New liquid crystal microdisplays permit phase-only light modulation

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Liquid crystal microdisplays that modulate phase rather than amplitude are used as adaptive and diffractive optical elements, and to reconstruct digital holograms.

In many optical setups, it is desirable to use adaptive optical elements. However, purchasing such specialized components, especially during concept evaluation, is time consuming and expensive. For example, diffractive optical elements (DOEs)—which function due to diffraction occurring at one or more of its microstructured surfaces—are produced in high volumes at reasonable costs by replication technologies. However, this activity requires intricate and expensive fabrication of master and replication tools. Fortunately, spatial light modulators (SLMs)—devices that spatially vary light phase and/or amplitude—perform a similar function to DOEs. The fact that they are electrically addressable means that SLMs allow fast evaluation of the functions performed by DOEs and other optical elements.

A twisted nematic (TN) microdisplay is a liquid crystal display (LCD) containing transparent or translucent liquid that changes the polarization of incident light waves. TN microdisplays were developed to achieve spatially resolved amplitude modulation for image projection. Their operation is based on the rotation of the incident light’s polarization, caused by voltages to the LC cells. The polarization rotation causes a phase shift of the light; that is, the cell acts as if it has a spatially dependent optical thickness similar to microstructured optical surface. Research shows that SLMs, based on such displays, operate in a phase mostly mode by using additional optical elements. However, it is not possible to eliminate the remaining effects on the amplitude of the light.

A special configuration of the LC molecules—known as electrically controlled birefringence (ECB) mode—overcomes the relationship between polarization and phase effects in TN cells. The ECB mode causes the molecules to rotate along an axis perpendicular to both the direction of propagation and the polarization of the incident light. Consequently, a phase delay of the transmitting optical wave is obtained without affecting the polarization. Reflective liquid crystal on silicon (LCOS) microdisplays were fabricated using this special LC mode (see Figure 1).

Using interferometric techniques, the researchers measured the optical performance of the new LC-based microdisplays. The researchers measured the phase shift between two partial waves traveling through the LC material. It was higher than $540°(3\pi)$ at a 633nm wavelength (see Figure 2). The measurement of the Stokes parameters (a set of parameters for specifying phase and polarization of radiation) for the modulated light shows that...
Figure 2. Measured phase modulation of the display as a function of the addressed gray-level value for 633nm wavelength.

Figure 3. Diffraction pattern obtained from the LCOS phase-only display when an optical function corresponding to a DOE was displayed.

the linear polarization of the incident light is preserved. As can be seen from Figure 3, the phase-only modulating microdisplay evaluates the performance of optical transmission functions computed for diffractive optical elements. It is also possible to investigate effects caused by imperfect fabrication of elements, such as defects in nonequidistant surface levels in multilevel DOEs.

The flatness of the microdisplay is important because deviations from an optically flat surface introduce optical aberrations. Therefore, the researchers used a Twyman-Green interferometer (μ-Phase™, by Swiss-company FISBA OPTIK) to measure

Figure 4. Surface measurement of the display (a) without correction and (b) with correction, obtained from a measurement with a Twyman-Green interferometer.

Figure 5. Optical reconstructions of a holographic interferogram of an electronic circuit board, obtained from two digital holograms in operational and nonoperational states.

the surface flatness of the LCOS microdisplay. The measured deviations from the plane surface were primarily spherical. It is possible to compensate for the resulting defocus by adding the corresponding inverse wavefront distortion. The results show

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that the remaining wavefront deformation is negligible for many applications (see Figure 4).

One application for phase-only modulating microdisplays is the reconstruction of digital holograms. A CCD camera, replacing the conventional holographic recording plate, records the holograms. The recorded interference pattern is relayed directly to the microdisplay, where it is turned into a variation in phase. By coherent illumination of the display with a laser, another CCD camera observes and records the optical reconstruction. The researchers recorded digital holograms from objects subject to small mechanical deformations or vibrations. As seen in Figure 5, the optical reconstruction of holographic interferograms makes these changes apparent. In this interferogram—whose images come from two digital holograms—thermally induced deformations become visible as fringes.

Summary
Spatial light modulators can replace optical components in proof-of-concept experiments. For example, the parameters of static optical components are determined, thereby allowing DOEs to be fabricated in large numbers. SLMs are also useful wherever optical function is frequently changed and moving parts are not desirable. Phase-only modulation using only a LC-based microdisplay represent a marked improvement over phase-mostly configurations: its advantages include higher light efficiency, negligible amplitude modulation, and a lower number of required components.

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References