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Session 2

Lectures:

LIGHT-GUIDE BASED DISPLAY SYSTEMS

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Abstract

During the last years, in collaboration with academic and industrial partners, ELOP has conducted R&D on compact and advanced remote sensing and display systems for improved performance of users under operational and time stress, including vehicle drivers, medical doctors, and assembly workers. These investigations resulted in new technologies and components with the most prominent ones being novel compact optical light-guides (OLGs) exploiting advanced holographic (diffractive) optical elements for see-through augmented reality projection. Additional innovative components developed and integrated in this context were variable-transmittance optical windows based on novel LC technology for display contrast adaptation, miniature display and light sources, associated driver electronics and interfaces for system enhancement. A novel replication process of OLGs masters was developed to demonstrate the feasibility of future mass production. The electro-optic and ergonomic performances of the fully integrated system was assessed and demonstrated on-board for an automotive head-up display.

Soft Materials for Optical Data Storage and Processing

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We present the results of an extended investigation on composite soft materials as basic media for high density data storage and for optical processing.

The properties of mixtures of nematic liquid crystal or un-polymerizable fluid and pre-polymeric compounds were investigated in the frame of a research project aimed at realizing a novel micro-holographic disk. A conventional holographic geometry coupled to a new spectroscopic method was used to record high resolution reflection gratings in the material and to characterize their optical properties during and after the grating formation. We have demonstrated that these materials fulfil the main requirements for a good holographic medium concerning the induced index modulation Δn (about 0.01) , sensitivity (few mJ/cm^2) and spatial resolution (over 7000 lines/mm). Shrinkage in the range 1-2% may represent a limitation depending on the specific recording/retrieval system. Methods used to overcome this problem will be presented and discussed.

Concerning optical processing, we report recent results obtained using dye-doped liquid crystals. In these materials it is possible to get a "colossal" nonlinear optical response (n_2 up to 10^3 cm^2/W). In this way it is possible to get spatial light modulation of weak light beams as in optically addresses light valves using devices of simplified architecture based on the highly nonlinear thin (1-15 μm) film. Wavefront correction of weak (100 μW/cm^2) beams with strong aberration has been obtained in the conventional four wave mixing geometry. The basic mechanism is the surface induced nonlinear effect (SINE) that can be easily controlled by a low voltage applied to the sample. In this way real time recording of phase gratings has also been obtained with multiple diffraction and switching.

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Electroholographic Tunable Wavelength Selective Switch in the g44 Configuration

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Electroholography (EH) is a wavelength selective photonic switching method based on governing the reconstruction process of volume holograms by means of an electric field. EH is based on the voltage controlled photorefractive effect at the paraelectric phase where the electrooptic effect is quadratic. EH has hitherto been implemented as transmission gratings in the g_{11} configuration in which the switch is pre-programmed to one wavelength. Presented here is an electroholographic switch operating with wavelength tenability. The switch is implemented as a transmission grating in the g_{44} configuration in which the applied field is perpendicular to the grating vector. It will be shown that in the g_{44} configuration the index ellipsoid rotates periodically back and forth as the beam propagates through the grating. It will be argued that this causes the polarization of the diffracting beam to be perpendicular to the polarization of the input beam. It will also be shown that in the g_{44} configuration the Bragg condition is electrically tuned so that the switched wavelength is determined by the applied voltage. Tunability of 7nm will be demonstrated in a 2mm thick single grating.

Detailed description of the g44 phenomena is described in reference 1.

[1] A. Bitman, N. Sapiens, G. Bartal, L. Secundo, M. Segev, and A. J. Agranat, "Electroholographic Tunable Volume Grating in the g_{44} Configuration",

Optics Letters 31 (19) pp. 2849-2851 **(**October 1, 2006**).**

MULTIPLE QUANTUM WELL SURFACE-NORMAL MODULATOR ARRAYS FOR IMAGING AND FREE-SPACE OPTICAL COMMUNICATION

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We have developed reflective, amplitude modulators based on GaAs technology working at 850nm. These devices use a resonant-cavity design composed of a Multiple Quantum Well (MQW) structure sandwiched between two distributed Bragg reflectors, and can be used for imaging, signal processing and free-space optical communication. We have designed and fabricated one- and two-dimensional arrays, including matrices with 128x128 pixels [1] reaching 11 000 frames per second, and devices with over 2 cm^2 of active area which can be modulated in the MHz range. To allow this, we have improved structure and device designs and processes to increase the modulation speed (limited by the RC constant) and the yield (limited by the defect density), in particular by segmenting large-area devices in application-specific ways. We have also achieved 3dB cut-off frequencies in excess of 1GHz using small area, high-speed designs. We are currently working with one-dimensional phase modulation arrays. Phase modulation, coupled with the high-speed potential of MQW modulators, is of great interest for many applications including optical signal processing and beam steering.

