Journal of Information Display, vol. 3, no. 3, 2002 © 2002 KIDS

Review of Liquid Crystal Spatial Light Modulators at Thales Research & Technology: Technology and Applications

Mane-Si Laure Lee, Brigitte Loiseaux, Daniel Dolfi, Sylvie Tonda, and Jean-Pierre Huignard

Abstract

Liquid Crystal Spatial Light Modulators (LC-SLMs) provide many interesting applications in laser optics and opto-electronic systems, in addition to displays. Among them, three topics developed at Thales Research & Technology are reviewed: wavefront correction for laser beam control, microwave processing in radar systems and holography for TN-LCDs viewing angle compensation.

Keywords : liquid crystal spatial light modulator, adaptive optics, phased array antennas, from birefringence, holography

1. Introduction

Apart from their main use for displays, LC-SLMs technology is very well suited for a large variety of applications in laser optics and optronic systems for active optical elements, laser cavities and metrology. In fact, this technology allows for an accurate control of the phase of an optical wavefront. In this paper, we describe different LC-SLM applications developed at Thales Research & Technology (R&T).

The first section deals with the wavefront correction dedicated to ultimate the brightness of a laser. The second section concerns the phase control in the microwave processing in radar systems area. The third section reviews a last incontestable application, the display, domain in which Thales developed hybrid holographic compensation for widening the viewing angle of Twisted Nematic Liquid Crystal Displays (TN-LCDs).

2. Liquid Crystal Spatial Light Modulator for Laser Beam Control

For many applications involving ultra intense laser system, the main features are the focusing ability and the power delivered on the target. Thus to achieve a high level quality beam, the beam should be focused as close as possible to the diffraction limit, while carrying high intensities (typically $>10^{21}$ W/cm^2). Unfortunately, the quality of the beam emitted by such short pulse sources is mostly limited by spatial distortions arising in the laser chain that results in phase aberration effects on the focused beam. Most of the laser facilities now try to implement a wavefront correction device. In most cases, deformable [1, 2] mirrors are coupled to wavefront sensors such as Shack-Hartmann. Here, we report on an original way of correcting the phase distortion [3] that associates a programmable beam shaping modulator based on a Optically Addressed electro-optical valve [4] and a phase sensor based on an achromatic three waves lateral shearing interferometer [5].

2.1 Optically addressed light valve

The adaptative beam shaping module is based on an optically addressed light valve (OALV) developed at

---

Manuscript received July 2, 2002; accepted for publication July 25, 2002.

Corresponding Author : Mane-Si Laure Lee
THALES Research and Technology Domaine de Corbeville, 91404 Orsay Cedex, France.
E-mail : mane-si-laure.lee@thalesgroup.com **Tel** : +33 1-69-33-9163
Fax : +33 1-69-33-9127

Thales R&T. It is aiming at transferring the intensity modulation held by a writing beam (from a blue incoherent light) into a phase modulation on the reading beam (λ=1.06 μm) to be corrected. This device is based on the generic liquid crystal technology used for flat panel display applications. The difference with conventional LCDs, is that the liquid crystal layer is optically driven by a bulk photoconductor material instead of electrically driven by multiplexing or active matrix. The device acts as an electro-optic phase plate whose retardation value can be continuously controlled by the voltage applied onto the liquid crystal layer which depends on the conductivity of the photoconductive material [4], see Fig.1.

