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SPIE's
International
Technical
Group
Newsletter

Holography

Instant holography

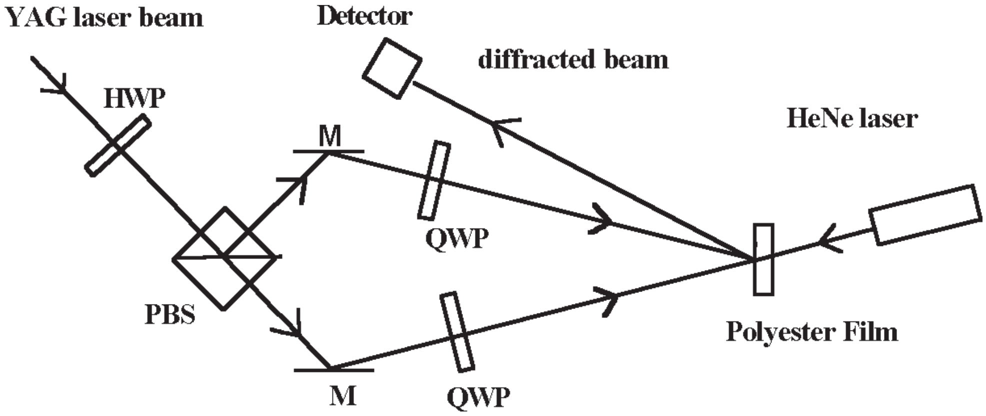

Figure 1. A polarization holographic set-up to record instant holograms. In the figure, PBS, is a polarization beam splitter, HWP, half-waveplate, QWP, quarter-waveplate and M, mirror.

The three dimensional display of images of moving objects has been a dream for many decades. Ranging from a study of microscopic objects, such as cells, in their natural environment to three dimensional movies, this dream has been realized under certain circumstances. Short recordings of moving objects have been made holographically in silver halide films. But apart from limited sensitivity, this type of recording requires the wetprocessing of film. Azobenzene-containing polymers have been under intensive investigation during the last decade as materials for digital as well as holographic storage. However, since storage in these polymers involves the physical reorientation of long polymer chains, this process was thought to take place over several seconds, if not minutes. We have shown that holograms can be written in side-chain azobenzene polymers with a single pulse lasting 5ns from a pulsed laser.[1]

The cyanoazobenzene side-chain polyester, P3aA, is prepared by transesterification of the cyanoazobenzene containing diol and diphenyl pththalate in the melt under vacuum. The diol is prepared in a sequence of reactions starting from bromopropyl alkylation of diethyl malonate, reduction to the corresponding 1,3-propanediol, ketal protection with acetophenone, coupling with cyanoazobenzene phenol and finally deprotection by acidic alcoholysis. Approximately 3 mg of the polyester material is dissolved in 150 microlitres chloroform and cast on to a clean substrate. The film is dried in an oven at a temperature of 90°C for ten minutes.

A polarization holographic set-up is used to record holographic gratings (Figure 1). We use a commercially-available small-frame frequency-doubled YAG laser, lasing at 532nm, as the source. This laser delivers Q-switched pulses of 5-7ns duration at 20 Hz, with a peak power output of 1.6MW/pulse. A polarization beamsplitter (PBS) is used in conjunction with appropriately-oriented quarterwave plates (QWP) to derive the orthogonally polarized beams. The two beams overlap on the polyester film. A HeNe laser is used to read-out the diffraction gratings. We find that after just one pulse from the laser, several orders of diffraction of the HeNe laser can be seen. The diffraction efficiency in the first order exceeds 4% at a spatial frequency of 160lines/mm.

Significantly, an atomic force microscopic scan of the irradiated polyester shows considerable surface relief. A peak-to-valley value of approximately 90nm was obtained at a spatial frequency of 900lines/mm. Several groups around the world have observed surface-relief in azobenzene polymers when irradiated with CW laser beams. However, the presence of a surface relief after just one 5ns pulse shows considerable mass redistribution in a short time. Later research, done with colleagues from the University of Jena, Germany, shows that a surface relief can be obtained with just a 100ps pulse.

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LAB NOTES

Diode laser holography

For several decades now, the vast majority of holographic images have been created using a continuous-wave gas laser. Relatively expensive, cumbersome and inefficient in terms of power-in/power-out ratio, it has always seemed that the gas laser was just crying out for it's own replacement.

The promise of inexpensive, high-power laser sources for work in holography has now been realized with the availability of the latest generation of laser diodes. Holograms up to 8×10" in size, with high diffraction efficiency and depth, have been created using sources as inexpensive as $7.99. Currently, power ranges in the visible part of the spectrum of up to 50mW can be obtained for less than $50. These are so small in size that if you dropped one on the floor, you would have to get down on your hands and knees to find it. These higher-powered diodes are capable of creating bright, deep, display-quality, large-format holograms.

Laser diodes have been in use for a number of years already, and have been replacing the traditional gas laser in an increasing number of applications (bar code scanners, optical data storage, etc.). One of the last hold-outs has been holography—where single-mode operation and long coherence length is a must.

With the newer generation of laser diodes, along with advancements in driver circuitry design (including optical feedback circuits for stability), these small wonders of laser light now exceed their gas predecessors in all three areas of importance: coherence length, stability and price. Through interferometric testing in my lab, I have measured a 35mW diode out to 14' of coherence length while maintaining extremely stable, high-contrast fringes. Keep in mind that this 14' coherence measurement indicates a minimum, not a maximum—the actual limit of coherence length is still unknown! This raw diode was $34, or roughly less than one dollar per milliwatt of output power.

The "recent" use of diode lasers for holography began in November of 1998 when holographer Steve Michael reported the creation of a hologram using an off-the-shelf, battery-operated laser pointer (with average output power of 35mW). I immediately confirmed Mr. Michael's results in my own lab after purchasing a laser pointer at my neighborhood drug store. I purchased several additional laser pointers and distributed them to several other holographers who also obtained positive results using the $7.99 laser source.

