Design of the Holographic Fiber-optic Electronic Speckle Pattern Interferometer for Optical Constants of Glasses Measurements.

O. IASENIUC, A. ANDRIESH, E. ACHIMOVA, V. ABASHKIN.

Center of Optoelectronics, Institute of Applied Physics,
Academy of Sciences of Moldova,
5 Academic str., MD-2028, Chisinau, Moldova
e-mail: oxygena08@rambler.ru

Abstract – **An elaboration the holographic fiber-optic electronic speckle pattern interferometer (ESPI) which can will be apply for measurement of the optical constants is described. This interferometer with CCD Smart Camera can be programming based on National Instruments' graphical programming LabVIEW software. Using the LabVIEW we can apply flexible program for different software steps for processing of recorded interferograms (extracting amplitude, phase map and frequency domain, subtraction), obtained by CCD Smart Camera for feather calculation the optical properties the refractive index and thickness of studying samples.**

Index Terms – digital holographic speckle pattern interferometer, ESPI, optical fibers, LabVIEW.

I. INTRODUCTION

The optical properties, especially the refractive index, of chalcogenide glasses are currently a subject of systematic research due to they manifest strong photo- and thermally-induced properties that offer the possibility of using amorphous chalcogenide for high-density information storage, fabrication of diffractive optics such as Bragg gratings elements, inorganic photo-resists, and different holographic patterns.

But one of the main problems is the precise definition of the refractive index and thickness of the samples. Different methods have been developed to measure the refractive index. Many of spectrofotomertic, ellipsometric, interferometric methods for determining the refractive index of materials have also been developed. But all they have errors and less precision.

The holographyc fiber-optic ESPI as a method of small displacement was formed in 80-th years [1], but to measure the optical parameters have learned recently. This is high precision, noncontact, full-field, optical method for measuring the optical properties changes.
Data from speckle interference patterns for further determining properties of the studying samples is processing by holographic and programming methods.

The main aim of this work is to design holographic fiber-optic ESPI and in future to study a new materials - determining of the refractive index, it variations and thicknesses (thin films and bulk materials) by method of holographic fiber-optic ESPI. Especially this method can be very useful for full-field measurements the index of refraction after recording process on chalcogenide glasses.

It should be noted that during the planned research is expected to establish that the application of digital speckle correlation interferometry technique can be extend the number of experimental data and expand the range of tasks due to flexibility of LabVIEW program, portable set-up, immunity to the environment influences (temperature, vibration).

II. THE DIGITAL HOLOGRAPHIC FIBER-OPTIC SPECKLE PATTERN INTERFEROMETER

Breadboard with tapped holes as a stable platform for mount interferometer and optical experiments for various test configurations was used. Fiber-optical design of ESPI was chose to sustain vibration immunity (Fig. 1, 2). There are 10 mW He-Ne laser (1), wedge prism as beamsplitters (2), multimode optical fiber as object arm (3), sample (bulk or thin films of the chalcogenide glasses) (4), object arm (5), camera objective (6), optical lever composed from negative lens and positive lens (7) as microobjective (8) (60^x and $NA_{objective} = 1.25$) and monomode optical fiber as reference arm (9), rectangular diaphragm (10), CCD Smart Camera (11), PC (12).
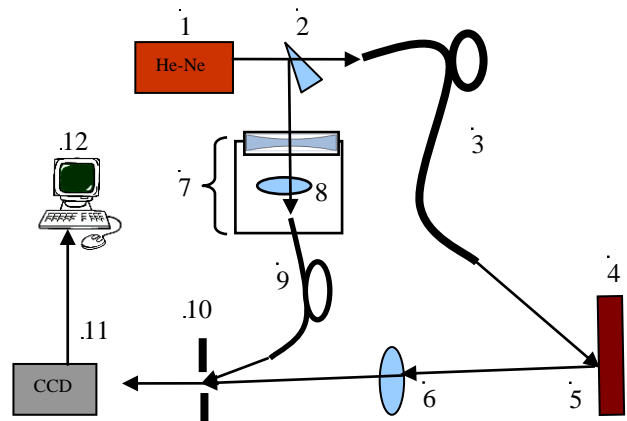

Fig. 1. Optical set-up of holographic fiber-optic ESPI.

