# International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

*Edited by George Otrio*

*State-of-the-art of photorefractive holographic interferometry and potentialities for space applications*

*Marc Georges, Philippe Lemaire, Gilles Pauliat,*
*Jean-Claude Launay, et al.*

# STATE-OF-THE-ART OF PHOTOREFRACTIVE
# HOLOGRAPHIC INTERFEROMETRY
# AND POTENTIALITIES FOR SPACE APPLICATIONS

## Marc GEORGES[a], Philippe LEMAIRE[a], Gilles PAULIAT[b],
## Jean-Claude LAUNAY[c], Gérald ROOSEN[b]

[a] *Centre Spatial de Liège (CSL), Université de Liège, Parc Scientifique du Sart Tilman,*
   *Avenue du Pré Aily, 4031 Angleur (Liège), Belgique*
[b] *Institut d'Optique Théorique et Appliquée (IOTA), Unité de Recherche Associée 14,*
   *Centre National de la Recherche Scientifique, Centre Universitaire, Bat. 503, BP 147,*
   *91403 Orsay Cedex, France*
[c] *Action Aquitaine de Recherche en Apesanteur (3AR), BP 11, 33165 St Médard-en-Jalles*
   *Cedex, France*

***ABSTRACT*** - *We present current achievements of applied researches concerning
the use of photorefractive crystals as recording media for holographic
interferometry. Breadboarded prototypes developed by CSL and IOTA on the
basis of crystals from 3AR are described and industrial results of non destructive
testing are shown. Transfer and applicability of these systems for the use in
space, especially for microgravity experiments monitoring, are investigated.
Particular problems of resolution encountered in such applications are discussed.
It is shown that photorefractive holographic interferometers appear now as
potentially matching the needs of space experimentators.*

## 1 - INTRODUCTION

Holographic interferometry (HI) is one of the techniques used in microgravity ($\mu$g) experiments for
crystal growth monitoring and measurement in fluids [Trol 90, Beda 90]. Also it allows
measurement of structure deformations in the micrometric range. Such devices use a holographic
recording medium that has to be processed for revealing the recorded hologram for further readout.
In situ self-processable media such as photothermoplastic plates or films were already considered
for $\mu$g (HOLOP-D2 by German consortium, [Sill 90]). Nevertheless these require electric and
thermal processes for revealing the hologram, implying cumbersome peripherals. Also, after a
certain number of exposures, the recording support has to be replaced.

An alternative are the photorefractive crystals (PRCs) that were already considered for $\mu$g
(HOLLIDO system by French consortium) [Mary 90]. The HOLLIDO experiment used $LiNbO_3$
(ferroelectric) crystals that respond in the blue-green spectrum with high efficiency but poor
sensitivity. Sillenite crystals ($Bi_{12}SiO_{20}$ (BSO), $Bi_{12}GeO_{20}$(BGO)), $Bi_{12}TiO_{20}$(BTO)), though less
efficient, are more sensitive permitting the use of smaller laser powers, which is an advantage for
spaceborne equipment. Prototypes of transportable holographic cameras based on sillenite PRCs
have appeared and show interesting possibilities. Presently they can be used in weakly perturbed
environments for industrial Non Destructive Testing (defects detection, vibration analysis,
structural changes, strain and stress analysis, ...).

In section 2, some basics of PRCs are presented as well as their applications to holographic
interferometry and current phase measurement techniques. We also show todays achievements of
PRCs based holographic cameras carried out at CSL (Liege) and IOTA (Orsay). The PRCs are
grown at 3AR (Bordeaux). Some typical results are shown. In section 3, we discuss the potential
applications to space experiments, especially the case of transparent objects in $\mu$g. Particular issues
of resolution and duration of phenomena are discussed on the basis of our knowledge of these
holographic materials.

## 2 - STATE-OF-THE-ART

### 2.1 - Basics of PRCs

In the photorefractive (PR) effect, photoabsorption arises where the crystal is illuminated. Charges are then created and migrates under the photoconduction effect towards the dark zones where they are trapped. At the steady state, a local space charge field is created under the illuminated and dark zones and will modulate the refractive index through the electro-optic effect. Therefore a refractive index grating is created that is the replica of the illumination pattern. PRCs can then record volume phase holograms. If a new illumination pattern is incident on the crystal, the charges will be furtherly displaced to reach a new steady situation. The PR effect is then a dynamic and reversible process, so the hologram recorded can be erased and the crystal reused. Charge migration can occur under thermal diffusion throughout the crystal (diffusive regime) and/or under an external electric field (drift regime). The properties and figures of merit are different for each process. What is important for holographic recording is the response time of the process and the diffraction efficiency. Mainly, the response time depends on the crystal, the geometry of illumination and is inversely proportional to the total interfering intensities. The diffraction efficiency depends on the absorption, the induced refractive index modulation, itself depending on the crystal and the beam ratio, and on the crystal thickness. Both figures of merit depend on the charge transport mechanism which is involved. There is a large number of photorefractive materials, particularly crystals. Sillenite PRCs (BSO, BGO and BTO) are reknown to be the more sensitive in the visible spectrum, especially in the blue-green wavelengths.