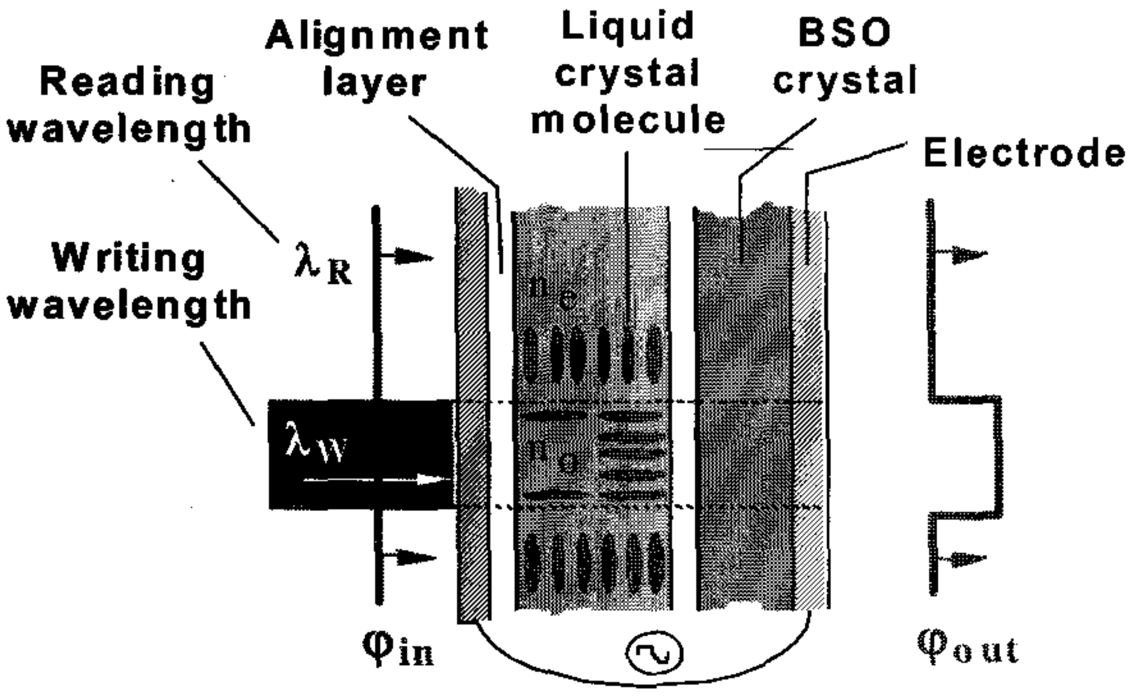


Fig. 1. OALV operating as programmable phase plate.

The OALV uses a 1mm-thick $Bi_{12}SiO_{20}$ single crystal (BSO), as photoconductor. When the photoconductivity is not activated (no illumination or at wavelength out of the sensitivity range, λ_R>600 nm), the high dark resistivity prevents from any voltage transfer to the liquid crystal layer. Then, when locally illuminated with incoherent light (the writing beam λ_w<500 nm), the photoconductive properties of the BSO allow local and partial transfer of the voltage to the liquid crystal layer according to the illumination level. Thus, the liquid crystal molecules exhibit a local change of their orientation, leading to a birefringence variation. Finally, after propagation through the liquid crystal cell, a polarized reading beam experiences local phase shifts. The OALV acts as an adaptive phase plate, which can be used in transmission directly for phase control or in combination with a polarizer for amplitude control of the reading laser beam.

The maximum phase excursion and the time response of the OALV can be adjusted, according to the thickness of the liquid crystal layer. Typically, the time response is in the range of 20 to 200 ms for a thickness between 4 and 25 μm. Typical phase shift value for standard liquid crystal materials (of Δn=0.15 at 1.06 μm) are thus in the range of $\lambda/2$ to 3λ. With a resolution of 100 μm and typical size of 1 inch, this device can compensate higher spatial frequency distortions than standard adaptive mirror.

2.2 Adaptive beam shaping module

To perform adaptive corrections with the OALV, we chose, as shown in Fig. 2, to control the spatial repartition of the illumination by imaging an electrically addressed liquid crystal display (LCD), using an incoherent light source. The LCD, used between crossed polarizers, has the VGA format. Interfaced with a computer, it can operate as a programmable mask at video frame rate.