There are 3 conditions for effective coupling laser beam energy and mono mode fiber:
- Coincidence of the aperture of the objective and fiber core respect to condition $NA_{objective} \geq NA_{fiber}$;

- Diameters coincidence of microobjective focal spot and monomode fiber core;
- Adjustment of the modes and wavelength transmission of the laser and monomode fiber.

This advantageous interferometric arrangement allows obtaining the speckle pattern fast enough (due to recording rate of CCD Smart Camera) and with high precision (less then $\lambda/4$).

A digital holographic speckle pattern interferometer relies on the correlation between two speckle patterns. Each one created by the interference between a reference beam and the image of an object illuminated by laser [2-4]. Typically the two images are of an object before and after some changes (in-plane or out-of-plane displacements). Acquired by CCD camera's image is converted into a corresponding video signal. This video signal is electronically processed by PC through Gigabit Ethernet, so that texture variations of the speckle pattern are converted into brightness variations. A speckle interferogram is generated arithmetically by subtracting two digitized speckle patterns. The similar operation of subtraction of two stored on PC interferogram can be made using our program in LabVIEW. In this case, the distribution intensity of the resulting speckle pattern will depend on the relative phase shift superimposed fields. Deformation of the object leads to a change in the phase of the object speckle field and, consequently, to changes in intensity of the speckle pattern. Obtained the digital speckle patterns interference are also subjected to computer processing in order to increase the contrast fringe and smoothing of optical noise - the speckle modulation. In practice, the intensity distribution in the camera detector plane is stored with the object in its reference state. The object is then deformed and a second frame is stored. The two frames are then subtracted and correlation live fringes are displayed on a monitor (Fig. 3). Images subtraction makes the interferogram easy to form, view, and recording no in time. (Recording rate of Smart Camera is about 60 fps.). NI 1722 Smart Camera simplify machine vision by analyzing images directly on the camera with a powerful, embedded processor capable of running NI Smart Camera digital I/O lines are optoisolated for direct connectivity with industrial devices such as triggers and actuators. All smart camera models incorporate an image sensor, processor, and digital I/O in a compact, rugged housing. The Smart Camera also includes LEDs for communicating system status, four DIP switches to specify startup options, isolated inputs, and isolated outputs for connecting to external devices. Developing applications with the NI Smart Camera requires one of the following software options:

- Vision Builder for Automated Inspection: (Vision Builder AI) is configurable machine vision software can use to configure the NI Smart Camera and prototype, benchmark, and deploy machine vision applications. Creating applications in Vision Builder AI does not require programming. It allows you to easily configure and benchmark a sequence of visual inspection steps, as well as deploy the visual inspection system for automated inspection.
  - LabVIEW 2010: LabVIEW Real-Time Module, NI Vision Development Module, NI Vision Acquisition Software-IMAQ. LabVIEW is a graphical programming environment for developing flexible and scalable applications.

The NI Smart Camera provides control of the image sensor exposure time through software.

If a squared difference is performed between two digitized speckle patterns and recorded at different states of the object, the result will be:

$$I(x,y)=8I_0(x,y)I_r(x,y)\sin^2[\upsilon(x,y)+\Delta\upsilon(x,y)/2]\{1-\cos[\Delta\upsilon(x,y)]\},\quad(1)$$