### 2.2 - Types of holographic interferometry techniques

It has been shown that sillenites can be used with the most common HI techniques.

Real-time HI, in which the hologram of the object is recorded at rest and readout when the object phase changes, is the most simple [Geor 95]. At the readout, if the new object state is stable, a new hologram is under recording and erases the previous one within the response time. A particular crystal orientation ("efficiency configuration") allows to use the anisotropy of diffraction : with a polarizer in front of the crystal, one can arrange that the diffracted wave has a linear polarization that is orthogonal to the one of the direct object wave. By using a second polarizer at the crystal exit, it is then possible to balance the intensities of both waves in order to reach very high contrast interferograms. Real-time HI is also possible on the basis of another crystal orientation ("coupling configuration") showing coupling between the direct object beam and the diffracted. Due to some wave mixing properties found in PRCs, the latter configuration enables an amplification of the incident object beam after being passed through the crystal. This has been applied to real-time HI under pulsed illumination [Labr 97]. These configurations have the advantage that no electric field is needed so large angles between beams are used. As a consequence, short focal lengths objective lenses can be used to image large objects [Geor 96/2].

Double-exposure HI is possible on the basis of both crystal configurations discussed above but mainly the efficiency configuration is used [Dirk 94, Poue 96]. The problem with double-exposure is that the second exposure erases the first one, so it has to be shorter. Moreover in order to work at high frame rates, the response time must be as short as possible, so the amount of light at the crystal has to be high, what is only possible with very small objects, if one considers objects that reflect the light diffusively.

Time-average HI was the first demonstration of HI with PRCs and was used to measure vibrations [Huig 77]. It is well suited to PRCs that adapt themselves to the frequency of the vibrating object, revealing the interferogram at resonant frequencies. Nevertheless for the quantification of phase, it is not well suited due to the besselian fringe profiles, except when using special techniques [Rohl 94].

The particular technique that uses stroboscopic readouts synchronized on the vibration frequency has also been shown recently [Geor 97]. Since it is based on real-time HI with anisotropy of diffraction, it has the advantage of allowing modes visualization on large objects.

## 2.3 - Phase quantification

In order to perform high accuracy metrology, phase measurement (PM) is a necessary step to be introduced in such instrument.

The most common and reknown PM technique is the temporal phase-shifting (TPS). When the interferogram of a stable phase change is observed, the phase of one of the two interfering waves is varied and several interferograms (at least 3) are acquired with a constant phase step between each other. The phase is then calculated from these images by relatively simple algorithms Although it leads to the highest accuracies, this techniques requires equal phase steps and equal intensities of interferograms. It can be implemented easily with real-time HI, by translating the phase in, e.g., the reference beam by means of a piezo mounted mirror somewhere in the beam path. Introduction of TPS into double-exposure requires to have separate reference beams for each exposure in order to shift the phase between each diffracted wave. The TPS is generally adressed to stationary phenomena under moderately stable environments. Its suitability to PRC HI has been thoroughly studied and especially the interferogram contrast decrease due to the hologram erasure during the readout [Geor 95/1, Geor 95/2]. With response time higher than typically 10 times the time between interferograms acquisition, the error on the calculated phase is negligible. This technique has been proven very effective in non destructive testing (fault detection in aeronautical composite structures) [Geor 96/3]. TPS is also suitable for analysis of vibration under the stroboscopic readout as was shown in [Geor 97].

Another possibility is the spatial phase-shifting (SPS) in which the phase-shifted interferograms are recorded simultaneously by means of a multicamera system. This is interesting because one keeps, in principle, the high accuracy of the TPS but with the possibility of analysing evolving events or also to use the system with pulsed illumination. A two-camera system has been designed in order to benefit from special polarization properties of waves emerging from the crystal [Labr 95/1, Labr 95/2]. It has been validated on known deformation and used in pulsed experiment for the analysis of vibration [Labr 97]. This method can be applied either with real-time and double-exposure HI.