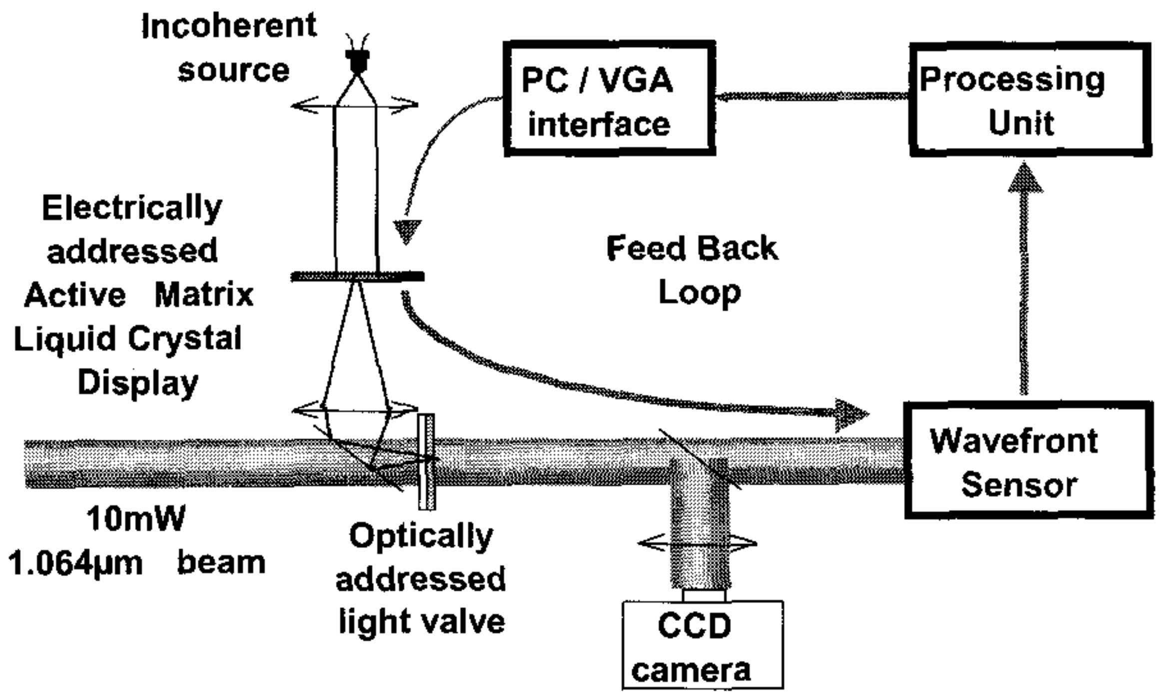
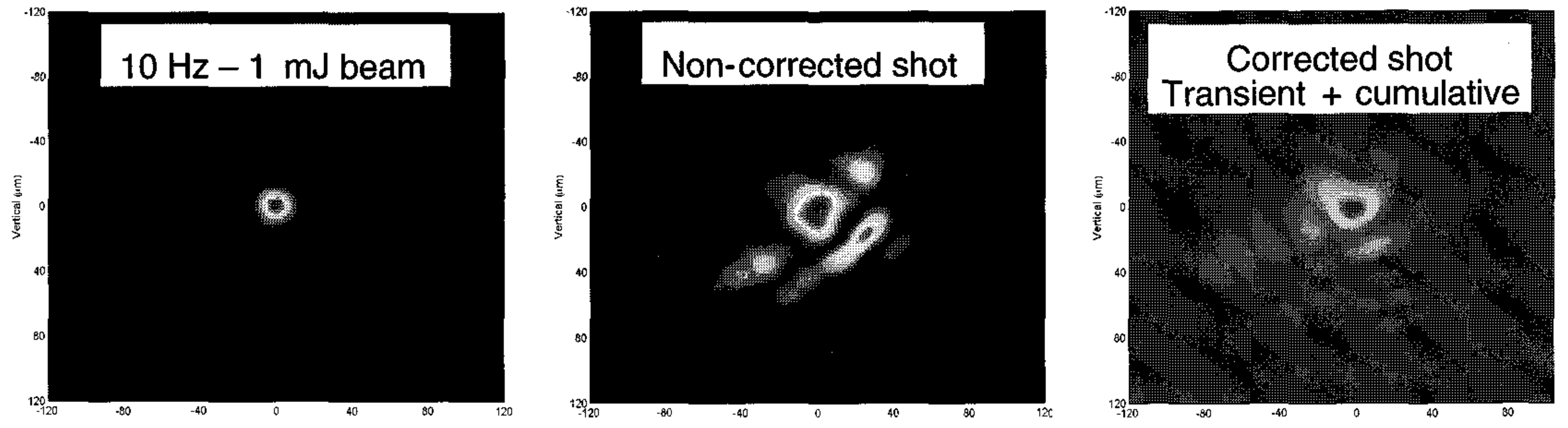


Fig. 2. Beam shaping module for adaptive control of laser beam profile.