In 1999, I have continued to experiment with higher-powered diode lasers along with color control and alternative power sources, including solar energy. (I have a 15mW diode in the lab that operates off of a solar panel outside an upper-floor window. This charges a lead-acid based battery pack that runs the diode at 3volts—free energy!). I eventually partnered with Sam Savage of Bell Labs, Whippany NJ, in developing our own diode laser system, taking into account the special requirements for holographic image recording—long coherence length and ultra-stable, high-contrast fringe recording.

There are a number of factors involved with this research that require a rethinking of the traditionally approach to holography. With the advent of ultralong coherence length, it no longer becomes necessary to match beam-path distances in split-beam recording setups. Just place your components wherever they are most convenient and offer the best subject illumination for recording. This will introduce new and more creative table geometries, and make more efficient use of available table surface area.

With the increased diffraction efficiency of the newer holographic recording materials, along with the advantages that the new diode lasers bring to the table, single-beam work is becoming more and more appealing as well. Some laser diodes can be operated without any collimating optics in place—depending on where the photodiode is located in the diode assembly (some photodiodes in modules rely on reflected light from the collimating optics). Diode operation in this fashion provides a beautifully clean spread of laser light—as clean as if the beam had been spatially filtered. This eliminates all optical components from the single-beam set-up (including expensive spatial filters), leaving only the diode itself and the recording media/object. Since the only items that need to be isolated from vibration in a single-beam setup are the plate and object, this eliminates the need for large isolation tables. Just build a small isolation platform for these items and you're all set. The higher diffraction efficiency of the newer recording materials allows for great results with single-beam transfers (including imageplane) as well.

After a long dry-spell of new and exciting techniques with continuous-wave holography, diode lasers are providing a wealth of uncharted territory. As output powers continue to rise and prices continue to drop, the promise and ability for the creation of large-format display holography becomes more of a reality for those who felt it was out of reach. In the not-too-distant future, the addition of inexpensive green and blue diode sources will make full-color holography a reality as well.

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For further information on the wwweb:

The Internet Webseum of Holography
http://www.holoworld.com
A complete record of all my experiments, from laser pointers to higher-powered diodes.

3-D Imagery
http://www.3dimagery.com
Steve Michaels site containing his work with laser pointers and suggested set-ups.

Holography in Norway
http://www.techsoft.no/holography/
Website containing diode laser experiments by Vidal Hegdal and Ronny Andreassen including advanced single-beam illumination techniques.

Sam's Laser FAQ
http://www.misty.com/~don/laserdio.htm#diotoc
The laser diode section of the on-line "bible" of lasers and laser technology.

Self-organizing photorefractive neural network

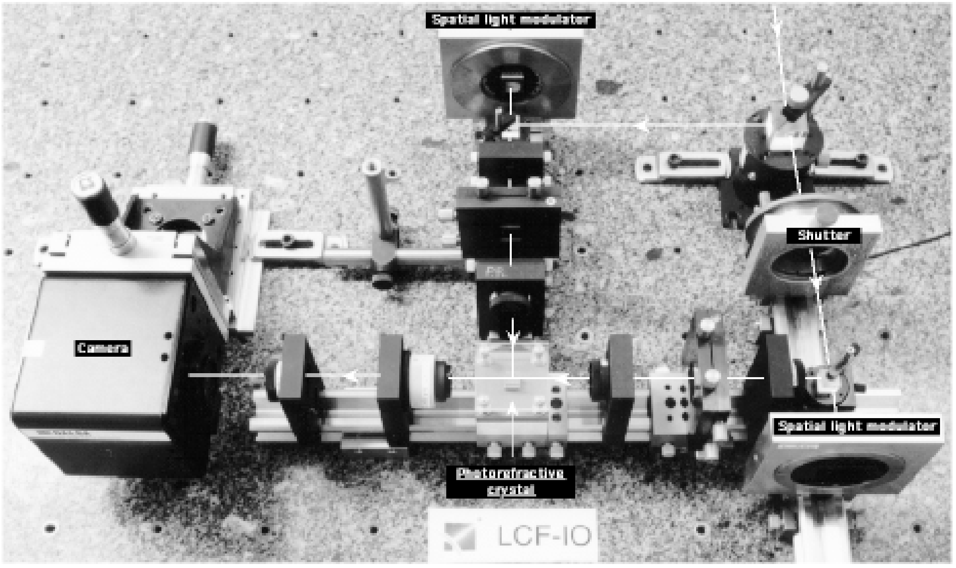

Figure 1. Photograph of the setup.

Over the past few decades there has been a growing interest in neural networks. Indeed these systems have been found to be good alternatives to traditional computers for solving certain problems such as pattern classification or recognition. They are particularly well-suited to the processing of complex and/or noisy data.

Neural networks basically consist of a large number of elementary processors that work in parallel and are connected to each other. Free-space optics is therefore particularly useful for the implementation of this kind of systems, thanks to its high connectivity and massive parallelism. However, very few optical neural networks with large capacities have yet been built.

Among all possible optical techniques, volume holographic interconnects are most promising because of their potentially high capacity. Indeed, holographic memories with 10^9 data points, or equivalent elementary holograms, have already been demonstrated.[1] If these holograms are read out every millisecond, we get an equivalent computation of 10^{12} operations per second.

To explore the possibilities of holographic interconnects, we have designed and built a self-organizing neural network producing “topological maps”.[2,3] This kind of system performs the automatic classification of patterns. The setup uses a laser beam divided into two separate arms (reference and signal). The intensities of the beams in both arms are modulated thanks to two ferroelectric spatial light modulators (SLMs). The beams recombine and interfere inside a photorefractive crystal where they write a series of holograms (Figure 1). These holograms are then read out with reference beams to determine the response of the system. The entire set of reading beams constitutes the input pattern. The advantage of using photorefractive materials is that they allow us to dynamically write, erase and modify the holograms.[4]

During the learning stage, several examples of patterns are presented to the setup. When presenting a particular input pattern, the CCD camera detects a diffraction pattern that corresponds to the response of the system. According to this response, an algorithm implemented in a host computer defines how the holograms should be reinforced or erased. At the end of the learning stage, each input pattern generates diffracted light in a localized area of the camera only. The relative locations of the responses for different patterns should reflect the correlations between these patterns: two responses should be closer to each other the more similar the corresponding input patterns are. This classification is said to preserve the topology of the input data. The system actually finds the relevant features in the patterns and uses them to perform the sorting. The classification is made without any control by the experimenter and requires no prior knowledge of the data.

