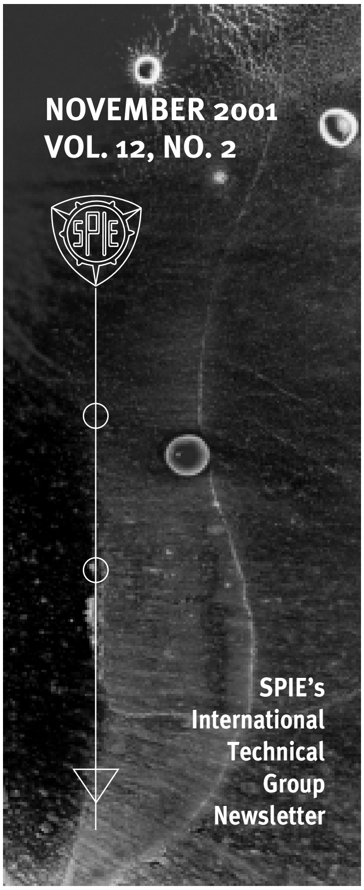

NOVEMBER 2001
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SPIE's
International
Technical
Group
Newsletter

HOLOGRAPHY

Lithographic holography in planar waveguides

Volume holograms are very powerful in that they can be used to both spectrally filter and spatially transform optical signals. Centimeter-scale holograms support spectral transfer functions that are arbitrary and programmable, are fully coherent, and have GHz-scale resolution. The wavefront mapping capability of volume holograms provides for the efficient mapping of signals from input to output ports. The incorporation of both spectral and spatial functions into a single structure offers uniquely powerful solutions to a variety of optical device design problems including those found in rapidly developing areas like optical communications.

Yet, despite their inherent and powerful dual functionality, volume holographic methods have not made widespread impact in device technology. Key to enabling their widespread implementation is the identification of fabrication means consistent with the complex micron- or submicron-scale diffractive structures needed and producing devices that are cost effective and of high reliability. A suitable fabrication approach has been difficult to realize in the context of fully three-dimensional (3D) structures, primarily because such structures must be written using optical interferometric methods. Interferometric writing methods are generally difficult and complex and require material properties that are often inconsistent with high stability.

Recent analysis[1] has shown that holograms written in thin slab waveguides (planar waveguides) retain essentially the same spectral filtering and spatial transformation capabilities exhibited by their fully 3D cousins. At the same time, however, planar holographic structures offer breakthrough pathways to fabrication. Planar waveguides[2] have a 2D core region a few microns thick and support a continuum of in-plane modes. The thinness of the planar waveguide means that propagation within the plane is strongly sensitive to surface structure. It follows that planar holographic structures can be fabricated entirely through surface scribing: that is, the desired diffractive structure is written in the form of troughs or ridges on the surface of the waveguide slab. Figure 1 shows a simple, cross-sectional schematic of a scribed planar waveguide. The refractive indices n_{c1} and n_{c2} are less than n_s. The spacing, *e*, between diffractive elements is typically an integral multiple of $\lambda/2$, where λ is the operative in-slab optical wavelength. The thickness, *f*, of the diffractive elements, or at least some structural subcomponent of

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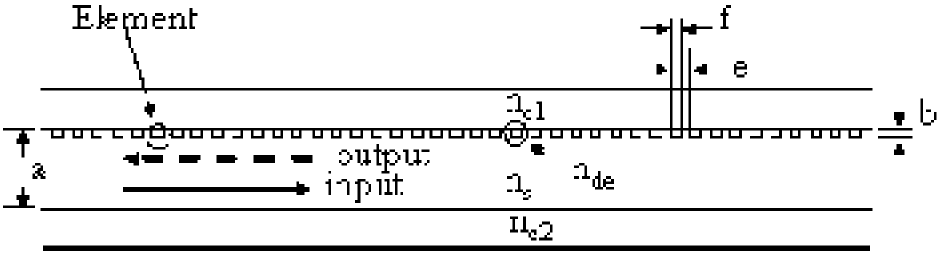

Figure 1. Cross sectional view of a planar waveguide with a surface relief holographic structure. While the surface relief shown is simple and periodic, lithographic mastering techniques, including e-beam, provide for arbitrary spacing and thickness of the holographic diffractive elements.

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NEWSLETTER NOW AVAILABLE ON-LINE

Technical Group members are being offered the option of receiving the Holography Newsletter in an electronic format. An e-mail notice is being sent to all group members advising you of the web site location for this issue and asking you to choose between the electronic or printed version for future issues. If you have not yet received this e-mail message, then SPIE does not have your correct e-mail address in our database. To receive future issues of this newsletter in the electronic format please send your e-mail address to spie-membership@spie.org with the word HOLOGRAPHY in the subject line of the message and the words "Electronic version" in the body of the message.

If you prefer to continue to receive the newsletter in the printed format, but want to send your correct e-mail address for our database, include the words "Print version preferred" in the body of your message.

New Technical Group Chairs introduce themselves

During the past few weeks I was asked to jointly head the SPIE Holography Technical Group with Hans Bjelkhagen. It is indeed an honor for me to do so and I hope that I can serve as a resource and offer direction for the Group. I have been involved with holography for over 25 years. I obtained my master's degree at the Institute of Optics at the University of Rochester (1975-1977). I completed my PhD at Stanford University (1982-1986), after having the opportunity to work under Joe Goodman on holographic optical interconnects. After graduating, I spent a year at the IBM Almaden Research Center in San Jose, California, where I again had a wonderful experience working with Glenn Sincerbox and Mark Levenson applying diffractive optics techniques to data storage problems. In 1987 I joined the faculty at the University of Arizona and have a joint appointment in Electrical Engineering and The Optical Sciences Center. At the UA I have had many projects related to holography and teach a graduate course in this area on a regular basis.

During these years I have noticed two parallel developments in the application of holography. The first is in displays and the second in optoelectronic device and systems. I think that Hans will do an excellent job covering the display technologies, however my experience falls in the second category. I have worked on micro-optical systems that incorporate holographic and diffractive optic components, holographic data storage systems, and most recently on subsystems for fiber optic communications. Some of the big success stories for holography on the component side have been fiber Bragg grating filters and gratings for distributed feedback lasers. In addition I see some really interesting new possibilities for holography as a technique for fabricating large 2D arrays of photonic bandgap layers. This possibility can potentially open many opportunities for device integration as well as display technology.

I'm looking forward to the upcoming technical group meeting at Photonics West. I hope to assemble a few people from the device side and let Hans bring in some people on the display side to lead a discussion on current trends in holography. I invite members of the technical group to offer suggestions and look forward to meeting with you in San Jose.

Ray Kostuk
University of Arizona
E-mail: kostuk@ece.arizona.edu

Plan to attend the

Holography Technical Group Meeting

Monday, 22 January 2002

7–9 pm

Room location to be announced
San Jose, California USA

As the new co-chair with Ray Kostuk, I thought I should introduce myself too. I received my MS degree in 1969 and PhD degree in 1978 from the Royal Institute of Technology in Stockholm, Sweden, and have since worked in many fields of holography—such as holographic interferometry—particularly using pulsed lasers.