Spatial carrier with FFT filtering is another powerful technique for analysis of transient events on the basis of a single interferogram. It requires the addition of a spatial carrier frequency before the observation of the interferogram. This is equivalent to a tilt addition in the fringe pattern. Afterwards, the phase can be calculated by separating the first order of the Fourier spectrum of the interferogram and translating it to the origin of Fourier space. This technique has been applied to the real-time HI method [Geor 96/1, Geor 96/3], several successive readouts of the evolving event are performed and each single interferogram is processed. It has been estimated that 100 readouts can be performed before substantial erasure of the basic hologram, provided that short readouts times are applied, what is possible with todays frame acquisition equipment. The technique can also be applied on the double-exposure HI if one wish to avoid the rather complicated two-reference technique used for TPS. A drawback is that the accuracy of this method is generally smaller than the one found with TPS.

## 2.4 - Present achievements at CSL and IOTA and results

Two holographic cameras have been developed in each institution. The CSL instrument has been developed under the EUCLID-CEPA3-RTP3.1 "Aeronautical Application Technology . Damage Detection Methods" project initiated by Ministeries of Defence. The instrument of IOTA has been developed under the EU BRITE-EURAM project BRE2-0364 "Photorefractive Holographic Head". For both, the goal was to observe opaque objects that reflect the light diffusively.

Figure 1 shows a scheme of the CSL holographic head. The holographic head includes the PRC, the laser (YAG 532 nm, 490 mW), the CCD camera and all necessary optics for beam forming, filtering, object illumination and beam splitting. All is contained in a casing of 80x30x20 cm³ (grey line). The optical head is constituted by a frontal objective (L2) that images the object onto the crystal, which is furtherly imaged by a second objective (L3). For objects set at 1 meter, the field observed is 55x37 cm². In that conditions, the response time of recording is typically 9 s, about half this time is then available for acquiring properly interferograms. When using stroboscopic readouts for analysing vibrations, an important part of the light is lost, so in order to keep enough intensity at the CCD, the object is set closer giving observed fields of typically 25x25 cm².

3

The TPS can be used by actuating the PZT in the reference arm. Also the spatial carrier technique with FFT filtering can be used. A computer for controlling the instrumental operations (shutters, PZT, video acquisition and any required object stimulation) as well as data processing (PM techniques and fast data interpretation) is interfaced to the holographic camera.
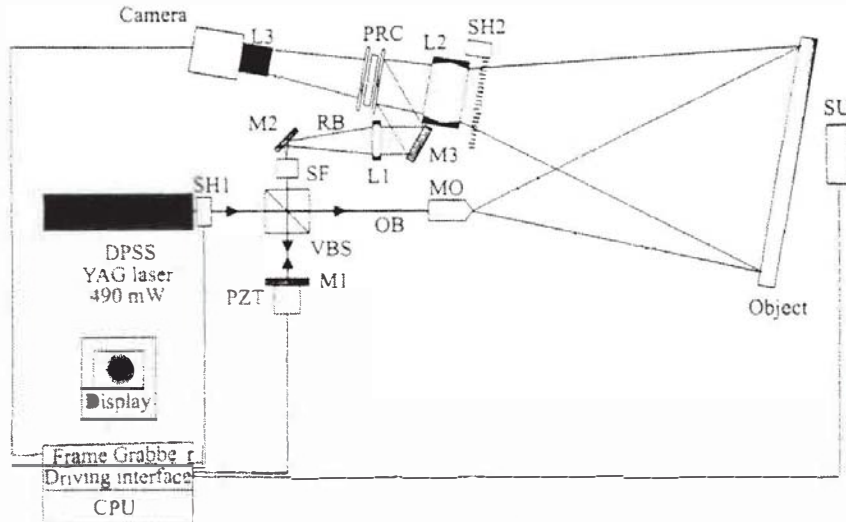


**Fig. 1**. Scheme of CSL holographic camera (L1, L2, L3 : lenses. M1, M2, M3 : mirrors. SH1, SH2 : shutters. MO : microscope objective. VBS : variable beamsplitter. PZT : piezo translator. SF : spatial filter. SU : stimulation unit. OB : object beam. RB : reference beam. PRC : photorefractive crystal between polarizers).

