with configuration exhibiting diffraction anisotropy. This device is connected with an interferogram-analysis method that uses the phase-stepping technique for quantitative measurement of surfaces displacements and deformations. So we captured holographic interferograms from analyzed surface, and calculated the phase map using the digitalized images with a software of microcomputer, then another program removed the wrapping of tangent function (unwrapping), using the Cellular-Automata technique, where obtained good results.

Introduction

Real-Time Holographic Interferometry using photorefractive BSO crystal. The Holographic Interferometry[1] is a powerful optical method for surfaces analysis, in the field of non-destructive testing, being extremely useful in applications in basic research, biomedical and technological areas. These techniques present advantages in relation the conventional techniques: therefore do not present any contact with the surfaces, what it guarantees absolute reliability to them; besides presenting high accuracy; and also it allows to make qualitative analyses through visual inspection. However, the holographic interferometry techniques in real-time with conventional materials (silver halide emulsions, photo-thermoplastics, and others) present serious difficulties, for example, is necessary chemical processing of the holographic film. The photorefractive crystals come presenting as an attractive recording medium. The phenomenon that characterizes these crystals is the photorefractive effect[2][3]. Such effect consists of refractive index modulation through photo-induction and linear electro-optic effect (Pockels Effect), what it allows the register volume holograms. These crystals also present advantages as *in situ* self-proceedings of recording medium and its indefinite reusability, or either, it does not present fatigue. Therefore, the processes are dynamic and reversible. These properties indicate these crystals for real-time holographic interferometry. The photorefrative crystal that we used in this work was the $Bi_{12}SiO_{20}$(BSO) of sillenite family (as $Bi_{12}TiO_{20}$(BTO) and $Bi_{12}GeO_{20}$(BGO))[3] presents some properties as good sensitivity and diffraction efficiency, short response time, birefringence, optical activity and other parameters; besides being indicated for works in diffusive regimen with configuration exhibiting diffraction anisotropy. Many works involving Holographic Interferometry using photorefractive crystals had been studied through in last decades[4][5][6].

The Real-Time Holographic Interferometry(RTHI)[4][6], where a hologram is registered, in the reading process the object is illuminated and we directly observe a resultant interferogram of the overlapping of diffracted wave-front for hologram and the coming in object. Each variation of object, when this is stimulated, observed directly in real- time, used on measurements in: Static Processes (static micro-displacements, deformations, tensions and shipments, detention of defects in surfaces, etc); and Dynamic Processes (dynamic micro-displacements, dynamic variation of temperature, deformations, dynamic tensions and shipments, etc), with sequential reading of holographic interferograms. In Real-Time Holographic Interferometry with photorefractive BSO crystals, the writing-reading hologram process is made in real-time in diffusive regimen, with configuration exhibiting diffraction anisotropy. The diffraction efficiency(η) and I is given by

$$\eta = \left(\frac{\pi n^3 r_{41}\Delta E}{2\lambda\cos\theta} m \frac{\sin\rho L}{\rho}\right)^2 \Leftrightarrow \Delta n = \frac{1}{2} n^3 r_{41}\Delta E\left(1-e^{-t/\tau}\right) \Rightarrow I = I_{residual} + I_{difractted}\left(1-e^{-t/\tau}\right)^2$$

where τ is the response time.

Phase-Stepping Technique. In these work, we use a spatial phase measurements technique with phase shift, it described by Creath[7] as *Phase-Shifting Technique*. The phase of interferogram were calculated using holographic interferograms intensities that they was obtained with our holographic interferometer. The many interferograms captured have had the intensities changed due phase shift did by a piezoelectric linear micro-displacements (PZL). If the phase shift was time continuous it will be called of Phase-Shifting, else, the phase shift was discrete it will be called the Phase-Stepping. We used the second technique, so, a sequence of interferograms is captured and between each pair of interferograms we introduced a change know in the reference beam, what to help in phase determination of the each point of interferogram. In accordance with the amount of interferograms captured we have a phase shift technique. Here, we used the 4 frames phase shift technique, it's called because use 4 interferograms to determine the phase of one point (i,j). In this technique we used the following values of phase shift (θ): 0, π/2, π, 3π/2. The term that bring the information is the term of the interference, and thus, the values of intensity $I_n(i,j)$ in each point (i,j) of the interferogram for each change of phase can to be write as:

$$I_n(i,j) = I_0(i,j)\cos\left[\Phi(i,j) + \frac{(n-1)\pi}{2}\right] \quad , n = 1, 2, 3 \text{ e } 4$$