In 1983, I joined CERN in Geneva, Switzerland, where I was involved in development of bubble chamber holography. A year later, at Fermilab, Batavia, Illinois, I participated in a large international team of scientists in the holographic recording of neutrino events in the 15-foot bubble chamber.

Between 1985-1991 I was with the Bio-Medical Engineering department at Northwestern University, Evanston, Illinois, working on medical applications of holography. After that, I returned to Europe, spending time both at the University in Münster, Germany, and Louis Pasteur University in Strasbourg, France.

I have been involved with display holography as well as more technical applications: pulsed portraiture in particular. Most recently I have been involved in the development of true-colour holography and Lippmann photography, work that I now pursue at the Centre for Modern Optics at De Montfort University, UK, which I moved to in December 1997.

Hans Bjelkhagen
De Montfort University
E-mail: hansholo@aol.com

Congratulations

We would like to congratulate our new co-Chair, Prof. Hans Bjelkhagen of De Montfort University, Leicester, UK, and holographic artist Margaret Benyon, also of the UK, for their recent Royal Photographic Society (RPS) awards. Bjelkhagen was given the Saxby Award (a prize endowed by well-known holographer and author Graham Saxby) for achievements in 3D imaging, as well as a society fellowship. Benyon received an Honorary fellowship for significant contribution to the art and science of photography for her holographic work. Both awards were clearly well deserved.

Sunny Bains
Scientist/Journalist
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Microholographic system for optical data storage

Storing many data pages within a small volume of a material, page-oriented holographic memories promise both high storage densities and data rates. However, despite ongoing research efforts in recent years, holographic data storage still encounters many difficulties and it is questionable whether such systems would ever be able to compete with the existing optical disks and drives in daily life.

Our approach to 3D optical storage offers a compromise by combining bit-oriented storage of CD/DVD and holographic volume recording. Microholography[1] expands surface storage into the third dimension by storing the data as microscopic reflection gratings instead of pits, while the optical system has most components in common with CD/DVD systems. High storage densities can be achieved by combining wavelength multiplexing[2] and multilayer storage, which is the simplest way to use the third dimension of a medium. Using multiple data layers instead of only one, the overall storage capacity will linearly grow with a number of layers. The success of the dual-layer DVD-ROM has attracted interest, but in conventional optical systems—based on a readout from the reflective layer—the multilayer approach has only a moderate potential to increase the storage capacity. Combined with microholographic recording techniques, this approach can become much more attractive.

Microgratings are written in the focal region of two counter-propagating, highly-focused laser beams. Localized volume storage allows for recording in several layers through the depth of a photopolymer. Crosstalk effects, which appear when illuminating several grating-structured layers with a read beam, can effectively be minimized by providing an appropriate layer spacing. In addition, the longitudinal intensity distribution of a highly-focused read beam supports optical separation of multiple micrograting layers.

Three experimental setups are currently being used for different investigations of microholographic storage. In particular, one of them has been designed around recording in thick samples of Aprilis ULSH-500 photopolymer (Figure 1). Aprilis CROP photopolymers[3] have several characteristics that make them attractive as media for microholographic storage.

Among other things, writing and reading of microlocalized volume gratings require high-precision positioning as well as dynamic control of the laser beam focus within the photopolymer. In our system, two aberration-corrected Olympus microscope objectives with 0.6 numerical aperture are mounted face-to-face to focus the incident and reflected beam into a storage layer. Correcting different kinds of aberration, they make it possible to focus the laser beam close to the diffraction limit and to maintain this spot size while translating it through the depth of a photopolymer.

A Nd:YAG laser emitting green light at 532nm is used for writing and reading. In addition, a HeNe laser at 632.8nm provides a pilot beam. The Aprilis ULSH 500 photopolymer is green-sensitive and optimized for 532nm. The material is not sensitive for red

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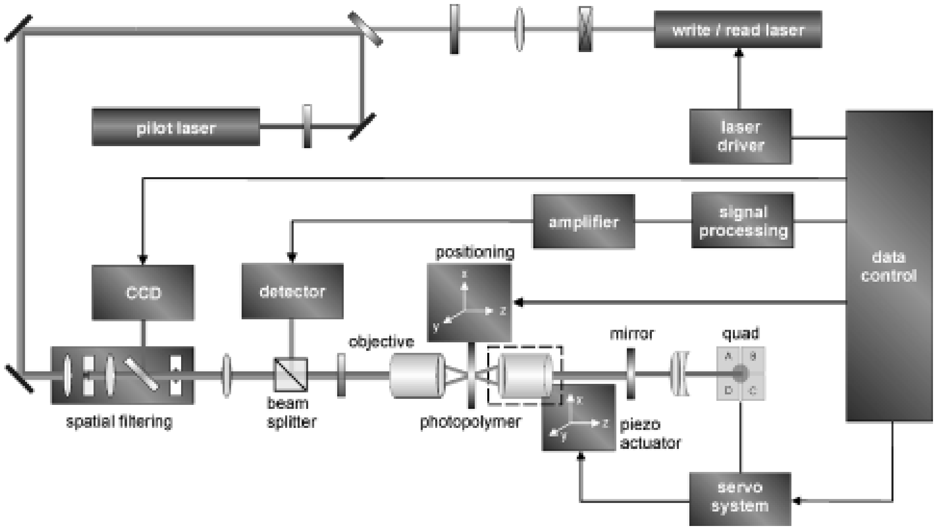

Figure 1. Microholographic system for recording in Aprilis ULSH photopolymers. Microgratings are written with a highly focused beam at 532nm. The incident beam is reflected back from the mirror to create an interference pattern within a photopolymer. The modulation range of a micrograting is localized in the focal region of the diffraction-limited write beam, which allows for multilayer recording within thick samples of Aprilis photopolymer.