An example of classification is shown in Figure 2. The input patterns are binary vectors that code the characteristics of some animals (size, presence of hairs or feathers, number of legs...). They are taken from Reference 2. Once the learning is complete, each presentation of a pattern produces a diffracted spot. Its location is shown in Figure 2, which represents the CCD array, by the position of the name of the corresponding animal. The system succeeded in sorting the animals according to the given characteristics. For instance, birds are grouped together and so are mammals. Moreover, predatory birds are close to predatory mammals.

So far we have been able to classify up to 100 patterns, each containing more than 100 features. The classification sometimes makes local errors, but the global ordering is good. Some minor problems remain to be solved, but we estimate that the capacity of the present setup is already about 1 million interconnect updates per second, which makes it one of the most powerful optical neural networks, in terms of capacity, ever built.

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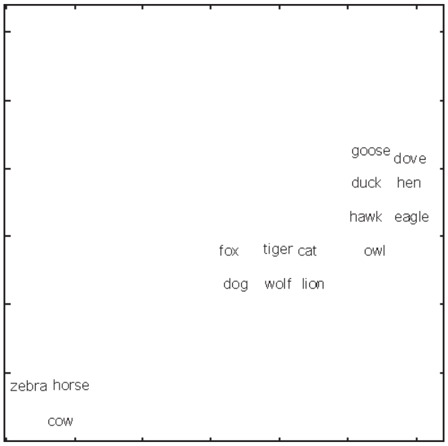

Figure 2. Example of classification: input vectors coding characteristics of animals.

References

1. X. An, D. Psaltis, and G. W. Burr, *Thermal fixing of 10,000 holograms in LiNbO$_3$:Fe,* **Appl. Opt. 38** (2), p.386, 10 January 1999.
2. T. Kohonen, **Self-organizing Maps,** Springer, Berlin, 1997.
3. Y. Frauel, T. Galstyan, G. Pauliat, A. Villing, and G. Roosen, *Topological map from a photorefractive self-organizing neural network,* **Opt. Comm. 135,** p. 179, 1 February 1997.
4. D. Psaltis, D. Brady, and K. Wagner, *Adaptive optical network using photorefractive crystals,* **Appl. Opt. 27** (9), p. 1752, 1 May 1998.

Pixel size limit for a holographic memory system

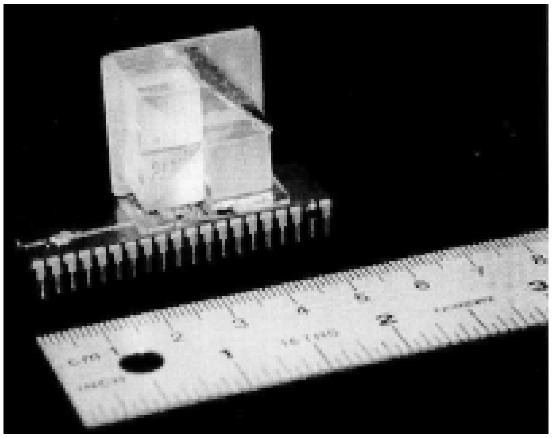

Figure 1. A compact holographic memory module with phase conjugation.

Holographic data storage provides a promising technology for large-density data storage and large data bandwidth. The theoretical data storage density is at the order of one bit per λ^3 inside the photorefractive material. The data access rate can be up to Gbytes per second due to the intrinsic parallelism of holography. The main barriers for providing a commercially competitive holographic memory system are the bulky system volume and cost. These barriers can be overcome by using phase conjugate reconstruction and small pixel size for the spatial light modulator (SLM) and detector array in the holographic memory system. This is something we are currently studying at Professor Demetri Psaltis' Optical Information Processing Lab at the California Institute of Technology

Phase conjugation reconstructs the back-propagating signal beams and self-focuses onto the original images without using a bulky and expensive imaging system. A compact read/write holographic memory module with phase conjugate readout has been proposed and extensively analyzed.[1,2] The cost of this module was studied and compared with current mature silicon storage and hard disk technologies. The studies show that the holographic memory cost compared to DRAM technology is determined by R/M. Here, M is the number of holograms multiplexed inside the photorefractive material and R is the pixel area of SLM and detector array used in the holographic memory compared to the pixel area of the silicon storage available in the market.

The number of holograms M is limited by the dynamic range of the material $M/\#$ and the photon budget for the reasonable read/write data-rate of the system. It is crucial to reduce or keep the ratio R to within a small limit for the holographic module, especially considering the consistent and fast shrinkage of feature sizes in the silicon industry. With current technology, R is around 16 with 4×4µm pixel area for SLM and photo sensor and 1×1µm for DRAM cell. However, to keep the ratio R at this number, the pixel area has to be reduced to around 1×1µm for holographic memory by the time DRAM cells shrink down to 0.2×0.2µm. The silicon industry predicts this will happen by 2007.

The minimal pixel size in a holographic memory system is fundamentally limited by the holographic recording and reconstruction bandwidth, in addition to the bandwidth of the optical system such as the numerical aperture of lenses, and the interface Fresnel losses. The holographic recording and reconstruction bandwidth is caused by the different grating strengths recorded due to different grating periods, directions and modulation depths for various signal spatial frequencies inside the material.[3] For our previous holographic module, which had a $LiNbO_3$ crystal in a 90˚geometry, we calculated the holographic bandwidth inside the material, with the consideration of the interface losses. The theoretical simulation indicates that the holographic bandwidth is broad enough for submicron feature information to be recorded and reconstructed with 488nm-wavelength light.

Experimental measurement of the holographic bandwidth proved the theoretical results. Sub-micron holographic features were demonstrated by the recording and reconstruction of a resolution mask with pixel sizes from 2×2µm down to 0.2×0.2µm. In Figure 2, (a) shows the direct image of the mask with an objective lenses (NA 0.65) and (b) shows the phase conjugate reconstruction of the hologram magnified with the same objective lens. The reconstruction image shows no degradation from the direct image of the mask, which proves the theoretical prediction of submicron feature-recording ability. It also demonstrates the feasibility of using pixel sizes down to 1×1µm in holographic memory systems and shows how essential phase conjugation is for removing the expensive, high-quality, large-NA imaging lenses previously required for imaging small pixels.

