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Bacteriorhodopsin Films for Optical Signal Processing and Data Storage

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Abstract

This report summarizes the research results obtained on NASA Ames Grant NAG 2-878 entitled "Investigations of Bacteriorhodopsin Films for Optical Signal Processing and Data Storage". Specifically we performed research, at Texas Tech University, on applications of Bacteriorhodopsin films to both (1) dynamic spatial filtering and (2) holographic data storage. In addition, measurements of the noise properties of an acousto-optical matrix-vector multiplier built for NASA Ames by Photonic Systems Inc. were performed at NASA Ames' Photonics Laboratory. This research resulted in two papers presented at major optical data processing conferences and a journal paper which is to appear in APPLIED OPTICS. A new proposal for additional BR research has recently been submitted to NASA Ames Research Center.

Introduction

Presented below are brief sections describing the progress made under NASA Ames Grant NAG 2-878.

A. Dynamic Spatial Filtering with Bacteriorhodopsin Films

The photocycle exhibited by Bacteriorhodopsin (BR) film presents the opportunity to use this material as an optically addressed spatial light modulator. Figure 1 illustrates a simplified photocycle for Bacteriorhodopsin. Illumination of the film induces a rapid transition from the initial BR state through several intermediates to the M state, which (in our films) has a lifetime of approximately ten seconds while the film returns to the BR state through several intermediates by thermal relaxation. These two states exhibit largely non-overlapping absorption characteristics as shown in Figure 2. We have exploited this shift in absorption spectra and the corresponding change in intensity transmittance to use BR film as an optically addressed spatial light modulator in a dynamic spatial filtering system.

Figure 3 shows the basic spatial filtering scheme. When illuminated with collimated light, the first lens produces the spatial frequency spectrum of the input plane in the Fourier plane. A filter transfer function may be inserted to selectively pass or attenuate spatial frequency components as desired. The second lens images the filtered object onto the output plane. We used BR film placed in the Fourier plane as an optically

addressed spatial light modulator and wrote the desired filter transfer function onto the film.

We then implemented the dynamic spatial filtering system shown in Figure 4. This system used two optical paths from a single argon ion laser operating at 514 nm. The first path, controlled by mechanical Shutter 1, is used to write the filter transfer function to the BR film. The unexpanded beam is first passed through an acousto-optic (AO) cell which serves as a shutter only. Its purpose is to deflect the beam into the 2D Mirror Scanning System effectively providing a "shutter" control more rapid than the mechanical Shutter 1. The 2D Mirror Scanning System is under computer control and positions the write beam to the desired location on the BR film. Lens L4 is positioned to focus the beam onto the BR film. In the second optical path, controlled by mechanical Shutter 2, the beam is expanded and collimated to illuminate the test Object. We used a standard Air Force resolution test pattern as the input function. A neutral density filter was placed in the optical path to attenuate the object beam to an intensity that will not induce a significant transition of the BR film to the M state. The object was located in the front focal plane of Lens L1 and its Fourier transform appeared at the plane labeled FP. A second lens L2 was located to magnify the Fourier transform at the plane FP' with a magnification of approximately 4. We placed the BR film in this second Fourier plane. We set the object beam at an angle with respect to the filter pattern beam to allow simultaneous

projection of the two beams without the filter pattern beam striking the output plane. Lens L3 was positioned to image the filtered test object onto the CCD camera where we recorded the output image on a VCR or captured the output image with a frame grabber. The overall magnification of the imaging system was approximately 0.25.

Since the Air Force test chart consists of vertical and horizontal stripes at various spatial frequencies, the Fourier distribution exhibits components only along the vertical and horizontal axes in the Fourier plane. We took advantage of this specific distribution and wrote filter transfer functions only to the horizontal and vertical axes of the Fourier plane. We wrote horizontal element only pass and vertical element only pass filters to the BR film. These filter transfer functions emphasize the vertical and horizontal stripes in the test object, respectively. We also wrote vertical element only and horizontal element only bandpass filters by writing a pair of "spots" to pass a particular spatial frequency. These filter transfer functions emphasize the horizontal or vertical stripes of that particular spatial frequency. We demonstrated the dynamic nature of the system by alternately passing horizontal and vertical elements of the Fourier distribution. The output alternately emphasized the vertical and horizontal bars of the test object.