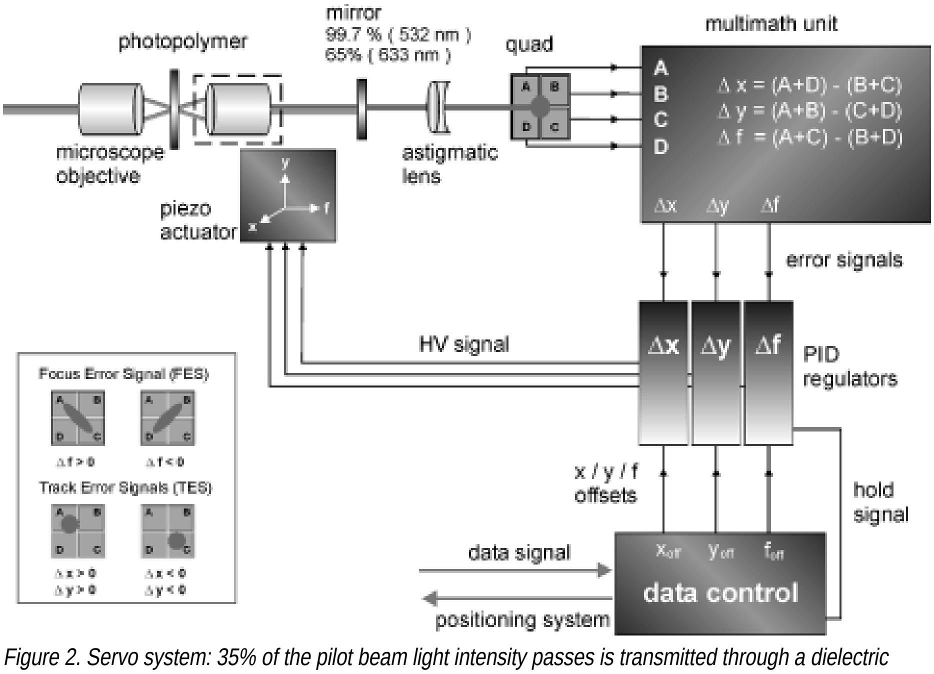

Figure 2. Servo system: 35% of the pilot beam light intensity passes is transmitted through a dielectric mirror. An astigmatic lens projects this light onto a quad. The Multimath unit derives both the track-error signals (TES) for lateral beam shift and the focus-error signal (FES) for defocus. The error signals are processed via PID (proportional integral derivative) to three piezo-actuators integrated into the positioning system.

Harriet Casdin-Silver: Pioneer art holographer

Long considered a pioneer figure in the world of American art holography, Harriet Casdin-Silver has more recently captured the attention of the broader spectrum of contemporary American art. In his review of her work in the New York Times issue dated 15 July, reviewer Miles Unger's statement acknowledges the art world's long-held attitude toward holography, "Energy and ambition have been conspicuous throughout Casdin-Silvers 30-year career as one of the country's leading art holographers, sustaining her in a profession that falls uncomfortably in the gap between art and science. The art world in particular has been slow to legitimize holography as an art medium."

On the other hand, Casdin-Silver has long held and has not hesitated to express her view that "Art speaks of its time; Our time is technological. The art of the twenty-first century will emanate from the laboratory. I have spoken these words often in the 33 years I have worked with holographic art and installations."

Casdin-Silver's work is internationally recognized and has been exhibited for over three decades in museums, galleries, and universities throughout the Americas, Europe, and Asia. She began her art career as a painter in the 1960s and soon moved on to explore and create multi-media and technologically-oriented artworks.

She started working with holography in 1968, making her one of the earliest artists to approach holography. Initially, Raoul van Ligten invited her to the American Optical laboratories in Framingham, Mass., to experiment with holography artistically. Her early laser-viewable holograms embraced both abstract and object-related subject matter. In the early 70s, Casdin-Silver worked with Stephen Benton, collaborating to create the first art works to use Benton's technique for white-light viewable transmission holograms. She also started to work with the human figure around this time, creating works dealing with both the female and male gender. Coinciding with the figurative work, she began to combine holograms with additional media resulting in installation works.

In the mid through late 70s, she divided her time between appointments at Brown University and the Center for Advanced Visual Studies (CAVS) at the Massachusetts Institute of Technology (MIT). She went on to spend nine years at CAVS, during which time she created the world's first art holograms displayed outdoors with solar-tracking devices for *Center Beam I*, a collaborative outdoor environmental sculpture presented at *documenta* 6 in 1977 (Kassel, Germany).

Nick Capasso of the De Cordova Museum and Sculpture Park, Lincoln, Massachusetts, was curator of the retrospective exhibition Harriet Casdin-Silver: The Art of Holography, 1998. Of her work he says, "Throughout her artistic career, Casdin-Silver has adapted holographic techniques and breakthroughs for artistic reasons, always with the intent of finding ways to put its unique attributes at the service of humanist, feminist, and political expression". This effort was rewarded five years ago (1996) when Casdin-Silver received the Lifetime Achievement Award at The International Symposium on the Art of Holography2 at the University of Nottingham, England.

A Celebration of Aging: a recent collaborative audio-visual installation on the theme of aging, by Casdin-Silver and Kevin L. Brown, a prize-winning Boston-based audio engineer, combines large format holograms with oral history. The artwork originally commissioned by First Night, Boston, Millenium Celebration, premiered at the Boston Hynes Convention Center, 2000. The installation has been reformatted for exhibition at the Main Gallery, Fine Arts Center Galleries, University of Rhode Island, from October 16 through December 12, 2001. *Celebration* features holographic portraits and audio narratives of nine Boston-area residents, "honorees", in their seventies, eighties, and nineties. Each portrait was created in Casdin-Silver's studio and transferred with John Perry at Holographics North Inc., resulting in nine 42"x32" white light transmission holographic stereograms. "At the end, it came out so well that I did myself," Casdin-Silver says. Her self-portrait is the youngest subject in "*A Celebration of Aging*."

The installation is presented with the holograms suspended in the shape of an octagon 48 feet across. Overhead at the viewing position for each portrait hangs one of Brown's "audiodomes." Stand beneath it, and one hears the voice of the person viewed, sharing the memories of his or her life. The soundtracks give the impression that the subject is speaking directly to the viewer. Casdin-Silver and Brown interviewed their subjects about what life has been like in the 20th century, and what they look forward to in the 21st. "This may be my masterpiece," Casdin- Silver said. "I've been working with the issue of aging for a while. I think it's one of the most important issues in society and art." Casdin-Silver turned 76 in February of this year.

This project is supported by a grant from the Artists' Resource Trust, a fund of the Berkshire Taconic Community Foundation. It is co-sponsored by the University of Rhode Island Colleges of Arts and Sciences; Engineering, Human Science and Services, Nursing, Pharmacy and by the Office of Graduate Studies, Research and Outreach. It is also supported by the State of Rhode Island's Department of Elderly Affairs, Forum on Aging, and Department of Mental Health, Retardation and Hospitals.

by Rebecca Deem
Rebecca deem is an artist, holographer, teacher, and writer based in Southern California.

Calendar

2002

Photonics West

19–25 January
San Jose, CA USA
Includes International Symposia on
BiOS 2002: Biomedical Optics and Applications
Electronic Imaging 2002: Science and Technology
LASE 2002: Lasers and Applications
Optoelectronics 2002
www.spie.org/info/pw

6th International Symposium on Optical Storage (ISOS 2002)

22 - 25 September
Wuhan, China
SPIE is a co-sponsor.

The Holography Group of the Royal Photographic Society presents an international one day conference supported by The Shearwater Foundation

Title: Holography & Art 2002

Chaired by: Dr Margaret Benyon MBE Hon FRPS and Dr. Andrew Pepper

Featuring international speakers on all aspects of holography and art. Including the following subjects:

State of the art
Acceptance of the medium
Digital influences
Latest projects and shows
Using new materials: cost and techniques
Financial support/sponsorship

Date: Saturday 23 March 2002
Times: 9.00am–5.00pm
Venue: The Royal College of Art, Kensington Gore, London SW7, UK

Lunch will be provided. Ticket prices to be announced.

