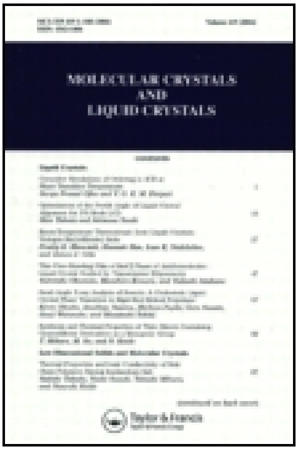

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Molecular Computing

Urs P. Wild [a] , Stefan Bernet [a] , Bern Kohler [a] & Alois Renn [a]

[a] Physical Chemistry Laboratory, Swiss Federal Institute of Technology, ETH-Zentrum, 8092, Zurich, Switzerland

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Urs P. Wild, Stefan Bernet, Bern Kohler, and Alois Renn
Physical Chemistry Laboratory, Swiss Federal Institute of Technology
ETH-Zentrum, 8092 Zurich, Switzerland

Introduction

Dye doped polymers are materials with new and exciting optical properties. At low temperatures host dynamics and solvent relaxation are frozen out and the lowest electronic absorption band of the dyes are inhomogeneously broadened reflecting a wide spread in different microenvironments. The invention of narrow bandwidth tunable lasers has led to new spectroscopic techniques based on energy selection, such as fluorescence line narrowing and spectral hole-burning [1]. The experimental resolution attainable now is limited by the homogeneous linewidth leading to an improvement of the resolution by four to six orders of magnitude. By virtue of their extreme spectral sensitivity to millions of different colors these materials allow for fascinating experiments in the field of optics. Applications in the frequency domain range from high density data storage to holographic image storage [2,3]. A new concept of "molecular computing" [4] is based on the spectroscopic properties of dye doped polymer films. The materials allow for information storage as well as parallel processing of the recorded information. Complementary to the experiments performed in the frequency domain, time domain applications have also been realized.

Optical Image Storage

Optical recording media are of growing interest and optical discs with storage densities on the order of 10^8 bit/cm^2 are already commercially available. Diode lasers are used for recording and readout of the data and hence the storage density per unit area is limited by the minimum spot size, which is determined by the diffraction. In order to further increase this storage capacity shorter wavelengths have to be used or a different storage technology has to be applied. An obvioue way to increase the storage density would be to use different colors for encoding bits. This can be achieved by means of spectral hole-burning. At very low temperatures the 10^6 different molecular subsets distinguishable by color within an inhomogeneously broadened band provide an additional dimension for the data storage. Thus, in every spot of a photochromic storage material we can store a large number of bits encoded as spectral holes in the frequency (color) dimension. The frequency multiplexing properties provided by the inhomogeneously broadened absorption spectra of dye doped polymer films is demonstrated in Fig. 1 where 2100 spectral holes have been burnt into a part of the absorption spectrum of a chlorin doped polyvinylbutyral film. Combining spectral hole burning and holography [5] as an alternative approach facilitates parallel recording and data access. Actually each of the dips shown in Fig. 1 corresponds to a holographically stored image. An electric field applied to the sample represents,an additional storage dimension and allows for a further increase of the storage capacity [6,7]. In a typical set-up for holographic image storage [2] the beam of a tunable single mode dye laser is split into reference and object beams and a hologram is formed by exposing the sample to the interference pattern of the two beams. Images of size 50x50 mm are generated in the object beam with a liquid crystal TV and they are focussed on the photocathode of a video camera. For retrieval the sample is illuminated by the reference beam and the addressing of the individual images is performed by adjusting the corresponding parameters, "frequency" to the values used during recording. The image information is recorded with the camera and the integrated diffraction efficiency can be simultaneously monitored by a photomultiplier. Exam-

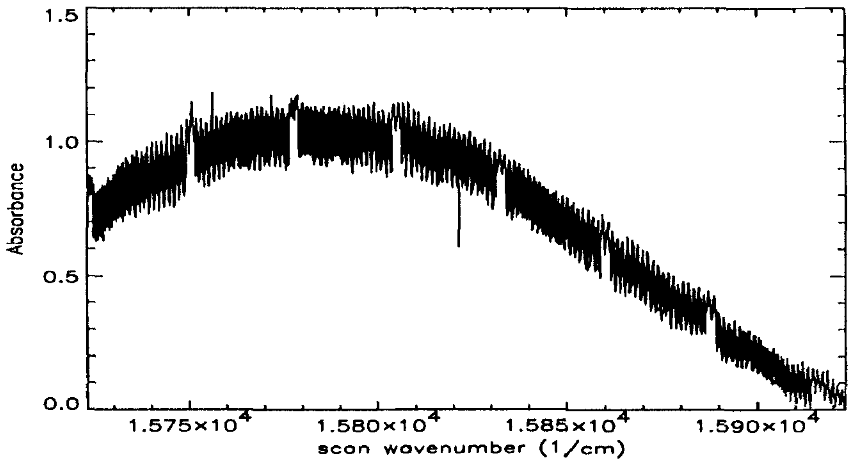

Fig. 1 Storage of 2100 images within the inhomogeneously brodened absorption bands of a chlorin doped polyvinylbutyral film. Each of the dips corresponds to a stored image.

