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Generalized Model of Photopolymer Behavior for Use in Optimized Holographic Data Storage Scheduling Algorithms

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Abstract: A generalized model of photo-polymerization in free radical chainforming polymers has been developed. Applying this model to data storage, optimized scheduling algorithms are developed for the multiplexing of multiple data pages of uniform diffraction efficiency.
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1. Introduction

With current technologies reaching the limit of their storage capabilities the optical data industry is searching for the next generation of storage system to meet the demands of the digital age. One possible solution is the use of holographic techniques where terabit capacity has been predicted and photopolymers are proving to be the recording medium of choice.

The generalized nonlocal polymerization driven diffusion model (NPDD) is used to describe holographic grating formation in free radical chain forming polymers and can be described using the following equation.

$$\frac{\partial u(x,t)}{\partial t} = D\left[H(x,t)\frac{\partial^2 u(x,t)}{\partial x^2} - u(x,t)\frac{\partial^2 H(x,t)}{\partial x^2}\right] - \int_{-\infty}^{+\infty}\int_0^t R(x,x';t,t')F(x',t')\times\left[u(x',t')\right]^{\beta} dt'dx' - \frac{u(x,t)}{u(x,t)+N(x,t)}\frac{\partial H(x,t)}{\partial t} \qquad (1)$$

where $u(x, t)$ is the free-monomer concentration, D is the monomer diffusion constant, $F(x, t)$ is the polymerization rate, $N(x, t)$ is the polymer concentration, $R(x, x'; t, t')$ is the nonlocal response function, $H(x, t)$ is the hole concentration, and β is a factor introduced to specify the dominant chain termination mechanism, either bimolecular ($\beta = 1$) or primary ($\beta = 2$).In this paper we examine the bimolecular case, $\beta = 1$. Volume changes are accounted for be assuming the generation of holes or free volume on the conversion of polymer to monomer. These holes can then diffuse and decay leading to volume changes and surface relief patterns in the material.[1]

2. Optimized Scheduling

We develop an algorithm based on the NPDD model, which determines an appropriate recording schedule for use in photopolymer materials.[2] The model is solved using a finite difference technique and an optimized schedule determined. The inverse-square scaling law of holographic diffraction given in Eq. 2 is also examined and shown to hold for photopolymer materials governed by the NPDD model for cases of gratings with weak diffraction efficiency.

$$\eta = \frac{\Gamma}{M^2} \qquad (2)$$

η is the diffraction efficiency, Γ is a material constant and M is the number of gratings (pages) stored. However for cases where a small number of high diffraction efficiency gratings the relationship is more complex. We examine this and comparisons to experimental data using the model showing a $\sin^2$ relationship to hold.

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[1] J. V. Kelly, F. T. O'Neill, J. T. Sheridan, "Holographic photopolymer materials: non-local polymerisation driven diffusion under non-ideal kinetic conditions," J. Opt. Soc. Am. B **22**, 407-416 (2005).

[2] J. T. Sheridan, M. R. Gleeson, J. V. Kelly, F. T. O'Neill, "Nonlocal polymerisation driven diffusion model based examination of the scaling law for holographic data storage," Opt. Lett. **30**, No. 3, 239-241, (2005).