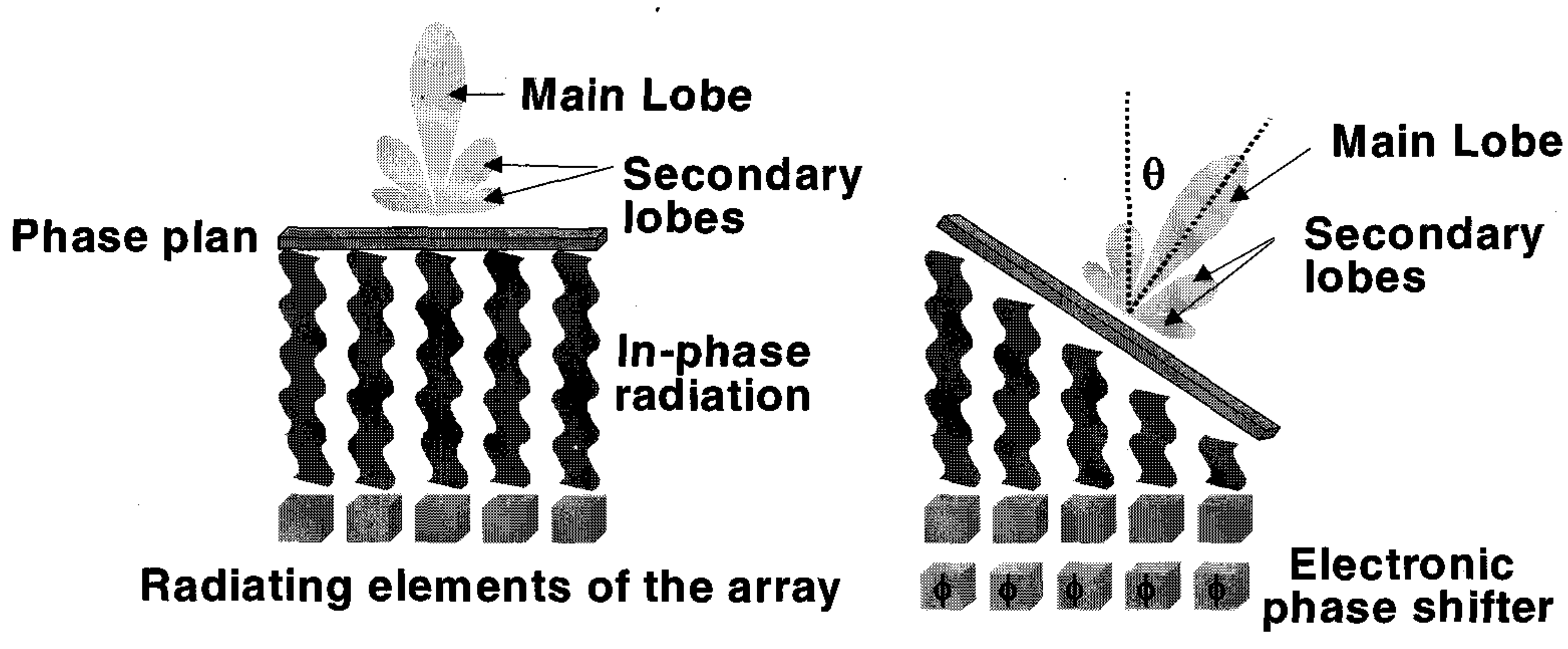
2.3 Experimental set up

To control the shape of the spatial wavefront of the pulses, an adaptive optic loop is used: the wavefront modulator is coupled to the wavefront sensor that measures the phase profile of the wave front via an achromatic three-wave lateral shearing interferometer [5], see Fig. 2. Hence, depending on the beam profile at the laser output, an adaptive phase plate is generated by the OALV through an interactive process involving a computer. The computer's role is to recover the phase recorded by the shearing interferometer and, according to this information, to generate a mask to be displayed on the LCD.



(a) (b) (c)

Fig. 3. Measured far-field patterns. The far-field was optimized with the 1 mJ/10 Hz alignment beam of the 100-TW laser chain (a). (b) and (c) Shots at 30 J – 300 fs.



(a) (b)

Fig. 4. Beam steering by time delay control.

2.4 Implementation in a high power laser

At first, the adaptive optic loop was designed to correct the wavefront of a high power laser chain: the LULI 100-TW Nd:Glass operating at 1.06 µm. In this kind of glass systems, thermal effects are quite important and mostly lead to thermal lensing which degrades the focal spot and limits the repetition rate. Thus, the adaptive system goal was not only to correct the wavefront distortions occurring during one shot but also to take into account both long term and transient thermal evolution of the laser chain before a new shot. For that purpose, a 1mJ/10Hz alignment beam is used [6] to close the feed-back loop between two shots. The resulting effect from the loop is illustrated by the far-field patterns of Fig. 3.

To conclude, we manage to correct the wave front of a 100-TW laser chain during series of shots. The resulting field patterns have twice more energy in the central peak a compared with non-corrected series shots. And when performed before complete thermal relaxation of the laser, the correction allows for increasing the repetition rate by a factor three.

3. Photonics Processing in Radar Systems

Future microwaves systems will be equipped by phased array active antennas that provide new capabilities in terms of performances, reliability, jamming robustness and flexibility. Future airborne antennas are planned to be distributed over the entire aircraft while ground based antennas will be remote from the processing unit. As a consequence, signal distribution will be confronted with propagation loss or