We have also demonstrated small- and large-area InP-based MQW modulators operating at around 1.55 micrometers [2], enabling the use of higher-power illumination sources, compared to GaAs-based devices, without special eye-protections. Large devices, with active areas of up to 17 mm^2, are also segmented to increase the performance, and can reach tens of MHz.

[1] S. Junique et al, Applied Optics 44(9), 1635-1641 (2005)

[2] Q. Wang et al, Eletronics Letters, Volume 42, Issue 1. (2006)

Liquid Crystal Optical Modulators for Biomedical Applications

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Liquid crystals (LCs) are birefringent materials that exhibit large electro-optic effects which make them useful for a variety of applications as fast, compact, and tunable spectral filters, phase modulators, polarization controllers and optical shutters. They have been largely developed for liquid crystal displays and in the last decade for optical telecommunications, however their application in the field of optical imaging just started to emerge. These devices can be miniaturized thus have a great potential to be used with miniature optical imaging systems. Using a collection of tunable phase retarders one can perform:

1. Full measurement of the Stokes parameters for polarimetric imaging.
2. Tunable filtering to be used for hyperspectral imaging and frequency domain optical coherence tomography.
3. Adaptive optical imaging and aberrations correction.

Basic optics of liquid crystals devices will be reviewed and some novel designs will be presented in more details when combined to imaging systems for a number of applications in biomedical imaging and sensing.

ADVANTAGES AND LIMITATIONS OF MICRO-OPTICAL ELEMENT ARRAYS IN SPATIAL LIGHT MODULATORS

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Aperture of a LED or laser originated light beam incident to transmissive liquid crystal spatial light modulator (SLM) is substantially (>40%) masked by TFT layer pixels that act as a micro-diaphragm array. Microlens arrays (MLA) inserted inside SLM are capable of raising a throughput SLM transmission by substantial reduction for lateral dimensions of a light beamlet passing through each pixel of a spatial light modulator, down to dimension of TFT clear aperture. However, this application of microlens arrays meets several problems:

- Pixel pitch and respective MLA pitch are relatively small (5-30 μm) .
- High NA microlens are necessary to prevent diffraction limit for the focal spot from approaching the size of micro-diaphragm's clear aperture.
- Microlens arrays should be introduced in the middle of technological process of SLM fabrication.
- Variation of a local incidence angle at every SLM pixel shifts the positions of each focal spots relative to centers of micro-diaphragms.
- Additional beam divergence introduced by the MLA creates higher demand of specifications of optical system following the MLA.

In order to resolve the trade-off limitations we proposed to exploit physical optics propagation combined with geometrical ray-tracing. These enabled us to investigate effects of light diffraction in combination with SLM layers geometry and illumination beam quality. We minimized a diffraction spread of the focal spot and accounted for aberrations of each lenslet. Modeling the MLA enabled to predict such MLA parameters as size of a focal spot, longitudinal variations of spot size, transmission efficiency for given clear aperture of each pixel, output divergence, cross talk between adjacent pixels and its minimization. Simulation data on combined effect of aberrated geometrical defocusing and diffraction spread is presented. Designed spherical, elliptical and also asymmetrical lenslet shapes were used as a base for designing advanced spatial light modulators with high diffraction efficiency.

EXPERIMENTAL STUDY AND COMPUTER SIMULATION

OF ULTRA-SMALL-PIXEL LIQUID CRYSTAL DEVICE

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Optical beam steering, switching and optical cross-connects are important applications of liquid crystal (LC)-based spatial light modulators (SLM). LC devices, such as LC-on-silicon microdisplays, are also promising candidates for practical implementation of computer-generated holograms and dynamic diffractive elements. The dynamic holography requirements call for relatively large panels (~10 cm) with ultra-small pixel sizes of < 5 micrometers. One of the key factors affecting the performance of LC devices is the fringing field effect.[1] This effect is the principal cause for the current resolution limitations of LC displays (LCD) as well as the reduction in both the maximum deflection angle and the diffraction efficiency of beam steering devices. In order to estimate the possibilities of practical realization of LCD with ultra-small pixel, we performed detailed simulation and experimental evaluation of a simple LC test-device. As a basis for our study, we have chosen commercially available array of 5+5 interdigitated, 1 mm-long, gold electrodes on a 1-mm-thick glass substrate. The electrodes are 2-micrometer wide and are separated by 1-micrometer inter-electrode gap. Thus, the pitch ("pixel size") of the periodic electrode array is 3 micrometers. The LC device operates as dynamic, reflective diffractive grating and simulates the performance of a LC-on-silicon (LCOS), ultra-small-pixel microdisplay, for dynamic holography applications. A unique experimental technique previously developed was used to allow controllable variation of the LC thickness. It was shown, that for a proper choice of LC material (MERCK's BL006 mixture with high birefringence of 0.286), cell thickness (less then 2 micrometers) and driving conditions, the device can attain high diffraction efficiency and switching rate, thus demonstrating the feasibility of a 3-micrometer pixel LCD for dynamic holography.