Figure 2 shows an example of non destructive testing on an aeronautical composite structure. After recording of the object hologram at rest, the sample has been heated by an IR lamp. After a certain relaxation time in order to reach a quasi stationary object deformation, the readout is performed and the interferogram of the global deformation is observed. The TPS is applied and the phase can be calculated. Local changes in the global pattern indicate the presence of defects (here impact damages). Figure 2 (a) shows the intensity pattern, (b) the resulting phase interferogram (modulo $2\pi$ because the phase is calculated as an arctangent function). Figure 2 (c) shows the result of phase unwrapping (elimination of $2\pi$ steps of (b)) followed by a differentiation that shows clearly the defects localization.
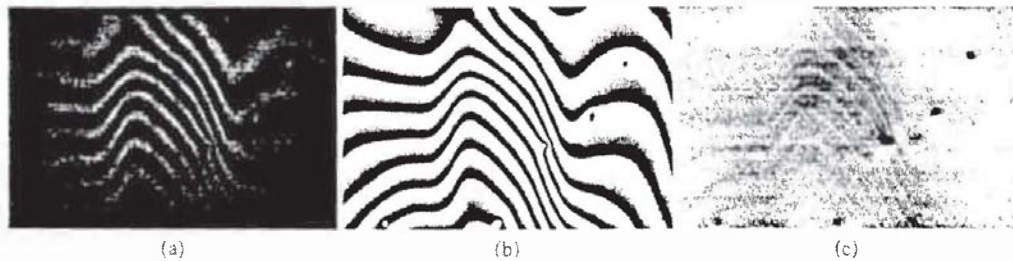


**Fig. 2** - Defects detection in composite structures. (a) intensity pattern. (b) phase pattern modulo $2\pi$ and (c) a defect map after phase differentiation.

Figure 3 shows example of phase interferograms mod $2\pi$ of vibration modes as obtained with the real-time HI associated to stroboscopic readout. (a) and (b) are two different modes of a 23x23 cm² aluminium square plate clamped on a part of its border (upper) and that is excited with a loudspeaker. Figure 3 (c) is one of the resonant modes of a turbine blade (used in aircraft engines) and that is excited by piezoelectric transducer.
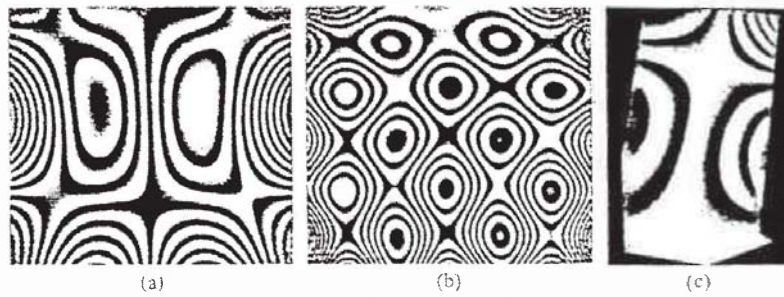
**Fig. 3** - Phase pattern mod $2\pi$ of vibration modes as observed by stroboscopic real-time HI.

Figure 4 presents an example of a 35x35 cm$^2$ object deformation. Figure (a) is the interferogram of the deformation superimposed to a spatial carrier fringe (vertical fringe pattern). After FFT filtering, the phase can be calculated mod $2\pi$ (b). The carrier frequency (number of fringes/mm) has to be high enough in order to filter out correctly the information concerning the deformation. What is remarkable is the number of fringes that are resolved by the system : in figure (a) 120 fringes are recorded on 512 pixels, say about 4 pixels per fringe, even less in some parts of the images. The small number of pixel per fringe (close to the theoretically required value) does not affect the quality of the final result, as can be seen. In fact it was possible to acquire such close fringes because of the very high signal-to-noise ratio of the interferograms that can be reached with the anisotropy of diffraction exhibited by the crystal.
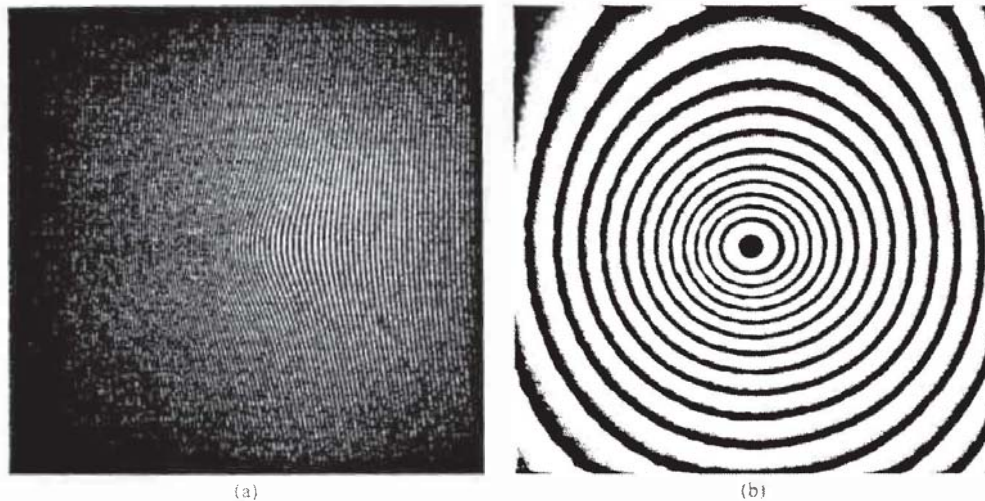