Using the trigonometrics relations and to combine the intensities obtain phase Φ(i,j):

$$\Phi(i,j) = \arctan\left[\frac{I_4(i,j) - I_2(i,j)}{I_1(i,j) - I_3(i,j)}\right]$$

When we know the phase Φ(i,j) of each point (i,j), can to build a 2D graphic where the (i,j)-coordinate identifies a point on xy-plan and each values of phase as a gray level intensity in point on xy-plan, changing between the white and black. The black correspond at –π and white at +π, and between it's the gray level correspond at values between –π e +π, having 256 gray levels for a system of images of 8bits. To remove the phase wrapping ϕ(i,j) of phase map, what is due the values of tangent function are between –π e +π, then is not possible to distinguish the values of phase that exceed this range. This wrapping appears in the phase map at areas where are presented the change of phase. It's look likes a border from white to black or black to white. This change corresponds a variation of +π to -π, or -π to +π. This change is known like phase jump. When this wrapping occurs, we call its the wrapped phase, else, when it is removed wrapping we call its the unwrapped phase. This process to remove the wrapping is called unwrapping. There are many works about unwrapping phase techniques, see Judge *et al*[8]. We used the Cellular-Automate Technique, this technique will be created by Ghiglia *et al*[9] em 1986, consist in removed of wrapping for phase integration of the near points. This technique is of path independent and not much sensitive at noise.

Experimental Setup

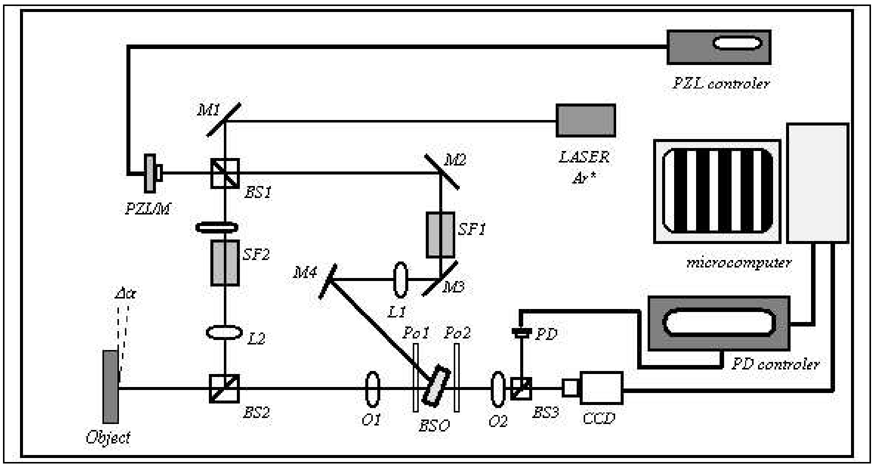

Figure 1: Real-Time Holographic Interferometry with photorefractive BSO crystals Setup, where, the light source is an Argon Laser (λ=514,5nm); M1, M2, M3, M4 are mirrors; BS1, BS2, BS3 are beam-splitters; SF1, SF2 are spatial filters; L1, L2 are lens; O1, O2 are objectives; Po1, Po2 are polarizers; PZL/M is piezoelectric translator + mirror; PD is photo-detector; BSO is photorefractive crystal; and CCD is the camera for capture of images.

