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Title	The approximate model for holographic grating formation in photopolymers
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Publication date	2006-10-10
Publication information	Close, Ciara E., M. R. Gleeson, John V. Kelly, and John T. Sheridan. "The Approximate Model for Holographic Grating Formation in Photopolymers." Optical Society of America, 2006.
Conference details	Paper presented at Organic Photonics and Electronics (OPE), Rochester, New York, October 10, 2006
Publisher	Optical Society of America
Item record/more information	http://hdl.handle.net/10197/3402
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The approximate model for holographic grating formation in photopolymers

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Abstract: Nonlocal Polymerisation Driven Diffusion model describes grating formation in photopolymer materials and gives valuable insight into the processes taking place during formation. For weak exposures, NPDD reduces to a simple approximate model describing polymer concentration. ©2006 Optical Society of America

OCIS codes: (090.7330) Volume holographic gratings; (160.2900) Holographic recording materials; (210.2860) Holographic and volume memories

Photopolymer materials are of significant interest in the area of holographic data storage [1], particularly for W.O.R.M. storage applications. Analytic solutions for the NPDD, which describes grating formation in these photopolymers, have been found for simple physical cases [2]. However, more complex physical parameters lead to an increase in the mathematical complexity [3]. Approximate analytic equations are derived from the NPDD for weak exposures, where the polymer concentration is linear with respect to exposure. Since the recording process in holographic data storage typically involves multiple weak gratings through the same material volume, the simple analytic expression can be used to describe the polymer concentration. Results from both the NPDD and the approximate analytic equations are compared.

Assuming the temporal nonlocal response to be negligible, i.e. $R(x, x'; t, t') \rightarrow R(x, x')$, the 1-D NPDD equation is reduced to:

$$\frac{\partial u(x, t)}{\partial t} = \frac{\partial}{\partial x} \left[D(x, t) \frac{du(x, t)}{dx} \right] - \int_{-\infty}^t \int_{-\infty}^{\infty} R(x, x') F(x', t) [u(x', t)]^{\beta} dx' dt' \quad [1]$$

where $u(x, t)$ is free-monomer concentration, $D(x, t)$ is monomer diffusion coefficient, $F(x, t)$ is polymerization rate, $R(x, x')$ is nonlocal response function and β is the termination mechanism. Using Eq[1], the first harmonic of polymer concentration, $N_1(\xi)$, is determined, where ξ is related to exposure energy. A third order Taylor series expansion of $N_1(\xi)$, assuming $\xi \ll 1$, about $\xi = 0$ is taken. From this, assuming very short exposure, i.e. $\xi \ll 0.1$, the higher order terms can be neglected and we have [4]:

$$N_1(\xi \ll 0.1) \approx u_0(0) f_1 S_1 \xi \quad [2]$$

where $u_0(0)$ is initial monomer concentration, f_1 is a Fourier coefficient and S_1 is the nonlocal parameter.

The numerical values for 1st and 2nd order harmonic monomer and polymer concentrations are determined. These results are compared with the linear approximations to the NPDD model to establish the range over which the linear approximations are valid.

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