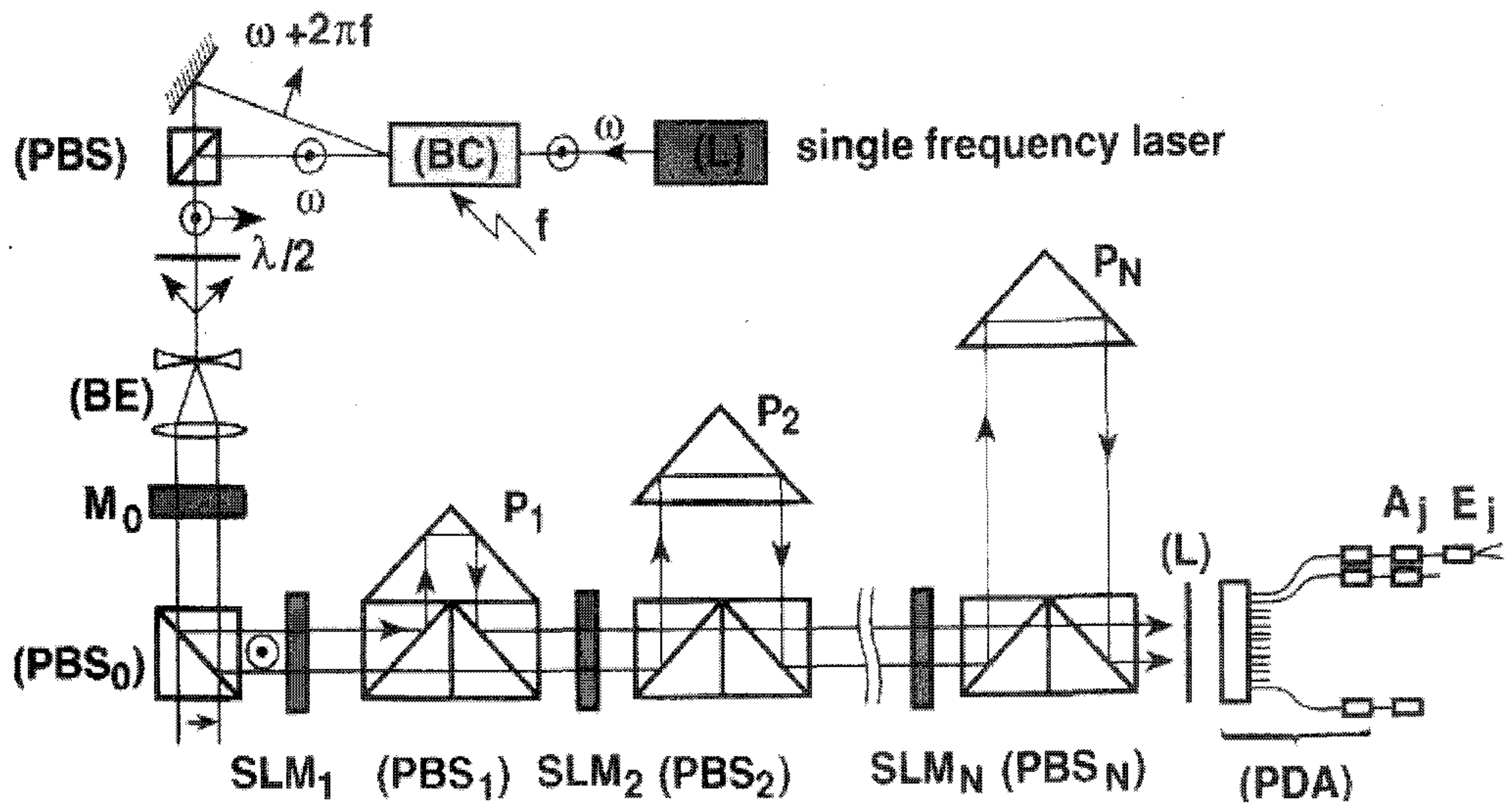


Fig. 5. Optical architecture for the phase and time delay control of a phased array antenna.

electromagnetic interference problems. Moreover, future multifunction phased array antennas will require frequency bandwidth largely exceeding those of the existing radars (typically 1-20 GHz) which is difficult to achieve with only microwave techniques.

An attractive solution available within these severe conditions is the use of opto-electronic components operating up to 40 GHz and the use of almost loss-free propagation of optically carried microwave signals. Here, we present an application of optical architecture using SLMs, dedicated to the control phased array antennas.

A phased array antenna is represented in Fig. 4. It is composed of in-phase radiating elements, see Fig. 4a. According to the phase law applied to set of phase shifters, see Fig. 4b, it is possible to control the phase plane radiated by such an antenna. Meanwhile, as the frequency varies, an angular shift of the main lobe appears and a beam squint occurs for large bandwidth antenna. To get rid of this, it is needed to add a time delay control.