Simultaneous Holography Exhibition at:
Gallery 286, Earl's Court Road, London SW5, UK

Curator: **Jonathan Ross** Tel: +44 20 7370 2239

Conference convened by:
Kevin C Brown Tel: +44 7770 840043
E-mail:kcblondon@altavista.co.uk

More info will be posted on our web site.
Please register your interest at www.holography.co.uk
or E-mail: kcblondon@altavista.co.uk

Really fast analog optical correlation

The creation of optical matched filters for pattern recognition has always depended on the availability of high-speed, high-resolution, optically-sensitive materials to record the interference fringes. Traditionally, the interference patterns have been captured on photopolymers, photorefractive crystals, or photosensitive emulsions coated onto glass plates. All of these materials have a finite recording time, and some require separate development and fixing processes before they can be used. In addition, the information stored in some photosensitive media will degrade with repeated exposure to light when not kept under restrictive environmental conditions: or simply with the passage of time. Digital techniques have been developed to calculate interference patterns from information about the object and the desired reconstruction angle, but these calculations require off-line computations and impose a time delay. All of these factors have prevented real-time matched filter generation for use in optical correlators.

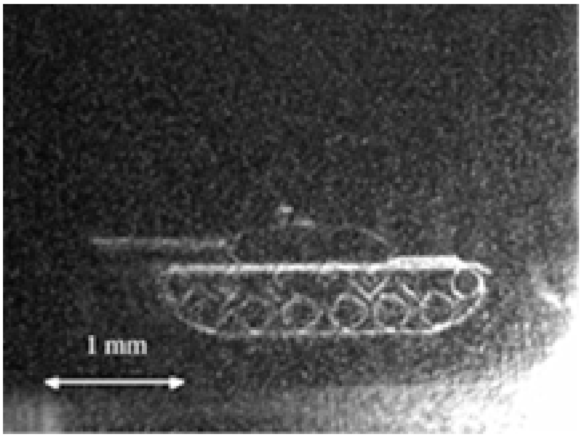

Figure 1. The reconstructed image of a tank.

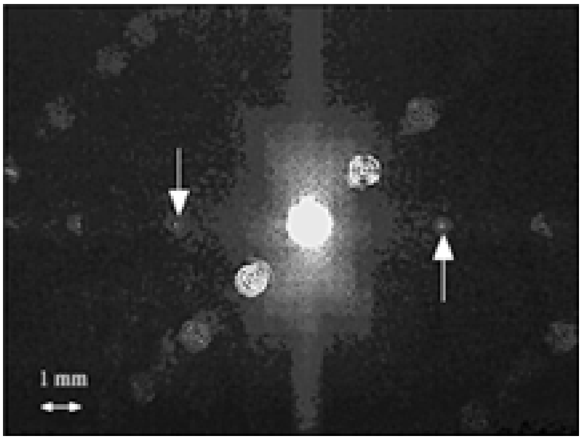

Figure 2. The correlation plane showing the real-time autocorrelation (and convolution) of a nested circle scene.

A real-time analog holographic optical correlation system has been developed in this study that is based on a modified Leith-Upatnieks architecture. (The system can also be modified for real-time recording and reconstruction of holograms.[1]) The matched filter of a scene is created, and the interference pattern is captured by a CCD camera. The filter is immediately displayed on a spatial light modulator (SLM), which is positioned in the filter plane of an optical correlator. An important difference between this system and a correlator using traditionally-recorded analog matched filters is that filters can now be generated and displayed very quickly. The system updates as quickly as the CCD camera, every 1/60 second, fast enough to be considered real-time for many applications.

However, a potential problem for this system is introduced by the pixel structures of the CCD and SLM. The optical interference pattern is sampled and digitized as the CCD captures it. This sampling is usually not problematic as long as the smallest feature (or fringe) size in the interference pattern is much larger than the size of the pixels. These feature sizes are determined by the spatial frequency content of the scene and the reference beam angle. This sampled signal is then displayed on the SLM. If, as in this case, the CCD and SLM have different pixel configurations, the scene is sampled again as it is displayed on the SLM. The re-sampling will be detrimental when the number and aspect ratio of the pixel arrays of the CCD and SLM are significantly different, but the problem can be avoided completely if the devices have the same pixel configuration. If slower performance is acceptable, the signal from the CCD can frame-grabbed and modified with image processing software before being sent to the SLM.

Simple scenes were chosen to demonstrate the ability of the system to create and reconstruct holograms and filters. A near-field diffraction pattern of a tank was interfered with a plane-wave reference beam. The angle between the beams was only a few degrees. The pattern was captured by the CCD camera and displayed on the SLM, which was then illuminated with a portion of the original laser source in the same manner that a classical transmission hologram would be addressed. A focusing lens and another detector allow the capture of the reconstructed image of the input scene shown in Figure 1. As a demonstration of the real-time filter creation and correlation capability of the system, a set of nested circles was used. A filter was created from the scene by interfering its Fourier transform with a plane-wave reference beam. The filter was addressed with the original nested circles scene, and the result of this autocorrelation is shown in Figure 2. The large, central spot is the usual dc term, and the two smaller terms indicated by the arrows are the correlation and convolution terms, which happen to be equal for the scene chosen. The diagonal terms are diffracted images of the input caused by the SLM pixel structure.

The new analog-digital hybrid system offers fast performance but is currently restricted to lower spatial frequencies due to the pixel size of the CCD camera. Preliminary tests have shown that the system can capture interference patterns of both holograms and correlation filters of some simple input scenes even with its current spatial frequency limitations. The real-time optical correlator is also capable of producing autocorrelations of simple scenes. As technological advances continue to reduce CCD pixel sizes, this new system will find wider use and greater applicability for general real-time optical processing. The system could then provide an inexpensive, fast, consistent alternative to analog optical correlators that currently depend on conventional recording materials.

This work was funded by the U.S. Army Aviation and Missile Command.

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Reference

1. N. Hashimoto et. al., *Real-time holography using the high-resolution LCTVSLM,* **Proc. SPIE 1461**, p. 291, 1991.

Holocenter announces AIR awards

The Center for the Holographic Arts (CHA or Holocenter) recently announced the recipients of the annual Artist-in-Residence (AIR) Awards. Nearly thirty artists have participated in the program thus far including leading holographic artists from around the world. The recent Cycle IV Awards were presented to: Patrick Boyd, London, England; Betsy Connors, Cambridge, MA; Michael Wenyon, Susan Gamble, NY and England; Roberta Booth, Hollywood, CA; Rudie Berkhout, New York, NY/Amsterdam, Netherlands; John Mitton, County Clerk, Ireland; Ann MacArthur, Santa Fe, NM; Jo Fairfax, Leicester, England; Adrienne Klein, New York, NY; and Eva Davidova, Madrid, Spain.

The selection committee based their results on proposals submitted by the artists. The Cycle IV committee included: Eduardo Costa, an artist and art writer who currently writes for “Art in America” and Sara Garden Armstrong a visual artist and Director of Arts Entrée, an arts and cultural tour service. The Cycle IV residencies are expected to begin in October of 2001 and end in May of 2002.