where $I_o(x,y)$ and $I_r(x,y)$ are the object and reference beam intensities, and $\upsilon(x,y)$ is the speckles random phase. The $\Delta\upsilon(x,y)$ term containes the phase variation between the two subtracted patterns. This equation represents a ESPI interferogram description obtained by subtraction technique.
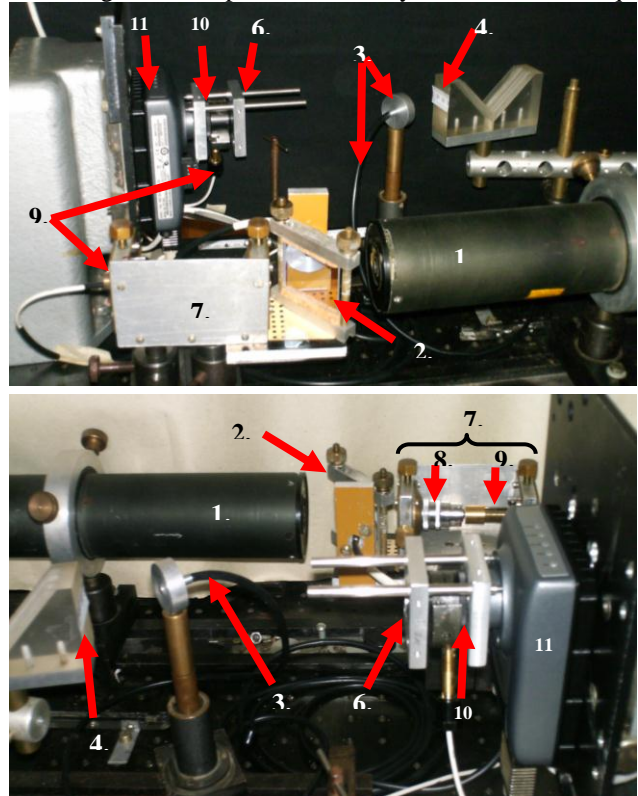

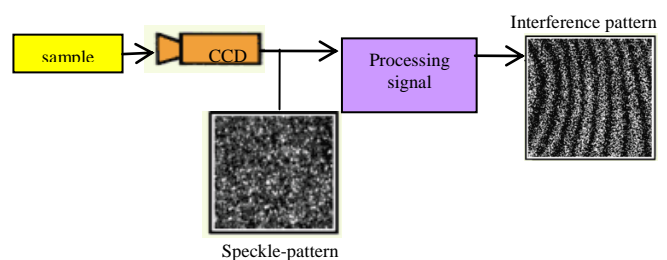Fig. 2. Two side photos of the holographic fiber-optic ESPI set-up with elements numbered respective to Fig. 1.

Fig. 3. Schematic of ESPI measurement processing.

III. LABVIEW

Most researches today are done with the aid of computers. The computers are used to control the experiment, acquisition, and processing of data. LabVIEW is a graphical programming language elaborated by National Instruments Company [5]. LabVIEW programs are called virtual instruments (VIs), because their operation imitates works of physical instruments made by user. Specifically, LabVIEW is used to interface the computer with programmable

measuring instruments. LabVIEW contains a comprehensive set of tools for acquiring, processing, analyzing, displaying, and storing data. Because LabVIEW graphical code is easy providing unique debugging tools that can use to watch as data interactively moves through the wires of LabVIEW program and see the data values as they pass from on function to another along the wires between VI or sub VI. Each VI consists of a front panel and a block diagram. The front panel specifies the inputs and outputs which make up the user interface. The block diagram consists of icons which represent subroutines and program control structures [6].

LabVIEW is a program development application, much like various commercial C or BASIC development systems, or National Instruments LabWindows. However, LabVIEW is different from those applications in one important respect. Other programming systems use text-based languages to create lines of code, while LabVIEW uses a graphical programming language, to create programs in block diagram form. Moreover anybody can use LabVIEW with less programming experience. LabVIEW programs are called virtual instruments (VIs) because their appearance and operation imitate actual instruments. However, they are analogous to functions from conventional language programs. VIs has both an interactive user interface and a source code equivalent, and accepts parameters from higher-level VIs.

LabVIEW has extensive libraries of functions and subroutines for most programming tasks. LabVIEW contains application specific libraries for data acquisition and instrument control. LabVIEW also contains application-specific VI libraries and serial instrument control, data analysis, data presentation, and data storage.