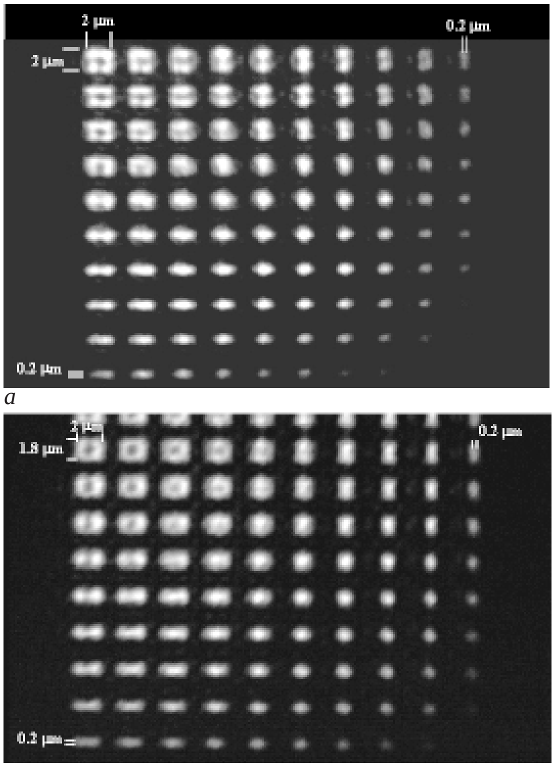

Figure 2. (a) The direct image of the mask, magnified by an objective lens (NA 0.65). (b) The phase conjugate reconstruction of the hologram, magnified by the same lens.

An actual 1×1µm random data mask was also used to record holograms in this system, and holographic read-out bit-error-rate was measured at 7×10^{-5}, with an assumption of Gaussian distribution for the ON and OFF pixels. However, using small pixels raises challenges for the development SLMs and detector arrays with high spatial resolution.

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References

1. J-J. P. Drolet, E. Chuang, G. Barbastathis, and D. Psaltis, *Compact, integrated dynamic holographic memory with refreshed holograms*, **Opt. Lett. 22,** p. 552, 1997.
2. E. Chuang, W. Liu, J-J. P. Drolet, and D. Psaltis *Holographic Random Access Memory (HRAM)*, **Proc. IEEE 87** (11), pp. 1931-1940, 1999.
3. W. Liu and D. Psaltis, *Pixel size limit in holographic memories*, **Opt. Lett. 24,** p. 1340, 1999.

Instant holography

continued from cover

In order to extend the scope of these investigations for practical holographic applications, the set-up was modified to fabricate Fraunhofer-type holograms. The object beam was expanded to cover a transparency containing the word “Risø”. The size of the object was 12mm. A single spherical lens was placed immediately behind the object, with the polyester film kept close to the focus of the lens. The unfocussed reference beam overlapped with the object beam on the lens, and the resulting hologram was approximately 1 mm. The image was quite bright and can be viewed with naked eye on a screen. The appearance of the image is instantaneous, not requiring any chemical processing.

Since the output of the laser was 20Hz, it is, in theory, possible to record a holographic movie. When a large number of holograms are required as in this case, the individual holograms must necessarily be small. The holographic set-up shown in Figure 1 makes optimum use of the hologram size by receiving the same range of spatial frequencies from each point on the subject. This results in an image that is uniformly resolved over its entire extent.[2] In order to view the full object through a small hologram, we believe that we can make use of a technique that was proposed originally by Leith et al..[3] In this case, a large lens, which need not be of good quality, is used to record the hologram. Large scale Fresnel lenses are available commercially. The idea is to preserve the spacebandwidth product of the object in the hologram. A reconstruction of the object is viewed through the same lens. A faithful reproduction of the object demands a high resolution hologram, which the azobenzene polymers are capable of. One disadvantage of this technique is that the image can only be viewed by a limited audience. However, we believe that this technique will be potentially useful for viewing microscopic objects and in particle image velocimetry.

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References

1. P. S. Ramanujam, M. Pedersen, and S. Hvilsted, *Instant Holography,* **Appl. Phys. Lett. 74**, p. 3227, 1999.
2. R. J. Collier, C. B. Burckhardt, and L. H. Lin, **Optical Holography,** Academic Press, 1971.
3. E. N. Leith, D. B. Brumm, and S. S. H. Hsiao, *Holographic Cinematography,* **Appl. Opt. 11,** p. 2016, 1972.

Announcement and Call for Papers

Holography 2000

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Circle-to-point conversion and optical rotary joints

Doppler shifts in the optical spectrum may be detected either by heterodyne methods using coherent sources or by direct detection of filtered and dispersed return light. The coherent method requires diffraction limited optical trains and a local oscillator. The direct detection method is far more relaxed, requiring only “photon bucket” collection optics and a series of blocking filters and etalons to separate the frequency-shifted light into a radial pattern. The direct detection of a Fabry-Perot pattern can best be done with a PMT or microchannel plate that has been constructed to have many equal-area electrically-isolated detection rings. Such a detector, placed at the image plane, can handle large fields of view and is good at preserving precious photons.

A less expensive alternative would be a device that could effectively transform the output of the etalons into a string of foci spaced correctly to fit into a line of fibers or onto a linear-CCD or photo-diode array. This device could be called a circle-to-point converter and simply redirects all the rays that enter each of the circular annuli into unique off-axis focal points. One way to do this is to cut out annular sections of the edges of lenses and piece them together with appropriate offsets in their respective focal positions. An extension of this method would be to cut up plastic Fresnel lenses or diffractive lenses. These devices can also be thought of as fractured zone plates, re-assembled for the purpose of separating and detecting the Doppler shift imparted to a narrow frequency laser pulse by winds or moving objects. The increments in frequency occur in equal area annuli, so the coarse appearance of such an optic is that of a zone plate as well. The main purpose for this optical element is the remote detection of regional wind speeds.

