Optical heating of nanorods in a laser tweezers

P.B. Roder[1], B.E. Smith[1], P.J. Pauzauskie[1] and E.J. Davis[2]

[1]Department of Materials Science and Engineering, University of Washington, Seattle, WA 98195-2120, USA
[2]Department of Chemical Engineering, University of Washington, Seattle, WA, 98195-1750, USA
Keywords: Electromagnetic heating, optical tweezers, nanorods
Presenting author email: davis@cheme.washington.edu

The capture of nanoparticles with the optical tweezers makes it possible to perform a variety of measurements of physical and chemical properties, but the high irradiances usually encountered can lead to excessive heating of the particles. In a previous paper we (Roder et al., 2012) analyzed the heating of nanowires illuminated at right angles to the wire axis using Mie theory to determine the heat source function. Here we extend the analysis to finite length nanorods illuminated end-on in a laser trap. The theoretical predictions of the rod temperature are compared with optical tweezer studies which involve measurement of the Brownian motion of trapped particles using the methods of Peterman et al. (2001) and Marago et al. (2008) to determine the particle temperature.

The temperature distribution in a circular nanorod satisfies the energy equation given by

$$\frac{\partial T}{\partial t} = \alpha \nabla^2_{r,\theta,z} T + S(r,\theta,z) \ , \qquad (1)$$

in which α is the thermal diffusivity of the rod, and $S(r,\theta,z)$ is the volumetric rate of heat generation, which must be determined from the internal electric field, that is,

$$S(r,\theta,z) = \frac{1}{2\rho C}\sigma(\mathbf{E}\cdot\mathbf{E}^*) \ , \qquad (2)$$

where ρ is the particle density, C is its specific heat per unit mass, σ is its electrical conductivity, which is a function of the complex refractive index of the particle. The electric vector **E** and its complex conjugate **E*** depend on the optical characteristics of the irradiation. It is assumed that the heat source is not a function of time, and for the special case of infinitely long cylinders it is not a function of the axial position, z.

Equation (1) has been solved for boundary conditions and initial conditions appropriate for a rod (or wire) trapped in a stagnant fluid for three cases of possible applications: (i) illumination at right angles to the cylinder axis, the case examined by Roder et al. (2012), (ii) illumination of the lower end of a highly absorbing rod by a plane wave, and (iii) the more general case of a rod illuminated by a plane wave propagating in the z-direction.

Examples of the dimensionless source function and temperature distribution for case (i) are shown in Figures 1a and 1b, respectively, for a strongly absorbing carbonaceous rod. In this case Mie theory was used to compute the internal electric field, and the dimensionless source function is seen to have a complex structure of peaks and valleys. The dimensionless temperature distribution, $(T-T_\infty)/T_\infty$, is seen to be highly non-uniform.

Computations for nanoparticles show that even though the heat source function can be very non-uniform, the temperature can be uniform due to internal conduction, eliminating the possibility of photophoresis. For a carbonaceous rod with the temperature distribution shown in Figure 1b photophoresis can be expected.

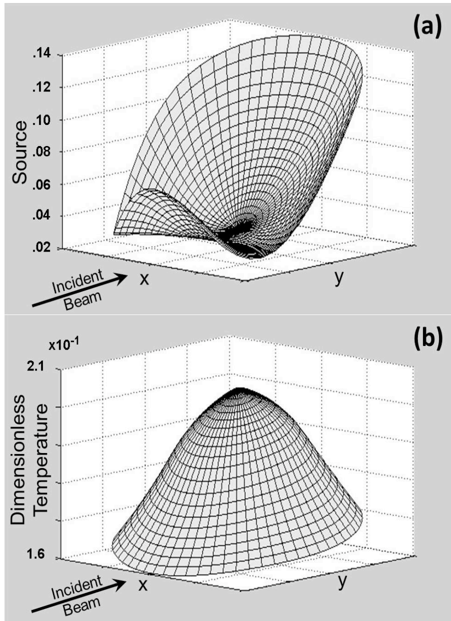

Figure 1. The dimensionless source function (a) and dimensionless temperature distribution (b) for a carbon rod with a radius of 100 nm in air irradiated at 1,000 W/cm^2 at a wavelength of 488 nm .

For case (ii), which applies to strong absorbers such a carbonaceous particles, we have applied the Fresnel equations to obtain an approximation for the internal field, and used that in the general solution of the energy equation to determine the temperature distribution. Very high temperatures are predicted for the high irradiances usually used for laser traps. For case (iii), which is a much more difficult problem, we have used numerical methods to determine the internal electric field, and then inserted the results in the general solution of Eq. (1).

Roder, P.B., Pauzauskie, P.J. and Davis, E.J.(2012) *Langmuir* **28**, 16177-16185.

Peterman, E.J., Frederick, G. and Schmidt, C.F. (2003) *Biophys. J.* **84**, 1308-1316.

Marago, O.M., Jones, P.H., Bonaccorso, F., Sardaci, V., Gucciardi, P.G. Rozhin, A.G. and Ferrari, A.C. (2008) *Nano Letters* **8**, 3211-3216.