The primary step of our program in LabVIEW is images acquisition and storage. Acquired images are stored in memory of CCD Smart Camera or in PC ready for processing.

The front panel of our program is shown on Fig. 4 In left side of screenshot one inserts names of two images.

to comprehend, common programming tasks, like debugging, become more intuitive as well. LabVIEW

Image acquisition window (on the right) used for image processing respect options presented on Fig. 5-7:
- Simple squared difference -Fig. 5;
- Phase map -Fig. 6;
- Rectangular determination for following unwrapped phase map extraction - Fig. 7.

The operator starts the primary task, the data acquisition program, namely the first step is reading a reference image file and a recording image file. Program recognizes image file configurations such as BMP, TIFF, PNG and JPEG. This type definition edits automatically. The reference image in our case is unloaded object image. The recording image represents loaded object. Object loading process can be made by suitable way for object under investigation, for example heating, vibration, etc. The LabVIEW execution engine then distributes data the three our tasks in dependence of the problem needed and chosen by operator on front panel. These tasks are a pointed above.

The simple difference task VI's serve for squired image to increase S/N ratio. This block diagram also produces a histogram equalization of the squired image.

Block diagram for rectangular determinations serves for elimination from complex image low frequencies which are haven't useful information about the object. After that step VI Mask recopies image source into new image for processing.

Inside phase map block diagram VI computes optical FFT of both images and creates complex images in which high frequencies are grouped in the center while low frequencies are located at the edges. Inverse FFT of complex image after VI Mask calculation must be doing for final step as phase map calculation. So this block diagram first produces wrapped phase map and then unwrapped phase map. After final processing surface changes in-plane or out-of-plane will be presented.
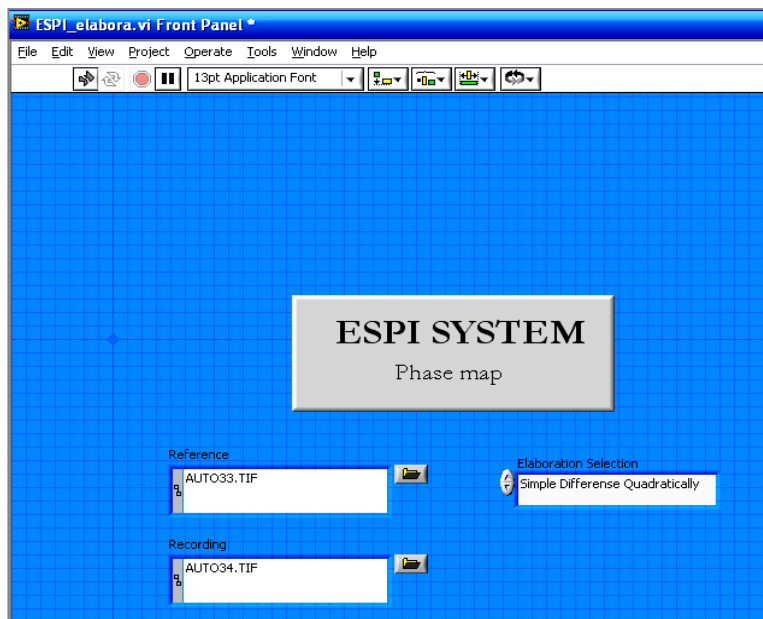