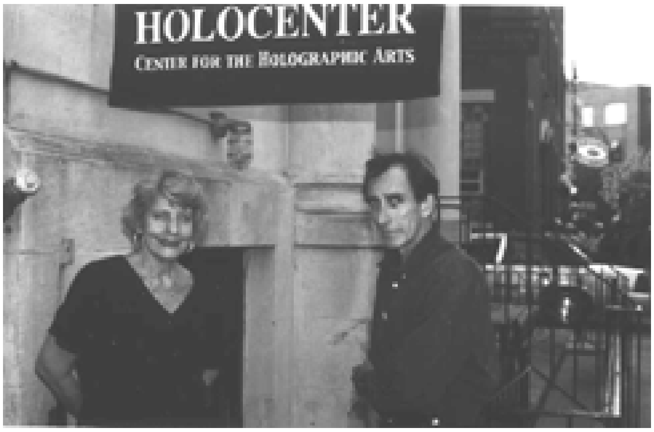

Figure 1. Ana Marie Nicholson and Dan Schweitzer, co-directors of the Center for the Holographic Arts (CHA or Holocenter). Photo: Sam Morée.

Figure 2. Posy Jackson pays a rare visit to the CHA during Mr. Mitamura’s time at the Holocenter. Left to right: Mitamura, Ana Marie Nicholson, Dan Schweitzer, Ikou Nakamura, Gloria Schweitzer, Posy Jackson. Photo: Sam Morée.

The CHA opened in ’98 to promote the development and dissemination of the art of holography. It offers an Artist-In-Residence program, small exhibitions of current work, larger travelling exhibitions, a series of talks, and maintains a web site with an online newsletter (ECHO). Periodically, the Center hosts visits by students from institutions such as the Massachusetts Institute of Technology and the School of Visual Arts in New York. The Center is a not-for-profit organization, funded in part by the Shearwater Foundation. Last year CHA received a third payment of $50,000.00 as the final part of a three-year grant from the Shearwater Foundation to assist with the development of the Center’s international Artist-in-Residence program. Ana Marie Nicholson and Dan Schweitzer, two long-standing well-known holographic artists share leadership as co-directors of the Center. Located in Long Island City, Queens, (Queens is one of the five boroughs of New York City), the CHA is currently thriving in a hotbed of arts activity, surrounded by high-profile art institutions like P.S.1, and Sculpture Park. In addition, this past summer The Museum of Modern Art (MOMA) announced that it is relocating to the area while renovations take place at its primary location in Manhattan.

The Artist-In-Residence Program is the focus of the Center’s activities. Artists with experience in the medium, as well as those without, are invited to contact the Center for proposal guidelines and submission policy. (If you are interested, please bear the following in mind: all proposal submissions should be brief, including a one-page description of the project, slide and videotape support materials, a CV, and a stamped self-addressed mailer if support materials are to be returned.) The Center is equipped with a 1-Joule pulse-ruby laser camera, a 6×10' vibration isolation table, for continuous wave work with a 50mW Helium-Neon (HeNe) laser. Under the guidance of the co-directors, artists are encouraged to explore the medium as part of their aesthetic vocabulary. It is hoped that through the strategic collaboration with other art establishments, the center will provide public exposure to the art of holography.

An Artist-in-Residence Award includes a period of time to create holograms on-site at the pulse-laser holographic facility. For Cycle IV, some recipients will have ten days to produce master and transfer holograms, while others will receive four days as a mastering session. Each artist in the Cycle IV program is allocated film valued up to $250.00 and some travel/living stipends may also be made available. For artists with little or no practical experience, a brief instructional session will precede the production of holographic artwork. Those wishing to explore the medium for the first time will be carefully assisted wherever needed through the holographic process.

The finished artwork is exhibited in the Center’s 500 square foot gallery. The co-directors recognize the value of presenting exhibitions to the public. The first exhibition mounted was titled *Generations*, which featured 12 pieces created by five Cycle I, AIR participants: Margaret Benyon, Sam Moree, Ikuo Nakamura, Mary Harmon and Dean Heady. The show also traveled to the Syzygy Gallery in Fort Myers, FL, and The Museum of Contemporary Art in Tucson, AZ. A second Exhibition entitled *Images From The Center* opened earlier this year in conjunction with the Queens art event, *Art Frenzy*, and features works created by AIR recipients and staff of the Center. The exhibition will be amended to include more works produced by artists who have participated in the previous three AIR Cycles. It is expected to travel to institutions throughout the country beginning with the Butler Museum of Contemporary Art, in Youngstown, OH. Funding for the exhibition was partially provided by the Queens Council On The Arts.

For further information, contact:
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Reconfigurable optical interconnect with holographic gratings

Constant progress in information and computing technology is, for the most part, associated with an increase in the operation rates of electronic components. This is a motivation for developing free-space optical interconnects, which seem to be able to resolve the bottleneck in data exchange between processors.[1] Planar-integration of free-space interconnection systems has been proposed in order to reduce alignment problems and to provide small, robust and monolithic optical systems.[2] These systems generally behave as passive links, merely offering determined paths for light signals between several processors, without allowing dynamical reconfiguration of these channels. We recently introduced a new architecture for planar-integrated active interconnects based on the association of polarization-sensitive holographic gratings and liquid crystal controllers.[3] This component family can be used to form a backplane bus in a computer or a switching node in a telecommunications network.

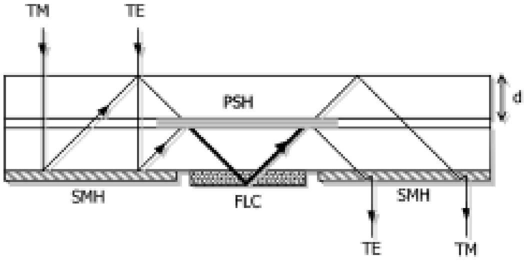

Figure 1. Principle and design of polarization-sensitive 2×2

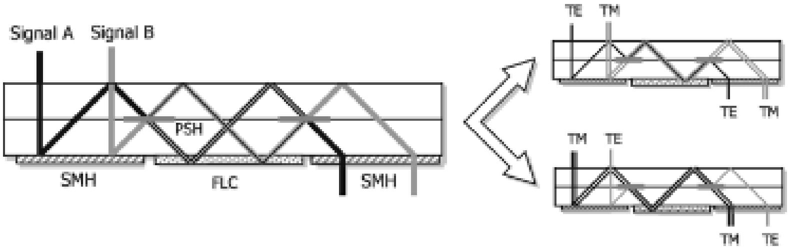

Figure 2. Polarization insensitive optical 2×2 switch: (a) principle and architecture; (b) focus on parallel paths in the switch.

The systems are based on the separation of polarization modes in a multi-layer planar structure. A polarization sensitive hologram (PSH) is inserted between two planar glass substrates. This grating diffracts the transverse electric (TE) light polarization state and not the transverse magnetic (TM). Polarized light beams propagate inside the system through 45˚ total internal reflection at the material interfaces. Each time a beam comes across the hologram, it is transmitted or reflected by Bragg diffraction, depending on its polarization state. By this means, it is possible to manage the optical paths inside the system by controlling each beam's polarization state. This can be done without coupling the light out by using a liquid-crystal cell, specially developed for this application, that and acts like a half-wave plate on the totally internally reflected beam.