**Fig. 4** - Example of deformation analysed with a single interferogram when the spatial carrier technique is employed. (a) Intensity pattern, (b) phase modulo $2\pi$.

Figure 5 shows the breadboard holographic camera developed at IOTA. It can be used either with a continuous laser (e.g. argon) or pulsed (YAG or ruby). Two phase-shifted interferograms (the sine and the cosine of the phase difference to be determined) can be observed by the two-camera system simultaneously. At the recording, both objet and reference beams are linearly polarized. At the readout, the reference beam polarization is circularized by the Pockels cell. After the crystal, one then has the superimposition of the the linear polarization of direct object beam and the circular diffracted polarization. The polarizing beam splitter cube separates both beams in two components that can interfere at each CCD camera but with a phase-shift between each other [Labr 97]. This system has been used with a pulsed ruby laser (694 nm) for the analysis of vibration.
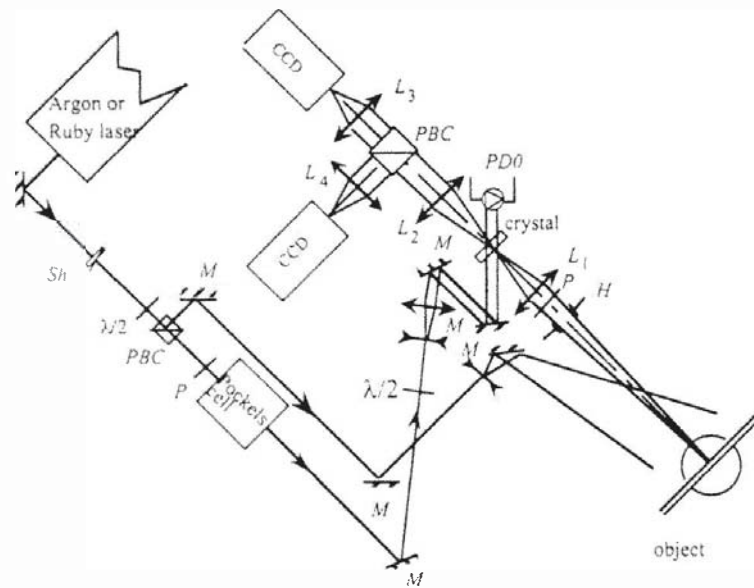
5

**Fig. 5** - Scheme of IOTA holographic camera. M : mirrors. $\lambda/2$: half-wave plate. P: polarizers. Sh: shutter. PDO: photodetector. PBC: polarizing beam splitter cube. H: diaphragm. L, : camera lenses.

Figure 6 shows an example of vibration phase interferogram as obtained with the system. It is the first example ever shown of phase measurement with a pulsed illumination. Using a fringe analysis software [STEIN] developed in the frame of the BRE2-0364 project, this map of deformation was obtained in a few seconds only. Moreover it shows that usable results can be obtained at such wavelength to which the crystal has normally a weak response. This is the reason why notable work has been carried out by both 3AR and IOTA to improve the sillenite crystals photorefractivity in this part of the spectrum. For that a BGO doped copper has been grown and used.
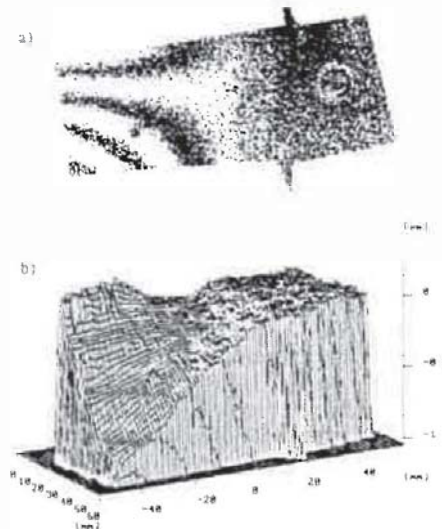


**Fig. 6** - Computed object displacement obtained for a vibrating turbine blade with a ruby laser (694 nm) (a) Phase modulo $2\pi$. (b) 3D plot of the unwrapped displacement map.