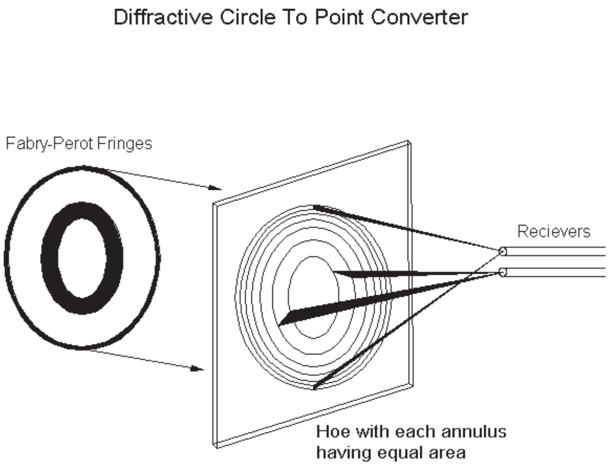

Figure 1. Diffractive circle-topoint converter.

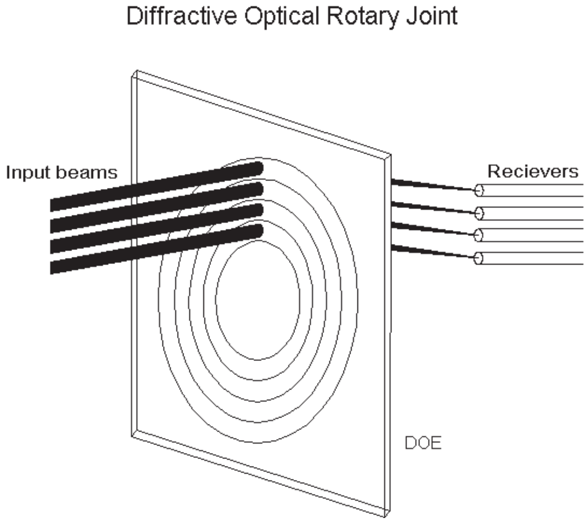

Figure 2. Diffractive optical rotary joint.

The same peculiar optical element constitutes a kind of optical rotary joint, useful in coupling wideband signals from a spinning platform to a stationary platform. In this alternative application, the device is best made with each annulus being the same width rather than the same area. That would make it appear to be a coarse axicon rather than a coarse zone plate. Otherwise, they are, or can be, the very same optical element. Each annulus is simply an off-axis focusing DOE or HOE that gets shifted laterally by some arbitrary increment between zones. Shooting them in a step-and-repeat fashion, we would simply change the way they are masked between exposures.

Figure 1 shows a likely layout of the circle-to-point pattern and Figure 2 is the corresponding rotary joint pattern. The circle-to-point pattern is used with full illumination over the aperture (designed to have as many as 24 annular regions in a 25mm diameter). The rotary joint would be used with individual modulated lasers or fibers addressing each zone with only a pencil beam. The number of channels would be limited by the size of the beams and the allowable crosstalk. The focus is shifted conveniently off the axis of rotation and out of the path of any zero-order light in both applications.

The method of fabrication and replication can be the same for each device. We made units with 24 zones as computer-generated binary patterns recorded directly in photopolymer. They could also have been patterned into photoresist and dry-etched into silica. We opted to add a high-frequency carrier to eliminate the possibility of cross talk from higher orders. Alternatively a correct blaze could have been used at lower frequencies so that the parts could easily be fabricated by mechanical replication. We also made the same functional units by starting with a holographically-constructed master that was subsequently stepped between exposures along with a mask of 7 or 24 rings. The HOE constructed this way can then be copied optically in one step into another volume recording material for higher volume production.

The diffractive design and fabrication of the rotary joints were carried out independently by Mathias Johansen and Sverker Hard, at Chalmers University of Technology in Sweden, and the design of the circle-to-point converter was contributed by Matt McGill and others at Goddard Space Flight Center, with fabrication being done at Ralcon development lab. Patents have been filed for or granted to both parties, and both are deserving, but I can’t help being amused by the entirely coincidental invention of the same complex diffractive optical element for two widely differentiated applications. It makes me wonder how often such things occur. Optical interconnects is another field where similar devices may be used, and could be searched for. It would not be a surprise to find the same device in the literature of that field and possibly also in holographic memories.

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References

1. Matthew J. McGill, M. Marzouk, V. S. Scott, and J. D. Spinhirne, *Holographic circle-to-point converter with a particular application for Lidar work,* **Opt. Eng. 36,** pp. 2171-2175, August 1997.
2. Mathias Johansson and Sverker Hard, *Design, fabrication, and evaluation of a multichannel diffractive optic rotary joint,* **Appl. Opt. 38** (8), pp. 1302-1310, 10 March 1999.
3. R. D. Rallison, *Fractured zone plates for spatial separation of frequencies,* **Proc. SPIE 3633**, pp. 92-102,1999.

Large aperture bacteriorhodopsin films

In the middle of the 1980s, the first reports appeared describing a new type of optical recording material: optical films made from the biological photochrome bacteriorhodopsin (BR).[1-2] At that time BR-films were not very much more than a curiosity. The material was very expensive and difficult to process, but the potential of BR as an optical material was recognized.

Figure 1. Three generations of BR-films. The earliest films had an aperture of Ø = 16mm in a Ø = 25.4mm mounting. The 90×90mm large-aperture films come in a 4" mounting and have an active area about 40× bigger than the conventional BR-films. The BR-D96N film (left) is completely bleached, whereas the BR-WT film (right) is in its initial purple state. The 8"×12" BR-film in the rear is a prototype.

In nature, BR acts as a light-driven photon pump[3] and converts sunlight into chemical energy, a function that has been optimized during evolution. The accompanying photochromism is, from a biological point of view, nothing more than a side-effect. For potential applications the photochromic properties are the most interesting features, but there are also some others, among them is its efficient light conversion. The quantum efficiency of the primary photoreaction of BR is 64%. This means that only 1-2 photons are needed to drive a BR molecule into its photocycle. The spectral shift of about 150nm between the absorption maxima of the bleached (λ_{max} = 410nm) and unbleached material (λ_{max} = 570nm) is quite large. With yellow and blue light, the BR material can be cycled between the two states. Both wavelengths are in the visible and, unlike many other photochromic materials, no UV light is needed. Last but not least is the excellent reversibility of BR-films. They may be used over and over without noticeable degradation.