1. Apter B., Efron U., Bahat-Treidel E. "On the fringing field effect in liquid crystal beam steering devices". Applied Optics, vol. 43, No 1, pp. 11-19, 2004.

OPTICAL SOLUTION FOR THE TRAVELING SALESMAN PROBLEM (TSP)

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Abstract

A new architecture of an optical processor for solving bounded (input length restricted) NP-complete combinatorial problems is suggested. These problems are hard to solve and therefore are frequently used as a comparative test of computational systems. The traveling salesman problem (TSP) is a member of this group of problems. The TSP is usually involved in finding the shortest tour of a salesman passing through a certain number of cities, where the weights (distances) between the cities are known. It can be shown that the number of tours of an N-city-TSP is in the order of N!. Therefore, solving a TSP with a large number of cities by checking all feasible tours may be a very hard task.

Due to the difficulty of solving this problem, many approximation and heuristic methods have been proposed in the literature. However, in approximation methods there is a known tradeoff between the computation time and the closeness to the optimal solution, and when the optimal solution is required the computation time may be too long. On the other hand, heuristic methods are able to solve these problems quickly for certain cases only. In fact, the computation time of the heuristic methods may be unexpected and even longer than that of an exhaustive search (checking all feasible tours in an exhaustive manner) due to unsuccessful attempts for optimization. Therefore, in applications where deadlines must be met, such heuristic methods are not a good choice and one may prefer to use an exhaustive search. For these cases, the authors propose a new optical method which can provide a dramatically better guarantied time for the solution.

The proposed optical system is capable of solving the TSP by checking all feasible tours more efficiently than a conventional computer. This design is based on a fast optical vector-matrix multiplication (VMM) between a binary matrix representing all feasible TSP tours and a weight vector representing the TSP weights. The multiplication product is a vector representing

the TSP tour-lengths. The advantage of the proposed method is that once the binary matrix is synthesized, all TSPs with the same number of cities or less can be solved optically by only changing the weight vector and performing the VMM in an optical way. An efficient way for synthesizing the binary matrix in the preprocessing stage is also suggested.

In order to check the feasibility of the proposed optical system, we have implemented the VMM by using the joint transform correlator (JTC). An expanded laser beam illuminates the input plane which is presented on a spatial light modulator (SLM). This plane contains both the grayscale weight vector and the binary (black/white) matrix. A positive lens Fourier transforms the input plane. The intensity of the Fourier plane is presented on the SLM and Fourier transformed again by the lens. The output plane of the optical system contains peaks of light representing the multiplication between the binary matrix and the weight vector, which gives us an indication of the shortest TSP tour. The synthesis of the binary matrix is preformed in the preprocessing stage by using another optical system which uses an SLM in order to duplicate large vectors by correlating these vectors with shifted delta functions (points of light).

On the Physical Limitations of Electro-Optical materials

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Electro-optical light modulators are key components for a number of optical systems including displays, optical interconnects, optical processing, optical beam steering and adaptive optics .The performance of these modulators can be characterized by three main physical parameters: (1) The electro-optical coefficient, (2) The RF frequency bandwidth and (3) The optical spectral bandwidth.

A recent study [1] has shown that the product of these three parameters, which we term "Susceptibility-Bandwidth Product" (SBP), is remarkably constant within 1-2 orders of magnitude, across a wide range of different material systems, including Liquid Crystal (LC), Solid State Electro-Optical Materials (SSEO) and Multiple Quantum Well (MQW) structures. This, despite the fact that all three parameters vary over many orders of magnitude across this range of material systems

. The feasibility of the SBP constancy based on stability considerations has already been proposed several years ago [2].

The phenomenological and theoretical basis for the SBP concept and its validity across various material systems will be discussed.

[1] U. Efron ,"Technology and Applications of Spatial Light Modulators", in Handbook of Opto-Electronics,J.P.Dapkin and R.G.W. Brown, Editors, Taylor & Francis, London (2006),Vol.2.

[2] U.Efron, "Spatial Light Modulators and applications for optical information processing", Proc. SPIE Vol.960, pp.180-203 (1988).

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