## 3. POTENTIALITIES IN SPACE APPLICATIONS

Like TV holography (ESPI), the main characteristics of photorefractive holographic cameras is their ability to work passively without any kind of intervention in terms of optical adjustement, physico-chemical processing and part maintenance. In this way they are basically well adapted for space purpose. In addition, as in classical holography, they allow direct observation of interferograms without computer, and high quality and low noise images. The latter properties appear also important for space applications where calculation ressources could be limited and data compression appears necessary for high resolution and images transfer rates.

Related to our experience with sillenite PRCs, potential applications in space can be envisaged either for structures active control that needs a global surface visualization or for investigations in $\mu$g, mainly in fluide science and crystal growth monitoring.

The performances for the first type of applications are directly related to the ones of the results presented in section 2.4, keeping in mind that any reduction of the observed surface or modification of the available laser power affects the response time in the same proportion.

In the second type of applications, the observations concern transparent objects or cells in which the optical path is modified by refractive index changes during an evolving process. This essentially different framework induces basic changes in the set-ups proposed above in order to match the particularities and specifications of such experiments. Firstly, all the object illumination path becomes collimated (Fig. 7). Assuming that the object has a good transparency, a large amount of light power is spared comparatively to the diffuse reflective object cases envisaged previously. Secondly, the imaging system between the test container and the camera is also strongly different. Essentially, it consists in a telescopic system with a large demagnification ratio in order to adapt the beam diameter to the detector size (CCD or other). It induces several important consequences :

- At equal basic laser power, the response time of the system can be largely decreased. A simple estimation gives recording times with BSO crystals of about 0.1 s for 50 mW/cm$^2$ intensity in reference beam. Inversely we can envisage to reduce the laser power if a recording time of several seconds for the object at rest (reference state) is compatible with the experiment.
- The optical crystal size can also be reduced to dimensions comparable to the beam diameter at the final stage ($\approx 1$ cm$^2$).
- The geometrical constraints present in diffuse objects measuring HI systems (intermediate image size, distance between objective lenses and crystal, imagery position, ...) can be relaxed, leading to more room and flexibility in the choice of optical configurations and components.

In term of optical resolution, crystals as recording medium appear also interesting. Since they can be obtained with good optical qualities (particularly for small dimensions and thicknesses), they should affect weakly the lateral resolution. Experiences, on diffuse objects, show that the latter remains principally limited by optics and sensor performances. With the same experience, we can also predict favorable results for the fringes spatial resolution. The example shown in Fig. 4 concerning the fringe analysis by the spatial carrier frequency technique indicates that high densities are achievable (average frequency of 4 pixels per fringe for 512 by 512 pixels). Considering that the fringe distribution is not homogeneous on the image field, some parts are effectively close to the maximumn sensor resolution (2 pixels per fringe).

Protocols or sequences of measurement must take into account the specific holographic erasure/rewriting process of photorefractive systems during the observation. However, it must be pointed out that the dark storage time of the crystal can reach several tens of minutes. With continuous illumination and without any intensities adjustement (between writing and reading steps), we have total useful observation intervals (cumulated exposure time for reading or visualization) of about half the response time. So for limited dynamics phenomena, we can easily operate by short readouts separated by darkness periods. For highly dynamical behaviors with continuous or 'real time' observation during several minutes, we could envisage to increase the effective erasure time by decreasing the intensity of the reference beam during the visualization step. However, as the camera has a limited sensitivity, the lost of diffracted power must be compensated by an increase of the diffraction efficiency that could be obtained by application of an external electric field to the crystal.

Another way to proceed in this case is the use of pulsed laser combined with an angular coding of successive holograms. The large thicknesses of crystal (> 1 mm) imply a high angular selectivity that allows separate holograms writing and reading by simply changing slightly the reference beam direction. Visualization of interferograms is operated during (real-time HI) or after (double-exposure HI) the process. Moreover, this step-by-step procedure allows to measure large optical path variations (high number of fringes) because each interferogram shows the change during a small time interval, the total change is then the sum of the phase changes retrieved from a whole sequence of interferograms.