The phased array antenna using phase and time delay control is implemented through an optical architecture [7], illustrated in Fig. 5. A monomode laser beam ($\omega/2\pi$) is focused in an acousto-optic Bragg cell that, when excited by a microwave at f, produces a transmitted beam at $\omega/2\pi$ and a diffracted beam at $\omega/2\pi+f$, polarized perpendicularly to each other. These two components are then superimposed by means of a polarizing beam splitter (PBS). This dual frequency beam is expanded: it is the optical carrier of the microwave signal. It travels through a set of Spatial Light Modulators (SLMs) whose number of pixels (p×p) is the number of elements of the antenna. M_o is a parallely aligned liquid crystal SLM. It controls the phase of the microwave signals by changing the relative optical phase of the crossed polarized components of the dual frequency beam. At the output of M_o, the now linearly polarized optical carrier intercepts N spatial light modulators SLM_i, polarizing beam splitters PBS_i and prisms P_i. They provide the parallel control of the time delays assigned to the antenna. On each pixel, the beam polarization is rotated by 0 ° or 90 °. That is when PBS_i is transparent (and the light beam intercepts the next SLM_{i+1}) or reflective (and the optically carried microwave signal is delayed). The channeled beam is then detected by an array of p×p fiber pigtailed photodiodes (PDA). The phase of the microwave signal delivered by each photodiode is determined by the applied voltage on the corresponding n pixel of M_o and by choice of the PBS_i on which the reflection occur. Since time delay values are set according to a geometric progression ($\tau, 2\tau, 4\tau$...), the beating signal can be delayed from 0 to $(2^N-1)\tau$ with step τ.

A demonstrator of an emitting phased array antenna composed of 16 elements and operating between 2.5 and 3.5 GHz was set up. The architecture is composed of 6 SLMs of 4×4 pixels, to feed a 16 element antenna with 32 delay values. The modulators are Twisted Nematic

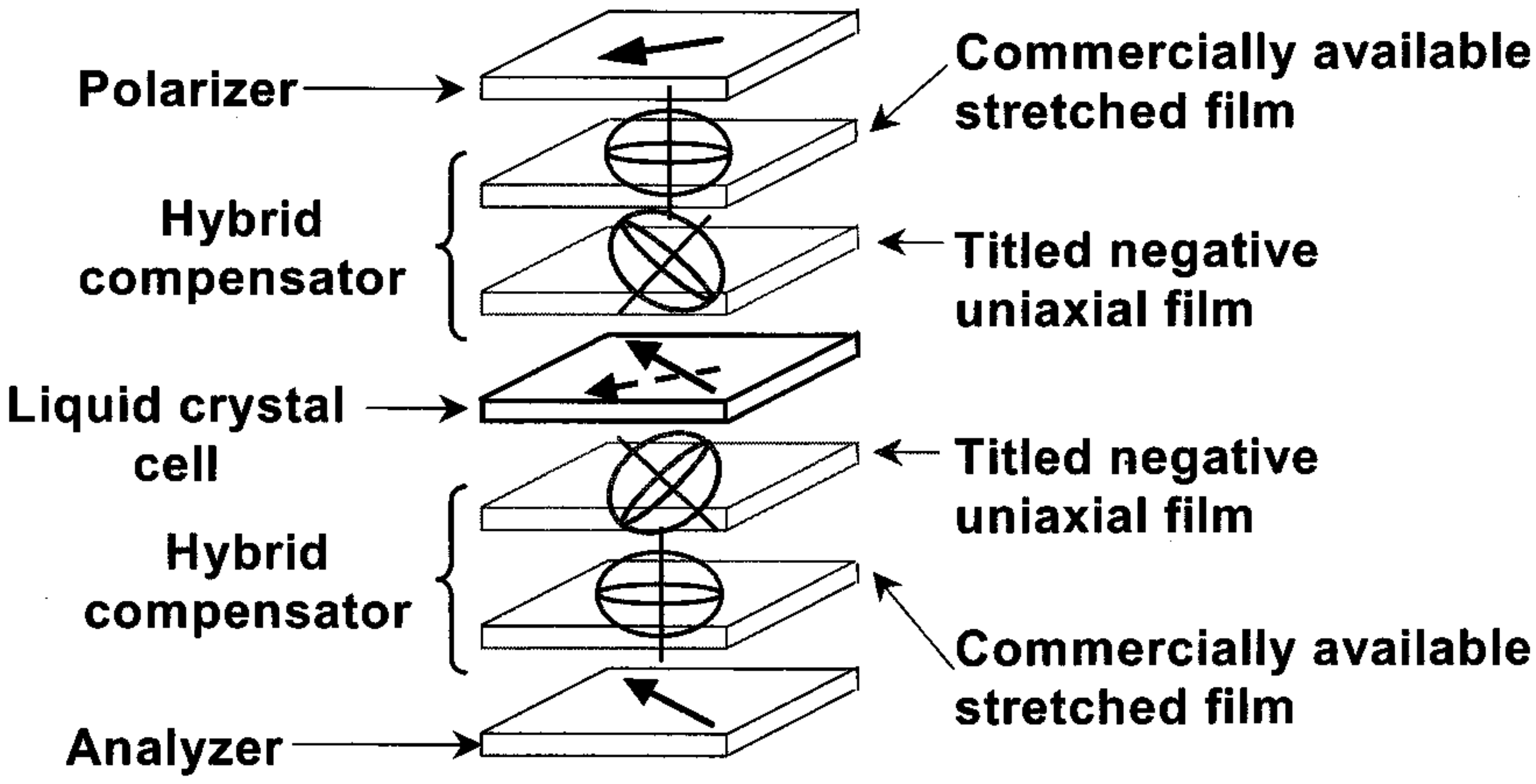


Fig. 6. Hybrid holographic compensator structure.