In the experimental setup for to determine some characteristic figures of merit of photorefractive BSO crystals, that we will use in our work, we evaluate the conditions here BSO crystal presented better performance for real-time holographic interferometer in diffusive regimen, showed in Figure 1. We worry them in determining the excellent holographic recording angle beams, or either, that it maximizes the diffraction efficiency (η) and it minimizes the response time (τ). Thus, we are analyzing the results the best ones resulted with measures in holographic gratings for angles in range 40 and 50 degrees; and the radio of intensities between reference and object beams were $I_R/I_S = 6.0$, that was well characterized by Gesualdi[10]. So, with the PZT calibrated and interferometer optimized, the experimental procedure used was: capture the holographic interferograms with the software Global Lab and Captura; calculate the Phase Map and remove the wrapping of Phase Map with software of calculate built with software Borland C++ and the functions of the Data Translation Global Lab; and plot and analysis the surfaces with software Mathcad. To calculate the phase map and to execute the unwrapping process, we used the programs of microcomputer those were developed by Soga[11].

Results and Discussions

We are presenting the results obtained in measurements of the surfaces of opaque objects, in each figure there are the four holographic interferograms digitalized, the phase map and the unwrapped phase map. In Figure 2 we studied a mirror static ($\Delta\alpha \cong 0$) that presents a phase map without any jump phase that was expected. In Figure 3 we studied a mirror slopping ($\Delta\alpha \cong 0{,}4$mrad) which phase map presents some phase jump, that showed the variations of phase, the phase jump appears in vertical direction due the axis of the slope was in the vertical direction.

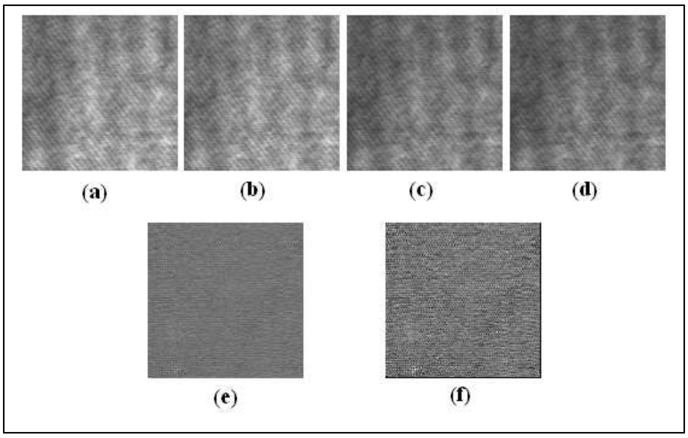

Figure 2: Holographic Interferograms of a mirror static: (a) $\theta=0$, (b) $\theta=\pi/2$, (c) $\theta=\pi$, (d) $\theta=3\pi/2$. Phase Map: (e) wrapped and (f) unwrapped.

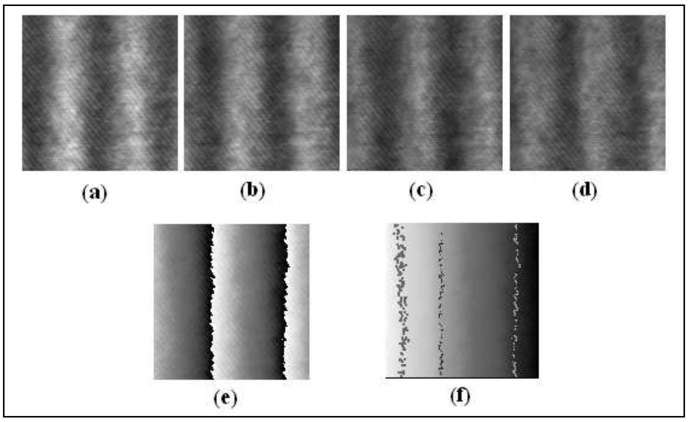

Figure 3: Holographic Interferograms of a mirror slopping: (a) $\theta=0$, (b) $\theta=\pi/2$, (c) $\theta=\pi$, (d) $\theta=3\pi/2$. Phase Map: (e) wrapped and (f) unwrapped.

Conclusions

This work connected the RTHI technique, using a BSO crystal, with phase-stepping technique. The phase map obtained have consistence with the displacements did on mirrors and coins. In the next step we will expect to obtain the values of displacements.

Acknowledgements
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