OBE: Object Beam Expander.
OBT: Object Beam Telescope.
PRC: PhotoRefractive Crystal.
PZT: Piezo-Electric Translator.
RB: Reference Beam.
RBE: Reference Beam Expander
SIA: Shutter and Intensity Adjuster.
TC: Test Cell.
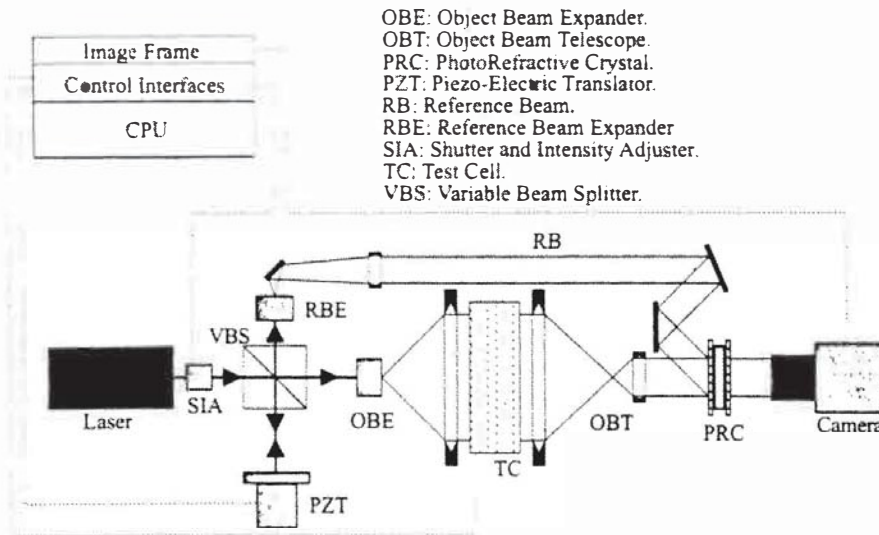VBS: Variable Beam Splitter.

Fig. 7 - Possible scheme of PRC holographic camera for transparent objects study.

At the level of image processing for phase quantification, it is now clearly established that photorefractive systems are compatible with the most used method (time or space phase shifting, fourier analysis). One important feature is that the response time or the sampling frequency of the readout step is not limited by the PRC, so we could also observe very fast phenomena and our systems are only limited by the peripherals, mainly the image acquisition rates.

On a general point-of-view and especially when one compares the segment of the holographic recording support, systems that use photorefractive crystals should be more compact than other competitive classical holographic media that use space compatible revealing processes (thermoplastics, photopolymers). This is clearly due to the very low number of peripheric devices needed to operate the crystal. Such potentiality is very important, in view of multichannel (tomographic) diagnostic instruments, such as e.g. the MHOI by Italian consortium [Alen 95].

## 4 - CONCLUSIONS AND FUTURE PROSPECTS

As shown above, among the PRCs, the sillenites are a good compromise in terms of sensitivity, holographic response and optical quality for HI applications. The systems developed up to now are currently tested for transparent materials investigations with regards to specification of classical fluide science experiments. However, if these holographic set-ups are promising, their spectral sensitivity remains essentialy limited to the blue- green wavelengths and consequently does not allow to use laser diodes which are perhaps key devices for space applications. Therefore current investigations on new kinds of PRCs, such as CdZnTe like those grown at 3AR, are in progress. The latter is more sensitive than sillenites and spectrally well adapted to the near infrared spectrum (from 1 to 1.5 μm) [Mont 96/1]. If progresses are still expected for these new PRCs, particularly in the growth control of large crystals, recent achievements with them for ultrasonic sensors by IOTA [Mont 96/2] show that they could reach rapidly the maturity for HI purposes.

## REFERENCES :

[Alen 95] "High Resolution Diagnostic Study", ESA/ESTEC contract : 8822/90/NL/PB(SC), Final Report, Alenia Spazio doc. SG-RP-AI-0097, Feb 95.

[Beda 90] F. Bedarida, P. Boccacci, G.A. Dall'Aglio, L. Gatti, L. Michetti, C. Pontiggia, F. Solitro, L. Zefiro : "Crystal Growth from Solution. Diagnostic Techniques", *ESA SP-295, Proceedings of the VIIth European Symposium on Materials and Fluid Sciences in Microgravity*, Oxford, January 1990, pp. 563-568

[Dirk 94] D. Dirksen, G. von Bally : "Holographic double exposure interferometry in near real time with photorefractive crystals", J. Opt. Soc. Am. B 11 (9), 1994, pp. 1858-1863

[Geor 95/2] M.P. Georges, Ph.C. Lemaire : "Phase-shifting real time interferometry that uses bismut silicon oxide crystals", Appl. Opt. 34 (32), 1995, pp. 7497-7506