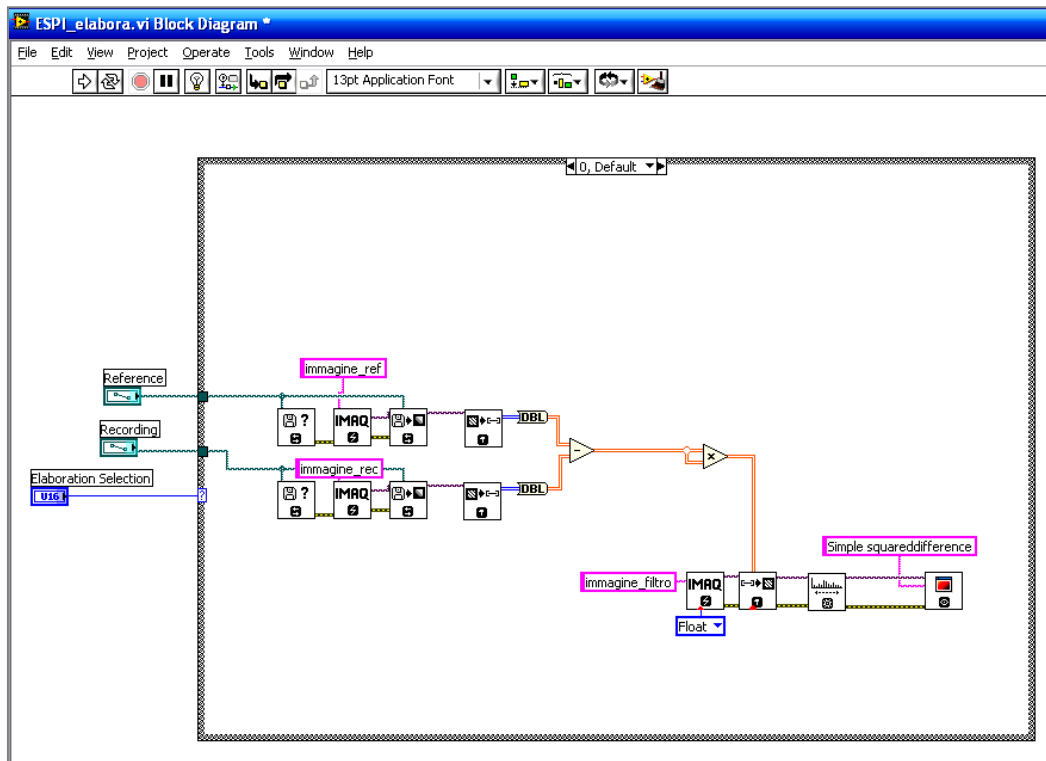Fig. 4. The screenshot of a LabVIEW user front panel

Fig. 5. The screenshot of a LabVIEW user block diagram of VI's for a simple squared difference processing.
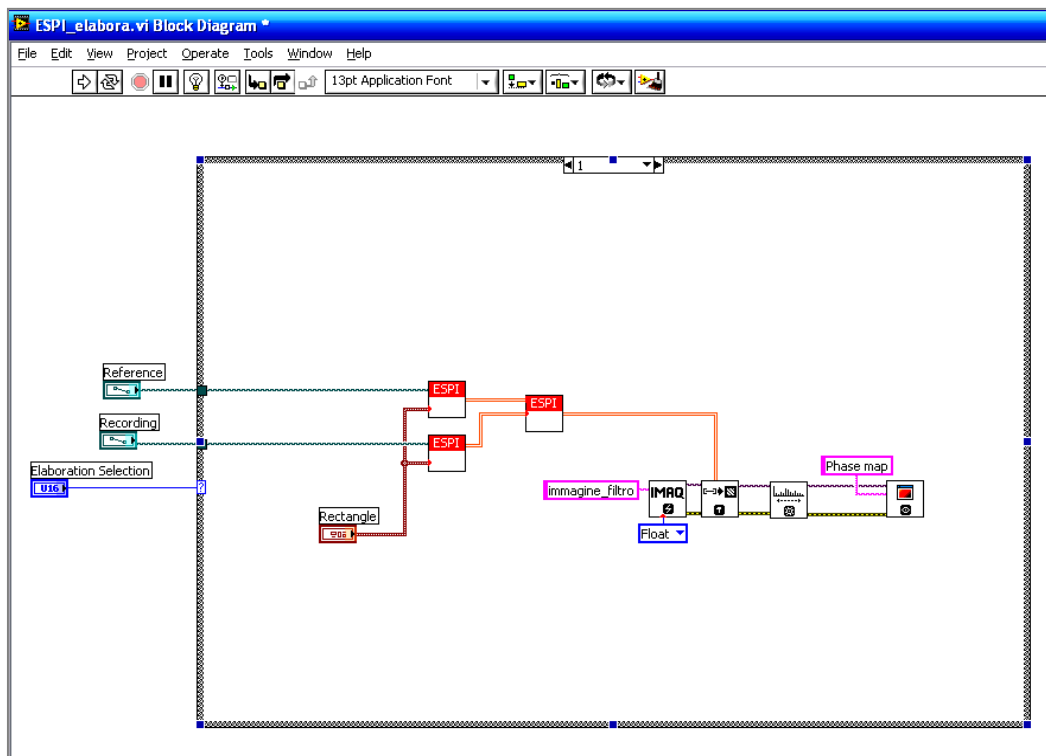