Input and output coupling of optical signals between free-space and substrate propagation is performed by a substrate mode hologram (SMH).[4] This holographic optical element diffracts a normally-incident beam at an angle of 45˚ to the substrate. SMHs are Bragg gratings working in reflective mode. Output coupling involves an additional total internal reflection in the hologram itself, resulting in a transmission-like process.

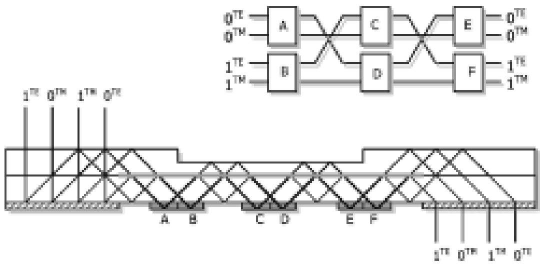

Figure 3. Planar implementation of multi-stage interconnect for 4×4 commutation.

The planar waveguide architecture of the system permits association of several basic elements in parallel and series layout, in order to build multilevel reconfigurable interconnects. A polarization-sensitive 2×2 optical switch is one of those basic components (Figure 1). This perfectly-symmetric system is made of two planar, integrated, polarizing beam-splitters and controlled by a unique ferroelectric liquid crystal (FLC) cell. Two orthogonally polarized incoming beams, separated by distance 2d (d is the thickness of each substrate), are coupled inside the substrate by diffraction at the SMH. They encounter the PSH under Bragg conditions. This grating transmits the TM wave and reflects the TE, so that the two beams are superimposed when total reflection in the FLC cell occurs. The cell is stuck to the lower substrate face, and permits orthogonal rotation of the polarization states of both signals. After being switched, the signals are separated and coupled out symmetrically.

A polarization-insensitive switch is obtained by parallel association of two polarization sensitive switches in the same substrate (Figure 2). Increasing the complexity of the design, one can imagine other multistage commutation device such as 4×4 optical switches (Figure 3), and 1×4 or 1×8 addressers.

Both PSH and SMH have been recorded in DuPont Omnidex™ HFR-600. The high index-modulation amplitude in this material allows the recording of volume holographic elements with high performance.[5] The dry process and the stability of the gratings produced this way are also important: the latter in particular means that alignment can be performed once and not again. A diffraction efficiency close to 99.9% (corrected for absorption at 632.8nm) can be reached for the PSH in TE-polarization mode, which guaranties an extinction ratio of about 1000.

Insertion losses for the 2×2 switch have been measured in the bypass and exchange configuration. In the worst case, absorption in the switch introduced a power loss of 3.5dB, half of it due to input and output coupling.

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Lithographic holography in planar waveguides

continued from front cover

them, is less than $\lambda/2$.

Figure 2 shows a simple planar holographic structure, aligned parallel to the page. The detailed spacing and relative amplitude of the diffractive elements, as a function of position along the input direction, determine the spectral transfer function of the device. While continuous variations in diffractive-element amplitude are difficult to produce with the standard lithographic process, planar holographic structures can achieve effective gray scale as shown in the enlarged blowup view in Figure 2. With appropriate design, each diffractive element, typically in the form of a long contour, contributes as a unit to the outgoing signal. Controlling the fraction of the contour written provides a gray-scale-like control of effective diffractive-element amplitude. When multiple scattering is weak, the spectral transfer function of a holographic structure—like that shown in Figure 2—is given by the Fourier transform of the diffractive-element spatial profile including effective gray scale.

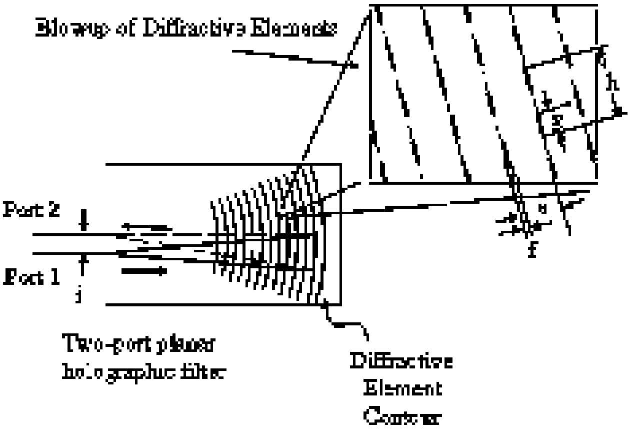

Figure 2. Top view of a simple two-port planar holographic structure. Light enters the planar waveguide at Port 1 and is spectrally filtered and spatially transformed by the holographic structure. The wavefront transformation leaves the outgoing signal optimally matched to Port 2, the output port.

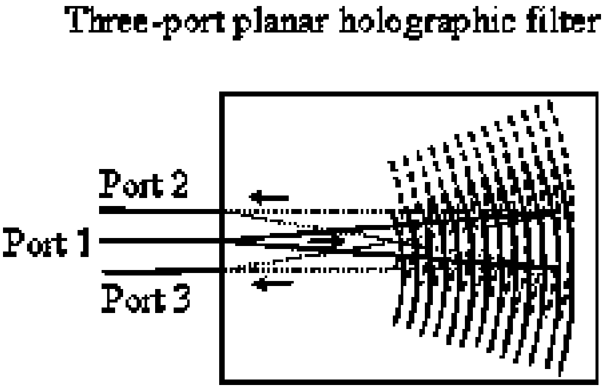

Figure 3. Schematic representation of a three-port planar holographic filter. Two holographic structures are superimposed. Each structure routes light from the input port, Port 1, to one of the output ports (Port 2 or 3), while applying a distinct spectral transfer function.

When multiple scattering is important, as when the device is to operate with very low insertion loss, the design of the spectral transfer function becomes more complex. The design problem is quite similar to that found in the case of fiber-Bragg gratings (FBGs).[3] Note that the planar holographic structure of Figure 2 offers much the same spectral filtering function of an FBG but can be used without an optical circulator since the planar geometry allows for the separation of input and output signals implicitly. It is also important to note that fabrication via lithography provides precise control over diffractive-element structure and hence spectral transfer function. Lithographic precision may be contrasted with the exposure-critical analog recording process used to produce FBGs.

Figure 3 shows a three-port planar holographic structure. A separate planar hologram routes input light to each of the output ports. Each of those holograms imparts an independent spectral transfer function. If the two spectral transfer functions are simple bandpass functions and act on separate optical wavelengths, the device acts as a wavelength demultiplexer. Here, the bandpass function and center wavelength of each channel are arbitrary and separately controllable. It is well know that holographic structures can be overlain. In the case of planar holographic structures, it remains to be determined how many can be overlain while maintaining acceptably low insertion loss and channel crosstalk. If a useful number of holograms can be overlain, planar holographic multiplexers may play an important role in reducing costs for these important devices while offering unique performance advantages.