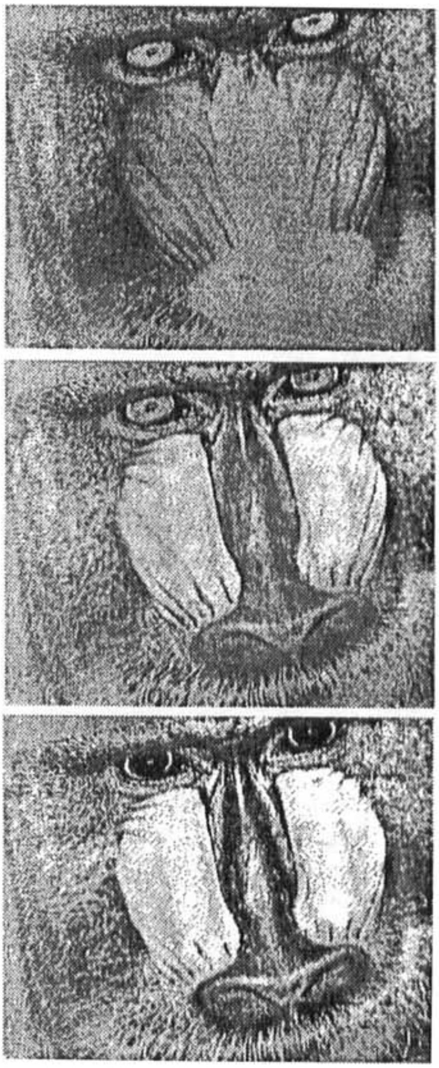

Fig. 2 3 Images demonstrating the resolution and grey scale capabilities of the recording medium. Each of the three images contains red, green and blue color information, respectively.

ples of stored images are shown in Fig. 2 where the red, green and blue color separation from an color image have been stored as holograms. From the retrieved images the color image can be reconstructed.

Molecular Computing

The frequency - electric field plane allows pairs of holograms to be stored in different arrangements, they can be burned either with a small frequency separation at the same field strength or at slightly different field strengths at the same burning frequency as shown in Fig. 3. A molecular system showing a splitting of a spectral hole under an electric field applied to the sample was used. The position of the maxima of the Stark components is indicated by the dashed lines. The images were recorded at different positions of the electric field, E_1 and E_2, and at the laser frequency, ν. A horizontal bar was stored at the position (ν, E_1) and a vertical bar at (ν, E_2). The burning coordinates are drawn as filled circles. Both of the images can be reconstructed individually by adjusting the correct experimental parameters used during recording. The superposition of the images can be reconstructed at the frequency, ν' or ν", and the electric field, $(E_1+E_2)/2$. The results of the image superposition are plotted for a phase difference of 0 and π. Constructive interference (phase 0) leads to an increase of the image intensity when the images overlap, the images are "added". Destructive interference (phase difference π) results in a "subtraction" of the images [4]. Logical operations corresponding to "AND" or "XOR" functions can be derived when appropriate discrimination is applied. Whereas electronic computers are based on the properties of electrons in an electric field, the molecular computer introduced here relies on spectroscopic properties - the behavior of molecular energy levels in an electric field. The storage device by itself becomes a parallel information processor - a molecular computer.

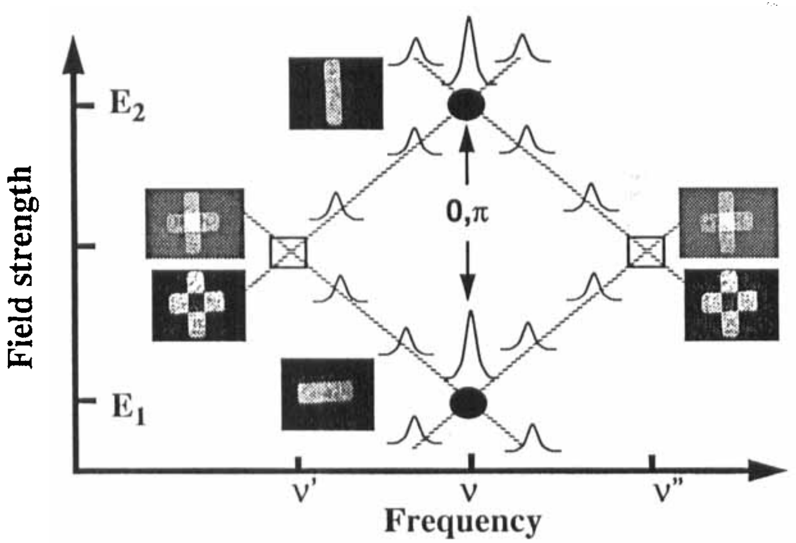

Fig. 3 Two images have been stored in a plane defined by the laser frequency and the electric field at different values of the electric field (E_1, E_2). The recording parameters are indicated by circles. Due to the Stark splitting of the spectral holes the holograms are made to overlap at the regions indicated by the squares. The reconstructed images show the result of the superposition

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