All these parameters make the naturally occurring BR-form, so-called wildtype BR (or BR-WT), an interesting material for optical recording: at least in principle. However, the storage time of BR-WT films, i.e. the time it takes for the bleached material to returns thermally to the unbleached state, is rather low: in the millisecond range. High light intensities are therefore necessary to achieve acceptable contrast in such a film.

Figure 2. The FringeMaker™ system for non-destructive testing and vibration analysis uses 4" size BR-films for recording.

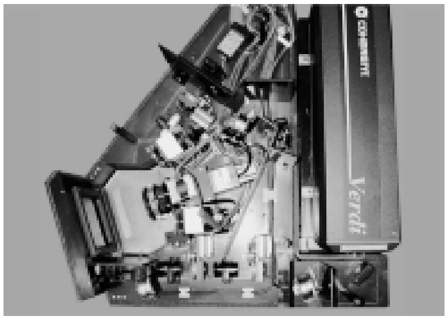

Figure 3. View inside the FringeMaker™ showing the mounting of the BR-film and the other optical components.

Table 1. Optical and holographic properties of large aperture BR-D96N-films

spectral range	recording	520-640 nm
	erasure	400-430 nm
exposure (at 532 nm)		**0.1-3 mJ/cm^2**
polarization recording		yes
diffraction efficiency		2-3 %
resolution		≥ 5000 lines/mm
mounting		100×100×20 mm
aperture		90×90 mm
optical density (570 nm)		1-3
maximal bleaching ratio		95 %
thickness of BR film		4.1 mm
thickness of BR layer		20-50 µm
antireflection coating		broadband
reversibility		$> 10^6$ recordings
shelf life		years

With the appearance of the first mutated BR,[4,5] the variant BR-D96N, this problem was solved.[6] BR-D96N was the first material where the tools of gene technology had been used to modify the physical properties of a biomaterial for the sole purpose of creating a valuable technical material.

Much effort was put into the development of BR-D96N films for optical recording.[7] The BR-films can now be used for polarization recording, a very useful technique for the improvement of the signal-to-noise ratio in optical recording with BR-films. Their applicability for a variety of optical applications has been demonstrated, among them nonlinear filtering, holographic pattern recognition, associative memories and interferometry.[8]

For several applications it is desired to have the recording medium be large: one example is high-resolution holographic interferometry. For lensless recording, which gives the best results in this respect, films with dimensions comparable to the old silver halide plates are needed. Now 4" BR-films can be prepared reliably in good quality and at reasonable cost. Their first application is to serve as reversible recording media in a holographic camera for non-destructive testing.[9]

Is a biomaterial like BR competitive to synthetic materials for optical recording? Each of the parameters of BR-films may be reached, or even exceeded, by other materials—but the combination of reversibility, sensitivity, polarization recording etc. is unique.

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References

1. N. N. Vsevolodov and G. R. Ivanitskii, **Biophysics 30,** p. 962, 1985.
2. A. A. Kononenko, E. P. Lukashev, A. V. Maximychev, S. K. Chamorovsky, A. B. Rubin, S. F. Timashev, and L. N. Chekulaeva, **Biochim. Biophys. Acta 850,** p. 162, 1986.
3. H. Luecke, B. Schobert, H. T. Richter, J. P. Cartailler, and J. K. Lanyi, ***Science* 286,** p. 255, 1999.
4. D. Oesterhelt and G. Krippahl, **Ann. Microbiol. (Paris) 134B,** p. 137, 1983.
5. H. G. Khorana, M. S. Braiman, B. H. Chao, T. Doi, S. L. Flitsch, M. A. Gilles-Gonzalez, N. R. Hackett, S. S. Karnik, and T. Mogi, **Chem. Scr. 27B,** p. 137, 1987.
6. N. Hampp, C. Bräuchle, and D. Oesterhelt, **Proc. Europ. Conf. Biotechn. EIT,** p. 124, 1988.
7. N. Hampp, C. Bräuchle, and D. Oesterhelt, **Biophys. J. 58,** p. 83, 1990.
8. N. Hampp and C. Bräuchle, **Studies in Organic Chemistry 40,** p. 954,1990.
9. N. Hampp, A. Seitz, T. Juchem, and D. Oesterhelt, **Proc. SPIE 3623,** p. 243, 1999.

Volume phase holographic gratings for astronomical spectrographs

The National Optical Astronomy Observatories (NOAO) in Tucson, Arizona, and Kaiser Optical Systems, Inc. (KOSI) in Ann Arbor, Michigan, have undertaken a study to evaluate the usefulness of volume phase holographic (VPH) gratings for astronomical applications. Funded by the National Science Foundation, the effort involved the fabrication and evaluation of eight different VPH gratings.

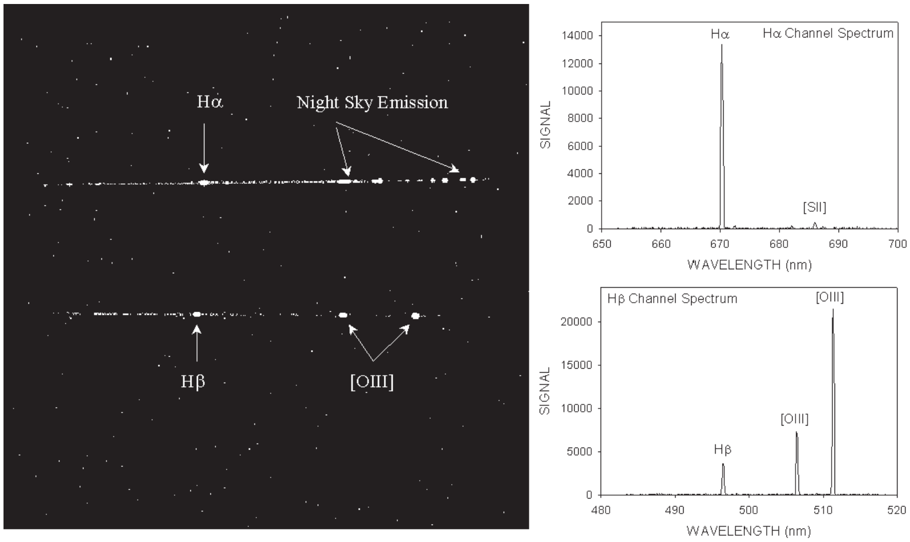

Figure 1. A CCD frame of the spectra produced by the holoplex grating is shown to the left. The extracted hydrogen-alpha and hydrogen-beta spectra of a faint blue compact galaxy are displayed on the right.