A very exciting aspect of planar holographic devices is that their implementation is supported by massive development efforts already underway in other areas. The lithographic methods needed to fabricate planar holographic structures have seen rapid advance over the last few years with better than quarter-micron resolution now achieved. Continued advances in lithographic resolution derive from the seemingly insatiable drive to produce ever-smaller integrated circuits. Today's ebeam lithographic capabilities are adequate to produce high-resolution masks for planar holograms. Actual surface relief can be applied either by standard optical lithographic methods or by newer imprinting methods. Planar holograms are ideally suited for this latter kind of fabrication since they are essentially immune to point defects. Planar waveguides have been the subject of intensive development in connection with arrayed waveguide gratings (AWGs) – a wave-division-multiplexing (WDM) multiplexer device.[2] AWG planar waveguide substrates have been developed to the point of excellent homogeneity and reproducibility and are perfect substrates for planar holographic structures.

Volume holographic structures are unique in that they can provide general spectral filtering and spatial transformation in a single device. The dual functionality of volume holograms makes them very desirable building blocks for optical device designers. Planar holographic structures (as 2D volume holograms) offer the same function and can be robustly and cost-effecty fabricated using the rapidly developing lithographic techniques of the electronics industry and the planar waveguide substrates already developed by the optical communications industry.

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Current BB640 color plates compared to HRT's

BB640 and BB520 plates have been on the market since 1995, manufactured by the German company HRT GmbH. At the end of 2000, this company announced it was stopping production of its emulsions. Early this year, British company ColourHolographics Ltd., a manufacturer of large format display holograms, showed interest in maintaining production of BB plates. By May 2001 the first BB640 plates manufactured by ColourHolographics became available.

In this work we have compared preliminary results, obtained with some processes commonly used with HRT BB640, to those obtained with new ColourHolographics plates. The intention was to confirm that old and new plates share the same characteristics. To this end, plates were holographically exposed to a symmetrical set-up with a spatial frequency of 1200 lp/mm using a p-polarized He-Ne laser. Beam ratio for all tests was 1:1 and exposure beam power was about 350 µW/cm^2.

Plates were developed with standard AAC[1] developer for 4 minutes at 20°C. Subsequent processing was done with direct, reversal, and fixation-free bleaching processes.[2,3] A process that produces efficient amplitude-phase gratings[4] was also studied. This process consists of developing for 3 minutes at 20°C with a pH-controlled version of the AAC developer, and later fixing with non-hardening fix F24 to produce high efficiency absorption gratings .

Results are shown for each case. Figure 1 shows D-LogE curve for plates developed with AAC and fixed with non-hardening fix F-24. Top density, energy needed to achieve it, and linear zone slope, are almost the same for both plates. These plates were later direct-bleached with potassium ferricyanide. Results are shown in Figure 2.

The new plates are slightly slower than HRT's and with a lower peak DE for this process. Figure 3 shows results of plates developed with AAC and bleached with solvent bleach R9.[5,6] The maximum DE value of 82% achieved with HRT plates is still very high for a solvent process, but it has dropped to 71%. Figure 4 compares results of plates processed with AAC plus fixation-free rehalogenating bleach R10.[1] Maximum DE values achieved are again slightly lower for ColourHolographics plates, but corresponding energies are similar. However, in this case curves show a different shape, with a flat zone in the high DE region for the HRT plates that is not present in ColourHolographics'. The latter shows an overmodulation behavior.[7]

In Figure 5, DE versus energy for amplitude-phase gratings processed with the low-pH version of AAC are shown. Although the DE value obtained with ColourHolographics plates is not as high as with HRT's, the effect is still important and the process needs some optimization.

In conclusion, results obtained with a variety of processing techniques with new BB640 plates manufactured by ColourHolographics Ltd are similar to former BB640 plates from HRT GmbH. Slightly lower sensitivities and DE have been found, pointing towards the need of some optimization of the processing procedures used.

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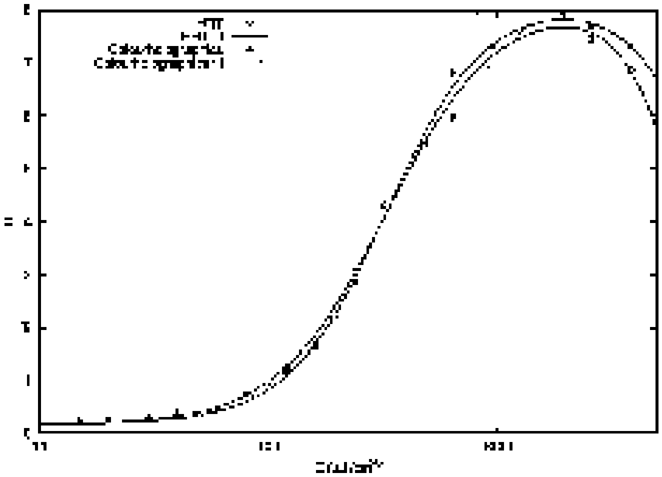

Figure 1. D-LogE curve of HRT and ColourHolographics BB640 plates. Plates were developed for 4 minutes in AAC and fixed with F-24.

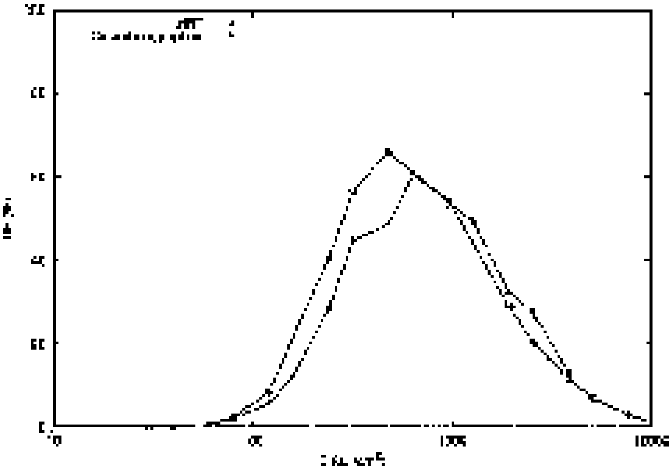

Figure 2. Diffraction efficiency of BB640 plates shown in Figure 1 and direct-bleached with potassium ferricyanide.

Microholographic system for optical data storage

continued from p. 3

light, so that the pilot beam can be used for non-exposing adjustment of the optical system.

The overlap of the incident and reflected beam is controlled by a CCD camera. In order to provide dynamic control of the beam overlap during recording, a servo system based on focus-error signals (FES) and track-error signals (TES) has been integrated in our system (Figure 2). The red pilot beam provides a high optical signal for the servo system and it is also used for the positioning of the write beam focus at different storage locations within a photopolymer. The servo includes three general PID regulators, which receive astigmatic error signals generated by a Multimath unit, in combination with a QUAD detector. The back microscope objective is coupled to an actuator system to control the focus position. Each time an error signal occurs, the piezo-actuator system shifts the objective in such a way as to compensate deviations and maintain focus at all times.

100µm and 200µm thick samples of Aprilis ULSH 500 photopolymer have been used in optimizing different system features. Good optical quality and high photosensitivity of the material make it possible to record large arrays of microholographic “dots” with automatically-controlled grating parameters. All single gratings are clearly localized in micrometer-sized volume elements. Aprilis photopolymers, which are relatively thick, allow us to use several planes within a medium for data recording. Recently, arrays of microgratings have been recorded in three independent layers within a 200µm-thick sample, and read out without any crosstalk effects.

