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Supplementary Information

Principles of voxel refinement in optical direct write lithography

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The intensity I of a Gaussian beam can be written as

$$I = \frac{1}{1+\left(z/z_0\right)^2}\exp\left[-2\frac{\left(r/w_0\right)^2}{1+\left(z/z_0\right)^2}\right],$$

where r and z are the radial and axial coordinates, w_0 is the beam waist and z_0 is the Rayleigh range. These relate to the numerical aperture (NA) of the focus by

$$w_0 = \frac{\lambda}{\pi}\frac{1}{NA}$$

and

$$z_0 = \frac{\lambda}{\pi}\frac{n}{NA^2},$$

where λ is the vacuum wavelength and n is the medium index of refraction. The absorption rate of an m-photon photoinitiator will be proportional to the intensity raised to a power m. In the presence of bimolecular termination, the steady state primary radical concentration is proportional to the absorption rate raised to a power α. Thus, the primary radical concentration is proportional to $I^{m\alpha}$. The full width at half maxima of this expression in the radial (i.e., transverse) and axial (lateral) directions are

$$D_{\mathrm{FWHM}} = 2w_0\sqrt{\frac{\ln 2}{2m\alpha}}$$

and

$$L_{\mathrm{FWHM}} = 2z_0\sqrt{2^{1/m\alpha} - 1}$$

which are denoted as equations (1) and (2).