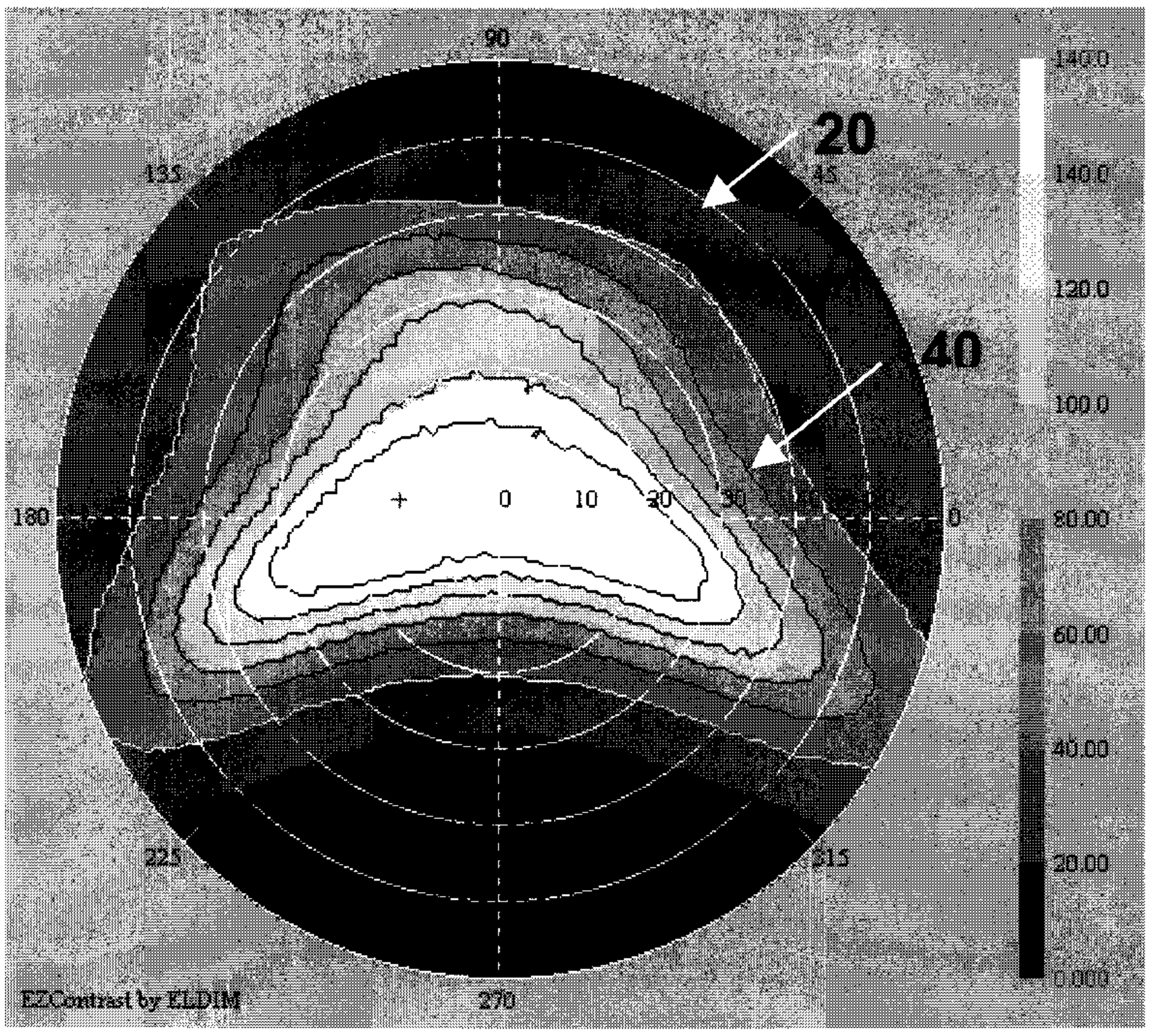


Fig. 7. Compensated TFT color display. The display cell gap is 5.6 μm. The area with no gray inversion (the interesting half plane) is the higher half plane.