Our current work focuses on a further improvement of the overall system performance in terms of areal storage density and write/read-out times. Modifications needed in the servo electronics include a second servo loop that controls the position of the front microscope objective. Both servo loops are then combined in a masterslave relationship in one system for automatic focus control. The next step to be achieved involves four-layer recording with two green wavelengths simultaneously.

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Grating-based DOVDs in high-speed semantic pattern recognition

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information channels (extracting characteristic features with the use of two independently-optimized DOEs) is performed in the ANN-based classifier.

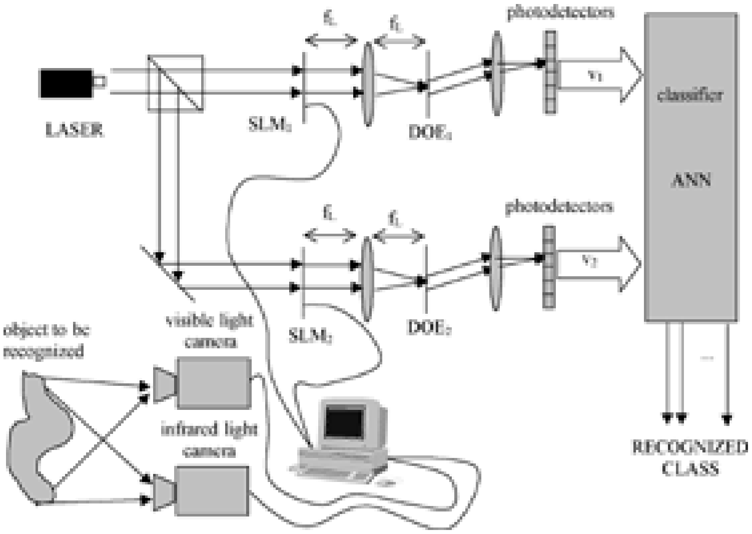

Figure 2. High-speed dual-sensor pattern recognition system. The object to be recognized is captured using two bands of electromagnetic radiation. The camera recording visible light presents its image via SLM_1, the infrared via SLM_2. Two DOEs generate two vectors of characteristic features (corresponding to two images of the same object). The concatenation of these vectors is the input for ANN-based classifier.

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Grating-based DOVDs in high-speed semantic pattern recognition

Diffractive optically variable devices (DOVDs) such as computer-generated holograms (CGH) or synthetic diffraction gratings (SDG) have proved their abilities in real-time semantic pattern-recognition systems. This article concerns exclusively the grating-based DOVDs (i.e. SDGs) applied in hybrid opto-electronic pattern recognizers. However we prefer the term *diffractive optical element* (DOE) since it is more general and concentrates on the operation of the element without having in mind the way of producing it.

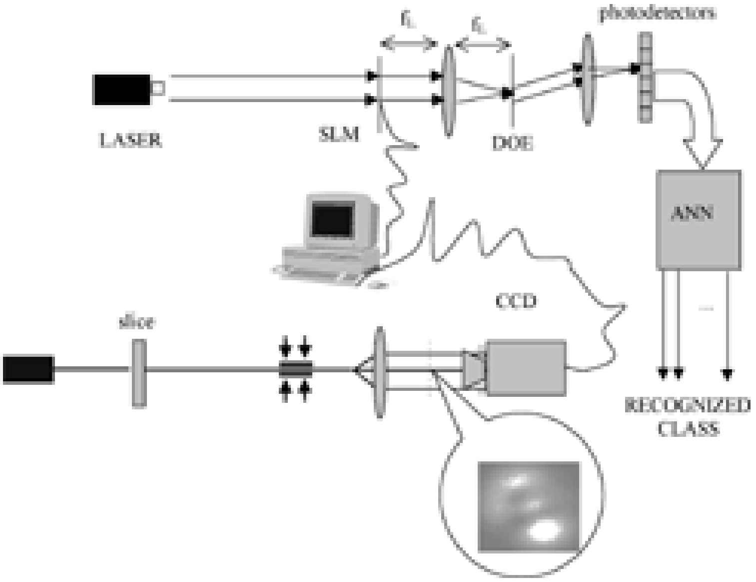

Figure 1. Laboratory setup for stress and strain recognition in optical fiber. The speckle pattern recorded by the CCD contains information about the internal stress (caused by external pressure) in the optical fiber. The recorded image is then presented by the SLM to the input plane of the pattern recognizer, with the DOE placed in the Fourier plane. Photodetectors convert light intensities corresponding to characteristic features of the image into electrical signals. These are then processed by the ANN-based classifier.

(For optical scientists involved in holography there exists a formal difference between CGH and SDG. The term *computer generated hologram* refers only to these diffractive structures for which the surface profile or transmission is a result of the complicated wavefront calculation. The term *diffraction grating*, on the other hand, is reserved for structures that are the result of interference of two or more laser beams or the result of computer generation according to a relatively easy analytical description of the diffraction grating fringes.[1] However, in optical implementations of information systems, this difference is of no interest and grating-based DOVDs are also often referred to as CGHs.[2])

The system presented here has its origins in the pattern recognizer composed of ring-wedge detector (RWD) used for feature extraction and artificial neural network (ANN) used for feature classification.[3,4] This kind of system has very good recognition potential, because it allows invariance with respect to typical transformations of input image. However, poor flexibility in the RWD (restricted to rings and wedges of the same size), as well as its high cost, mean that such systems are not very practical.

Casasent[2] showed that replacing the RWD with a DOE (he called it a CGH, but it was really a SDG), consisting of diffractive regions in the shape of rings and wedges, results in the separation of light intensity integration (in diffractive grating regions) from light intensity conversion (in an additional array of photodetectors). Furthermore, he showed that a computer-generated binary grating is sufficient for this purpose and therefore the process of DOE fabrication can be relatively easy and cheap. This lead to the need to optimize the DOE in terms of number of regions and their sizes.

The optimization method we proposed[5] used elements of rough set theory for objective function definition and modified evolutionary algorithms for solution space search. The method was then applied to the experiment using a set of speckle pattern images taken from the output of the optical fiber.[6] The purpose of the system (schematically shown in Figure 1) was to recognize one of the eight classes of internal stress in the optical fiber. The normalized decision error was reduced from 4.8% for the standard system to 3.8% for the optimized DOE system. Further modifications of the optimization procedure, based on different strategies of dealing with constraints, reduced this error to as little as 1% for the best strategy (with the average for all strategies at 2.2%). Since rough sets were used for the optimization of the feature extractor (DOE), a system with a rough set-based classifier (instead of an ANN-based classifier) has also been considered.[7]

The promising results from the optimized DOE-ANN recognition system provided the foundation for a subsurface stress monitoring system used for the nondestructive testing of composite material constructions.[8] An example of this kind of system is shown in Figure 1, where an optical fiber is fused in the composite material to be monitored. The next modification (see Figure 2) to the system will allow us to further improve recognition ability through dual sensing (visible light as well as in infrared). The integration of the two separate

continues on p. 10

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