[Geor 96/ 1] M.P. Georges and Ph.C. Lemaire "Real-time quantitative holographic interferometry using sillenite crystals for the study of varying objects", *EOS Topical Meetings Digest Vol. 7 of Conference Materials for Non Linear Optics*, Val Thorens, France, Jan96, p. 145-146

[Geor 96/2] M.P. Georges and Ph.C. Lemaire : "Holographic interferometry using photorefractive crystal for Quantitative Phase Measurement on Large Objects", *Proceedings SPIE 2652*, 1996, pp.248-257

[Geor 96/3] M.P. Georges and Ph.C. Lemaire : "Holographic interferometry using photorefractive crystal : recent advances and applications", *Proceedings SPIE 2782*, 1996, pp.476-485

[Geor 97] M.P. Georges and Ph.C. Lemaire,"Real-Time Stroboscopic Holographic Interferometry using Sillenite Crystals for the Quantitative Analysis of Vibrations", Opt. Comm., to be published

[Huig 77] J-P. Huignard, J-P. Herriau, T. Valentin : "Time Average Holographic Interferometry with Photoconductive Electrooptic Crystals", Appl. Opt. 16, 1977, pp. 2796-2798

[Labr 95/1] L. Labrunie, G. Pauliat, J-C. Launay, G. Roosen : "Real-Time Phase Shift Determination mod 2pi in Double Pulse Laser Holography with BGO Crystals", *Technical Digest of NIST/OSA Topical Meeting on Photorefractive Materials, Effects and Devices*, Estes Park, Colorado, USA, June 95, pp.512-515

[Labr 95/2] L. Labrunie, G. Pauliat, G. Roosen, J-C. Launay : "Simultaneous acquisition of pi/2 phase-stepped interferograms with a photorefractive Bi12GeO20 crystal : application to real-time double-exposure holography", Opt. Lett. 20 (15), 1995, pp. 1652-1654

[Labr 97] L. Labrunie, G. Pauliat, J-C. Launay, S. Leidenbach, G. Roosen : "Real-time double exposure holographic phase-shifting interferometer using a photorefractive crystal", Optics Comm. 140, 1997, pp. 119-127

[Mary 90] J. Mary, Y. Bernard, F. Lefaucheux, J.P. Cadoret, F. Gonzalez : "A New Interferometer : HOLIDDO", *ESA SP-295, Proceedings of the VIIth European Symposium on Materials and Fluid Sciences in Microgravity*, Oxford, January 1990, pp. 581-586

[Mont 96/1] L.A. de Montmorillon, Ph. Delaye, G. Roosen, H. Bou Rjeily, F. Ramaz, B. Briat, J.P. Gies, J.P. Zielinger, M. Tapiero, H.J. von Bardeleben, T. Arnoux, J.C. Launay :"Correlations between macroscopic properties and the observed photorefractive response of Vanadium doped CdTe and CdZnTe". J. Opt. Soc. Am. B 13, 1996, pp. 2341-2351

[Mont 96/2] L.A. de Montmorillon, I. Biaggio, Ph. Delaye, J.C. Launay, G. Roosen : "Eye safe large field of view homodyne detection using a photorefractive CdTe:V crystal", Optics Comm. 129, 1996, pp. 293-300.

[Poue 96] B. Pouet, S. Krishnaswamy : "Dynamic Holographic Interferometry by Photorefractive crystals for Quantitative Deformation Measurements", Appl. Opt. 35 (5), 1996, pp.787-793

[Rohl 94] H. Rohleder, P.M. Petersen, A. Marrakchi : "Quantitative measurement of the vibrational amplitude and phase in photorefractive time-average interferometry: a comparison with electronic speckle pattern interferometry", J. Appl. Phys. 76 (1), 1994, pp. 81-84

[Sill 90] K.H. Sill, K. Heimann, M. Roth : "HOLOP D-2, A Holographic Interferometer for Microgravity Research in Space". *ESA SP-295, Proceedings of the VIIth European Symposium on Materials and Fluid Sciences in Microgravity*, Oxford, January 1990, pp. 575-580

[Stein] Labor Dr. Steinbichler, Am Bauhof 4, 83115 Neubeuern, Germany.

[Trol 90] J.D. Trolinger, R.B. Lal, A.K. Batra : "Holographic Instrumentation for Monitoring Crystal Growth in Space", *Proceedings SPIE Vol. 1332*, 1990, pp. 151-165