Fig. 6. The screenshot of a LabVIEW user block diagram of VI's for a phase map mode.

III. CONCLUSIONS AND PERSPECTIVE

Our work consist of two main objectives: the optical set-up design of fiber-optic ESPI and elaboration LabVIEW program. The process of measuring by our installation is reduced to receiving two speckle snapshots of unloading and loading object. They will be recorded by using the CCD image sensor. Farther with image processing of speckle patterns and data processing with LabVIEW we can extract phase map, and finally calculate the required optical parameters by elaborated method. Important feature of this method are the full-field measuring of object properties which is important for investigations of optically recorded diffraction elements with very small location of refraction index changes.

In our work the methods was used:
• Speckle-interferometric method of speckle-interferogram

with Fourier optical processing in objective plane;
• Holographic method of recording images on Smart Camera CCD image sensor;
• Method of forward and inverse Fourier-transformations;
   Methods of processing by using LabVIEW are optical

type of FFT, histogram, phase extraction, S/N of image enhances.

   In perspective we plan to apply set-up and method for measuring the refractive index of As-S-Se-Sn chalcogenide glasses [7-11].
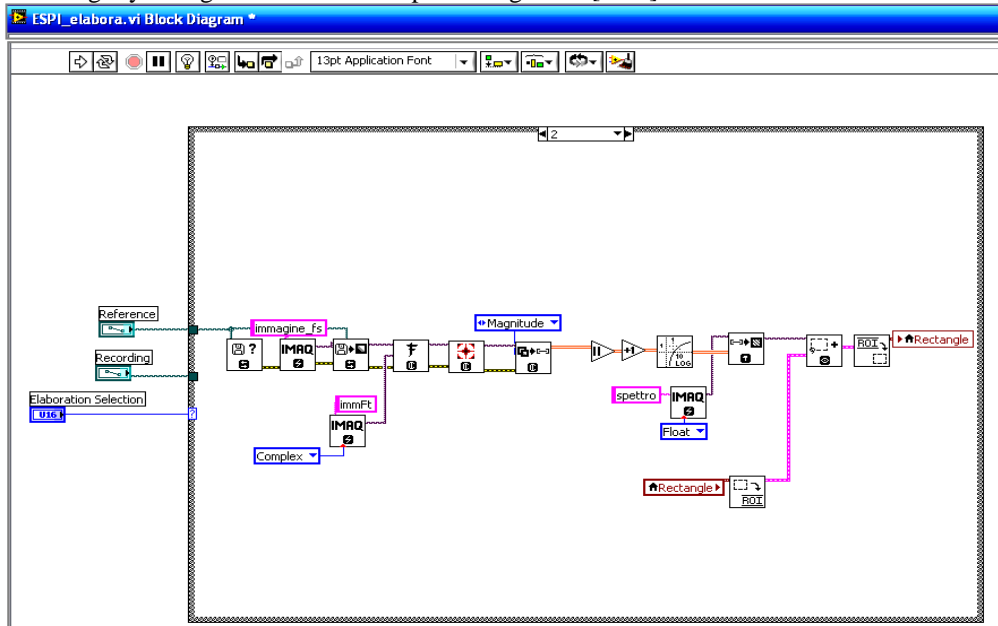

Fig. 7. The screenshot of a LabVIEW user block diagram of VI's for a rectangular determination.

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