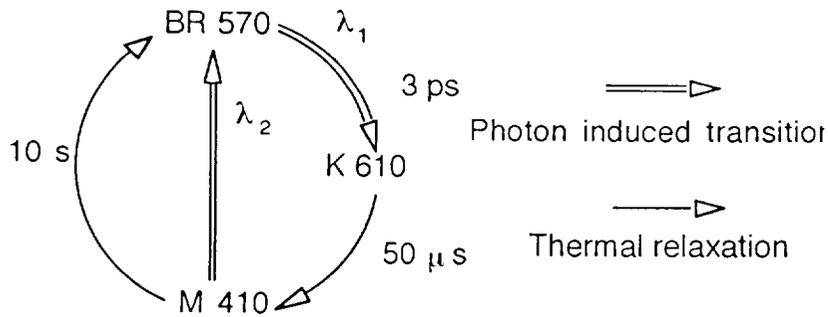


Figure 1: Simplified depiction of photocycle for Bacteriorhodopsin.

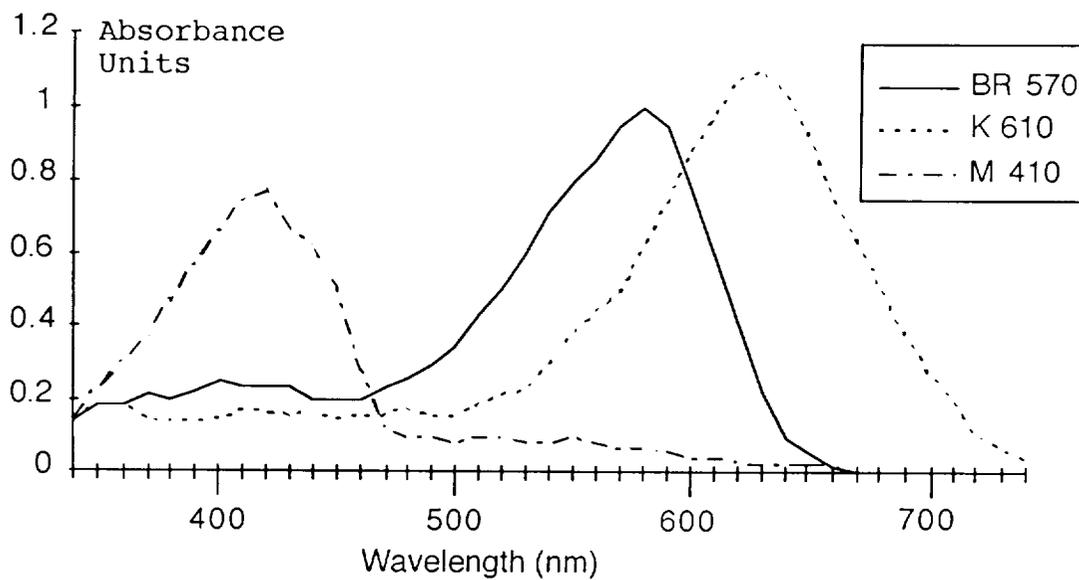


Figure 2: Absorption spectra of intermediates in the photocycle of Bacteriorhodopsin.

successfully recorded using SO-424 Kodak film and a HeNe laser. The recorded objects consisted of stencils forming the words "TTU" and "NASA". The lens shown in Figure A5 is used for Fourier transform holograms, and is simply removed from the system when recording Fresnel holograms. Fourier transform holograms must also employ a lens during reconstruction in order to reconstruct the original image.