Liquid Crystal cells. The far field pattern of this antenna was characterized, using optical phase and time delay switching, with no beam squint between 2.5 and 3.5 GHz.

4. Widening the Viewing Angle of TN-LCDs using Hybrid Holographic Compensation

In this section, we present the work developed at Thales R&T on the most usual application of LC-SLM: the direct view display. With the increasing demand for LCD panels, the active matrix Twisted Nematic Liquid Crystal Displays (TN-LCD) has become the most successful technology for their various application extents, such as computer desktop, automotive and avionics. Meanwhile, even if they offer high performances in terms of luminance, resolution, color and gray level capabilities, it is well known that for a conventional TN-LCD in the normally white mode, these parameters are dependant on the viewing angle: in particular, the contrast and the colorimetry are affected.

Several approaches are proposed to improve the viewing angle characteristics, using various LCD modes such as multi-domain TFT-LCDs, Optical Compensated Bend, In Plane Switching, Vertical Aligned or/with compensation films. Recently, we introduced [8] a hybrid compensator composed of a holographic sub-wavelength grating combined with "in plane' birefringent films, as illustrated in Fig. 6.

The "in plane" birefringent film is a commercially available biaxial film. The holographic component operates under form birefringence regime, i.e. the period of the index-modulated structure is small compared to the illumination. Thus, all non-zero diffraction orders of the grating are evanescent and the grating acts as a negative uniaxial birefringent material. Hence, it can be used to compensate the positive uniaxial birefringence of the liquid crystal. Then, by changing the orientation of the grating index layers, we obtain a tilted negative uniaxial film.

The hybrid holographic compensation was implemented on a 5.6 μm-thick TFT TN display with its color filter. Note that the use of a 5.6 μm cell gap is of interest, since it optimizes the cell transmission. The volume holographic gratings were recorded on DuPont photopolymer at 363 nm, which ensures the form birefringence operation. They offer a 33°-slanted uniaxial behavior with a –35 nm retardation.

The compensated display was then characterized. The conoscope, given in Fig. 7, shows that hybrid holographic compensator highly widens TN-LCD viewing angle: the horizontal and vertical viewing angle, for the iso-contrast 25, are >[–60°;+60°] and [–25°;+45°], respectively, while keeping high on-axis contrast (>160).

5. Conclusion

Liquid Crystal Spatial Light Modulators (LC-SLMs) provide many varied applications from displays to laser optics or opto-electronic systems. First, we demonstrated experimentally that, introduced in a high power laser chain, an optically addressed LC-SLM, allow for a highly resolved wavefront correction and thus to ultimate the energy of a laser in the central peak by a factor two. Secondly, we showed that optical architecture using electrically addressed LC-SLMs offers interesting features in microwave processing in radar systems. Finally, in the area of direct view displays, we developed hybrid holographic compensation for widening the viewing angle of TN-LCDs. The enhancement of viewing angle was demonstrated by the implementation of the compensators on a TFT display.

Acknowledgement

The authors are thankful to the European Union for partial support of the work(ADAPTOOL and OCDIS projects). They are also grateful to the Laboratoire pour l'Utilisation des Lasers Intenses, Ecole Polytechnique (Palaiseau, France) for their contribution.

References

[1] F. Druon, G. Chériaux, J. Faure, J. Nees, M. Nantel, A. Maksimchuk, G. Mourou, J.C. Chanteloup, and G. Vdovin, Opt. Lett., **23**, 1043 (1998).

[2] M.D. Perry, D. Pennington, B.C. Stuart, G. Tietbohl, J.A. Britten, C. Brown, S. Herman, B. Golick, M. Kartz, J. Miller, H.T. Powell, M. Vergino, and V. Yanovsky, Opt. Lett., **24**, 160 (1999).

[3] J.C. Chanteloup, H. Baldis, A. Migus, G. Mourou, B. Loiseaux, and J.-P. Huignard, Opt. Lett., **23**, 475 (1998).

[4] P. Aubourg, J.-P. Huignard, M. Hareng, and R.A. Mullen, Appl. Opt., **21**, 3706 (1982).

[5] J. Primot, Appl. Opt., **32**, 6242 (1993).

[6] B. Wattelier, J.C. Chanteloup, J.P. Zou, A. Sauteret, A. Migus, J.-P. Huignard, and B. Loiseaux, Proceedings of SPIE, **4457**, 159 (2001).

[7] D. Dolfi, P. Joffre, J. Antoine, J.-P. Huignard, D. Philippet, and P. Granger, Appl. Opt., **35**, 5293 (1996).

[8] C. Joubert and J.C. Lehureau, Asia Display, **98**, 1119 (1998).