VPH gratings differ in many ways from the classical surface relief (SR) gratings currently used in astronomical spectrographs. The light is diffracted by modulations in the refractive index of the grating volume rather than by surface structure. This allows a VPH grating to be encapsulated, which, in turn, protects the grating from a variety of environmental factors that might otherwise be detrimental to surface gratings. The volume aspect of the VPH grating controls the energy envelope of the diffracted light by the Bragg condition similar to the diffraction of X-rays by crystalline structures. Very high diffraction efficiencies are possible with VPH gratings that in some cases can be nearly a factor of two higher than that achievable with SR gratings. Although this Bragg condition may provide high efficiencies at a specific wavelengths, it can unfortunately lead to narrower angular and/or spectral bandwidths for a fixed grating configuration than that of a SR grating. However, a VPH grating can be tilted, or tuned, to shift the Bragg response to other wavelengths beyond the design band with efficiencies that can exceed those of the classical SR grating.

Astronomical spectrographs typically require the use of quite large beam diameters. The upper limit has typically been set by the unavailability of SR gratings with sizes larger than about 200mm. With VPH grating technology, however, it will be possible to fabricate very large grating structures (up to 1m) enabling new concepts in instrumental design.

Another additional benefit is the fact that VPH gratings can be operated in a true Littrow configuration. This simplifies the spectrograph camera design since it would no longer have to be oversized to compensate for the anamorphic magnification present in a non-Littrow design.

KOSI has also developed a grating concept that actually takes advantage of the narrow bandwidths produced by VPH gratings. Their patented holoplex element contains two gratings within one grating assembly. The first interacts with, and diffracts, a specific wavelength of light. As the wavelength deviates from the Bragg condition, the grating diffraction efficiency approaches zero at some other wavelength. Through careful process control, KOSI is able to fabricate grating pairs that complement each other in such ways as to diffract two different spectral regions at the same angle of diffraction. In other words, one grating diffracts a specific wavelength regime while remaining “invisible” to the light at another spectral region, while the complementary grating has high efficiency at the second spectral region, but minimal efficiency at the first.

The grating produced for the NSF study was designed to diffract both the light of Hydrogen-alpha (656nm) and Hydrogen-beta (486nm) to the same diffraction angle of 23° with a 1200 and 1620l/mm grating pair. Although this particular grating performs exceedingly well, with nearly 93% peak diffraction efficiency at 656nm, the 1200 l/mm component has a slightly narrower bandwidth than desired and diffracts 15% of the light originally intended for diffraction by the 1620 l/mm grating. This loss results in a peak efficiency of only 75% at 486nm rather than the 90% efficiency predicted. This type of multiplexed VPH is of particular interest in astronomical applications in which the simultaneous observation of multiple spectral features is desired. Figure 1 shows the simultaneous spectra obtained for a faint blue galaxy with this particular NSF grating.

The NSF study is nearing completion as all eight gratings have been fabricated and are currently under analysis. In response to the very encouraging results achieved by VPH gratings, several observatories around the world (NOAO, Anglo-Australian Observatory, European Southern Observatory, etc.) are investigating the implementation of VPH gratings in existing and new astronomical spectrographs. A market demand of 120 gratings is expected for the next three year period. This includes VPH gratings ranging in line density from 200-2400l/mm and with sizes of 60-200mm in diameter. These gratings are for use in the optical (300-1000nm) and non-thermal infrared (1-1.7µm) spectral regions. Future instruments on the next generation of telescopes will likely require access to gratings with sizes of 300mm and larger. There is also growing interest in using this grating technology for the thermal infrared (1.5-5µm) spectral region if these gratings can be shown to operate at liquid nitrogen temperatures.

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Holoknight ritual held during interferometry ’99

A new “Holoknight” was named recently in a ceremony performed at the banquet of The Interferometry ’99 Conference, held in Pultusk Castle, near Warsaw. The most recent addition to the International Order of Holoknights was Professor Mitsuo Takeda, of the University of Electro-Communications, who received a traditional sword (A Samurai sword in this case), the symbol of the order. The exclusive order was founded in 1988 by Dr. Hans Rottenkolber of Amerang, Germany, a well-known holographer, who also established the original rules.

Each year, the most recently selected Holoknight selects a well-known holographer from the optics community, from a country other than his own, and one who also has a reputation as an excellent international host. The new candidate is presented to the group for approval as the next Holoknight to be presented with his own sword and parchment in the language of the selecting Holoknight. Each member promises to promote and defend the field of holography, to promote international friendships, and to assist each other in all such endeavors.

The order now has seven members from five countries. “Mitsuo of Tokyo” was selected by “Ole of Trondheim” (Ole Lockberg) and was knighted during the banquet by “Werner of Bremen” (Werner Juptner). “Jim of California” (Dr. Jim Trolinger) and “Paul of Alsace” (Paul Smigielski), read Laudatios and letters from other holoknights to complete the ritual. The next Holoknight will be a “Holosamurai” selected by “Mitsuo of Tokyo”, and the knighting ritual will take place during the San Diego SPIE meeting in 2000. The selection is kept secret until the moment of the ritual.

Figure 1. Holoknight ritual at Interferometry ’99. Professor Mitsuo Takeda is named “Mitsuo of Tokyo”. Holding the sword (out of the picture) is Werner of Bremen. Officiating were “Jim of California”, left, and “Paul of Alsace”, right.

It seems this year that a major challenge for the new Holoknight was getting the sword through the various customs of several countries from Poland to Japan. The new sword rode with airplane captains, was held in custody for several hours in Moscow, and was almost confiscated in Japan; however, it now hangs in Professor Takeda’s office.