Later attempts to record holograms using BR films, using an Ar+ laser, were only partially successful, resulting in poor diffraction efficiency. Our 5W argon laser is currently putting out only 200mW of power, and we suspect that the tube needs replacement. This limited power is marginal with regards to our efforts to write holograms in BR. It was also determined, by use of a Michelson interferometer setup, that the argon laser had a problem with vibrations. Although the setup was constructed on an air-suspended table, it was determined that the vibration problems may have stemmed from pressure fluctuations in the chilled water supply used to cool the argon ion laser. Consequently, the vibrations tended to wash out the holographic fringe patterns. We subsequently replaced the tube in our Ar+ laser, fixed leaks in our air-supported table and installed a pressure surge tank in the water line, in order to successfully store holograms of various objects, so that properties such as crosstalk and readout signal-to-noise ratio can be evaluated.

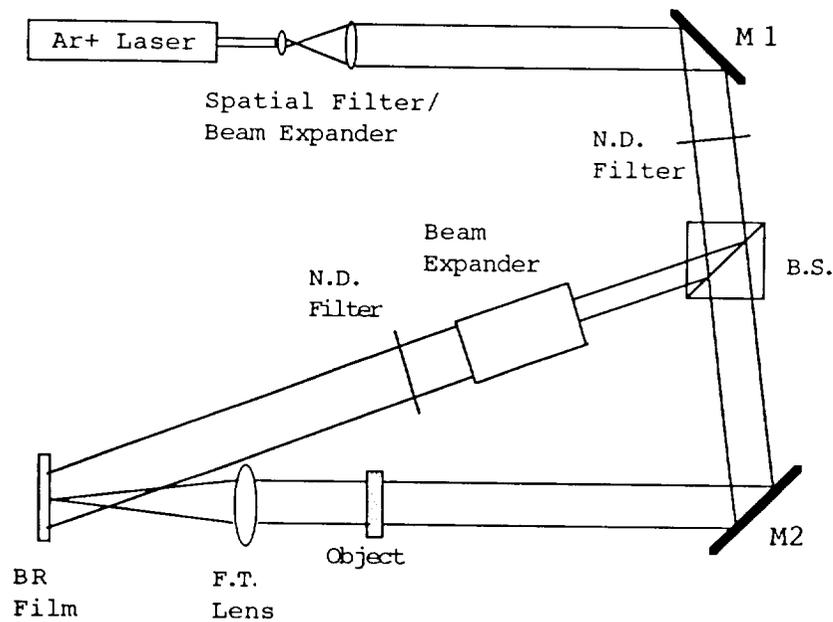


Figure 5: Setup for recording holograms for information storage.

C. Noise Measurements on Acousto-optical Matrix-Vector Multiplier Performed at NASA Ames Research Center

In late May and early June, 1994, Mr. Michael V. Morelli of the Optical Systems Laboratory travelled to NASA Ames and performed various measurements on an 8-channel input acousto-optical matrix-vector multiplier constructed, under contract to NASA Ames, by Photonic Systems Inc. These measurements were based on research techniques developed at Texas Tech University, by Mr. Morelli, as part of his AFOSR-funded Ph.D. dissertation research. The results of these measurements were communicated to Dr. Charles Gary, the technical program manager on this grant and used by Dr. Gary in an SPIE San Diego Symposium presentation in July, 1994.

Papers Presented/Publications

A conference paper entitled "Dynamic Spatial Filtering with Bacteriorhodopsin Films " by S. M. Storrs, J.F. Walkup and D. J. Mehrl was presented at the 1994 Annual Meeting of the Optical Society of America in Dallas, Texas. A second conference paper entitled "Holographic Data Storage in Bacteriorhodopsin using Phase-Encoded Multiplexing and Spectrum Spreading Techniques" by J.Y. Choi, J.F. Walkup, D.J. Mehrl and T.F. Krile, SPIE Proc. vol. 2754, was presented at the SPIE Orlando Aerosense '96 Symposium, April, 1996. A journal article entitled "Dynamic Spatial Filtering with Bacteriorhodopsin Films", by S.M Storrs, D.J. Mehrl and J.F. Walkup will appear in the Aug. 10, 1996 issue of Applied Optics.