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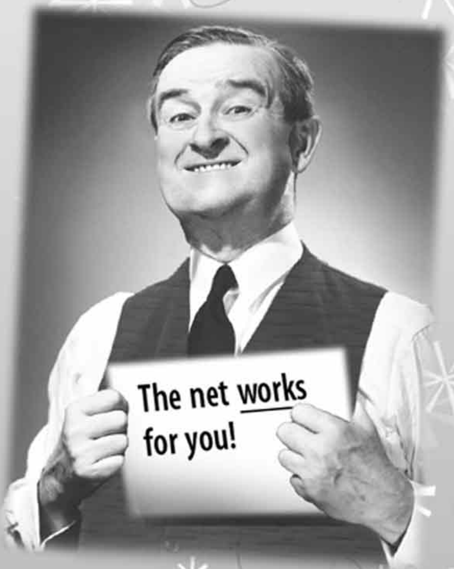

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Enlarging the viewing angle of computer-generated holograms

It has become quite practical to synthesize semi-gigapixel Fresnel-type computer-generated holograms (CGHs) of 3D objects using personal computers, because computational power has improved dramatically since the 1960s, when the elements were originally proposed.[1] This means that, if you have a personal computer, you can make your own CGH. However, it is not easy to output the CGH at your home, because the required output resolution is smaller than one micron. This is roughly 50 times higher than the resolution of regular laser printers.

The electron-beam printer is ideal device for 3D CGH writing because of its excellent resolution.[2,3] Though it is the best device for mass production, it is obviously not suitable for home use. Classical photographic reduction is often used by those requiring an easier way of fabricating CGHs. If the element is calculated using collimated reference beam, its viewing angle is equal to or less than its diffraction angle. Therefore, the viewing angle depends on the pixel pitch of the CGH. Since the resolution of the photographic film or camera limits the diffraction angle, the resulting viewing angle is not enough for binocular viewing.

We are investigating the use of a lensless Fourier hologram[4] for the photographic reduction of the CGH because the viewing angle is independent of the resolution but proportional to the number of pixel in the hologram.[5] Since the lensless Fourier hologram is recorded with the point reference source beside the object, the point illumination or converging illumination must be located near the hologram for image reconstruction. This kind of the special illumination is not practical. We have, therefore, made a secondary hologram using a collimated reference beam and the object beam from the reconstructed image of the lensless Fourier-type CGH. With this approach, we have obtained the holograms with a viewing angle wider than 20˚ that can be reconstructed with collimated white- light illumination. The proposed method can also be applied to rainbow holograms[6, 7] to reduce image blur and computation time.

Figure 1 shows a pair of white-light reconstructed stereoscopic images from a transmission hologram made by this method. The recorded object is a wire-frame cube and its size on the hologram is 2.8×4.0mm. The number pixels in the master CGH is 3200×2200 (horizontal × vertical) and the pixel pitch is about 5.5μm. The horizontal viewing angle is as wide as 22.6˚, about seven times wider than that of the CGH calculated with collimated reference beam. Since the master CGH is calculated as a full parallax hologram, a viewer can appreciate vertical parallax as well as horizontal parallax. We have also made reflection holograms and rainbow holograms.

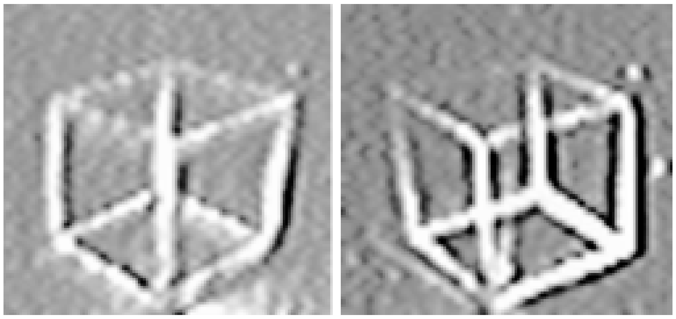

Figure 1. Reconstructed images from the proposed transmission hologram. (a) View from left. (b) View from right.

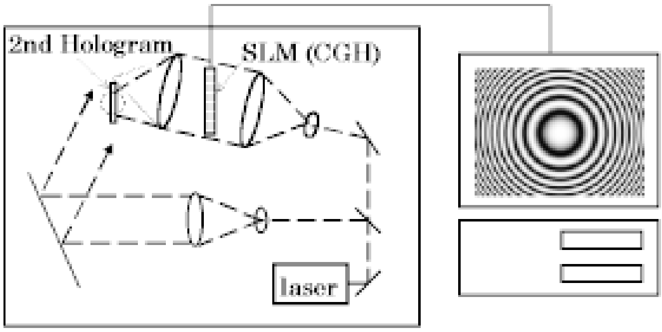

Figure 2. Schematic setup of the CGH printer.

Although, the proposed method requires optical transfer to make secondary holograms, it can be done automatically with a spatial light modulator as the first hologram shown in Figure 2. The final goal of our research is making homemade CGHs easier.

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References

1. J. P. Waters, *Holographic image synthesis utilizing theoretical method,* **Appl. Phys. Lett. 9,** pp.405-407, 1966.
2. T. Hamano and H. Yoshikawa, *Image-type CGH by means of e-beam printing,* **Proc. SPIE 3293,** 1998.
3. T. Hamano, M. Kitamura, and H. Yoshikawa, *Computer-generated holograms with pulse-width modulation for multi-level 3-D images,* **Proc. SPIE 3637,** 1999.
4. George W. Stroke, *Lensless Fourier-Transform Method for Optical Holography,* **Applied Physics Letters 6,** pp. 201-203, 1965.
5. H. Yoshikawa and M. Yamagishi, *Enlarging viewing angle of computergenerated holograms,* **Proc. SPIE 3749,** 1999.
6. S. A. Benton, *Hologram reconstructions with extended incoherent sources,* **J. Opt. Soc. Am. 59,** p. 1545A, 1969.
7. H. Yoshikawa and H. Taniguchi, *Computer Generated Rainbow Hologram,* **Optical Review 6,** pp. 535-538, 1999.

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