Comparison of Optical Powerlimiting in Bacteriorhodopsin and Azo-Benzene Films

Jagadish Chandra Saraswatula[1], Shuvan Prashant Turaga[1], B.Raghavendra Prasad[2], and S.Sivasankara Sai[1]

[1] Department of Physics, Sri Sathya Sai University, Prasanthinilayam 515134, India
[2] Indian Institute of Astrophysics, Hoskote, Bangalore, India

Abstract. In this paper a comparison of the optical power-limiting characteristics of Bacteriorhodopsin (bR) and Azobenzene films is reported.An attempt is made to find out the technique which gives best powerlimiting for each of the materials. An input pump of 532 nm was used to study the first order self-diffracted output. Input beam intensity is varied over two orders of magnitude and the clamped output is measured in both the cases. The threshold intensity of limiting is governed by saturation intensity of excited state of the films and hence can be varied by choosing films of different upper state lifetimes. In both cases the output was clamped at the eye safe level of about 0.1 mW/cm^2 but threshold intensities differ.

1 Introduction

Since the development of high power lasers, it has become essential for the development of such devices to protect human eye and optical sensors from intense laser beams. Optical power limiters (OPL) are nonlinear devices, which exhibit linear transmittance at low intensities and strongly attenuate the beam at high intensities. Early optical limiters for cw lasers were based on thermal lensing phenomenon. Other techniques such as nonlinear absorption, photo refraction, nonlinear scattering, thermal beam spreading, excited state absorption, two-photon absorption, photoinduced anisotropy have been proposed in the literature [1–6]. Most of these techniques are for the high intensity cw and pulsed lasers and are found to have a limiting threshold around 0.1 J/cm2. There is also need of optical limiters for low power cw lasers because even laser pointers with power in the 1-5 mw range can damage the human eye if directly exposed in less than 0.25 seconds. CW optical limiters using azobenzene and bR films have been demonstrated recently [7, 8]. In the case of bR, self-diffraction technique has been used. For the azobenzene case, the transmittance of an input beam that passes through the film between two crossed polarizers is enhanced at low intensities and clamped at high intensities. In this paper, comparison of OPL characteristics of bR and azobenzene films is reported based on self-diffraction technique.

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Bacteriorhodopsin is a naturally occurring transmembrane protein found in living systems that converts light energy into metabolic energy by pumping protons across the cell membrane [9]. It is related to visual pigment rhodopsin contained in the cone cells of human retina. bR has received considerable attention due to its potential application in real time holography, optical pattern recognition and nonlinear effects [9]. bR displays a characteristic broadband absorption profile in the visible spectral region and when the molecule absorbs light it undergoes several structural transformations in a well-defined photocycle 10. Here we have considered only two (B and M) states for the bR photocycle, as the lifetimes of the other states (K, L, N, O, J) are in picosecond to microsecond scale. This is negligible in comparison to the M state lifetime of the order of milli seconds. Upon excitation with photons (wavelengths 500-600 nm), the molecule goes through a series of short-lived intermediate states to the relatively long-lived M state. The M state can revert to the initial B-state via thermal relaxation process (typically in the order of milliseconds) or by a photochemical process (typically in the order of nanoseconds) upon excitation with the blue light. The lifetime of M state depends on the re-protonation process and can be varied from milliseconds to tens of seconds [10].

Azobenzene also possesses optical properties of both trans-cis photoisomerization and photoinduced reorientation. It has a broad absorption band with a maximum absorption at 487 nm. The films absorb light in UV region around 240 nm strongly, which originates from the absorption of the PMMA polymer. In the absence of light the azobenzene exists in the trans form that is stable with an elongated structure. The photoinduced cis molecules have a bent shape and can revert back to the trans form by thermal or photo-assisted isomerization. The length of the azobenzene segment in the trans form is approximately 1.0 nm whereas that of the cis is approximately only 0.56 nm.

2 Materials and Methods

Azobenzene film used in our studies contains azobenzene molecules embedded in polymer matrix of PMMA (poly methyl metha acrylate). Bacteriorhodopsin film used was purchased from Munich Innovative Biomaterials (MIB), GmbH. The absorption spectra of bR and azobenzene are shown in figure 1(a) and 1(b) respectively. The technique of self-diffraction is used to study the optical power limiting characteristics of azobenzene and bR films. The experimental set up is shown in figure 2. A 532 nm diode laser was used as the input beam. It is split into beams with unequal intensities, which interfere on the film at a very small angle (less than 10 degrees). This creates a periodic spatial concentration distribution of B and M states in bR and cis and trans states in azobenzene. In the places of constructive interference bR is driven to M and in regions of destructive interference no photochemistry is initiated. The spatial concentration of distribution of bR and M (cis and trans) states can be viewed as a spatial modulation of materials adsorption coefficient and index of refraction. This absorptive grating diffracts the incoming beams. The 1st order diffracted beam is

passed through a slit and made to fall on a detector whose output is given to signal analyzer (IWATSU) for noise free detection.

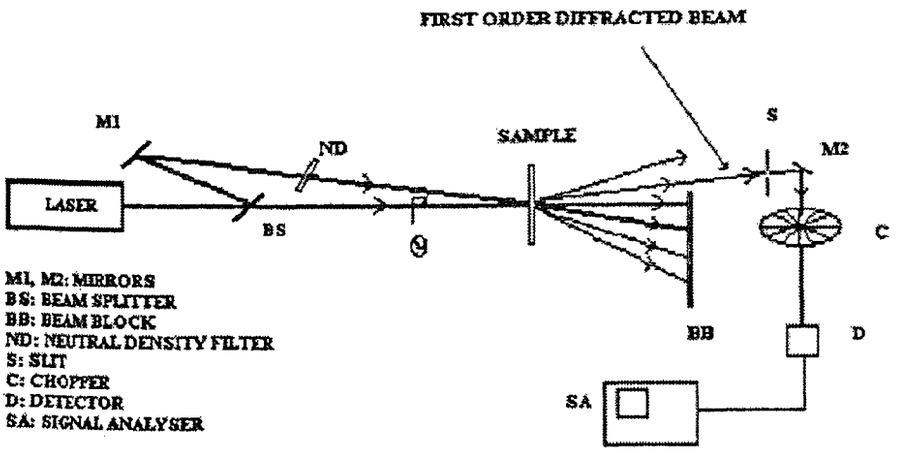

Fig. 1. Experimental setup for self-diffraction experiment.

The diffraction efficiency η for an absorptive grating is defined as the ratio of the diffracted light intensity I_{out} to the input beam intensity I_{in}. The diffraction process can have both absorption and a phase component. So the diffraction efficiency is given by

$$\eta = I_{out}/I_{in} = \eta_{abs} + \eta_{phase} \tag{1}$$

The total diffraction efficiency is given by

$$\eta = exp[-2d\alpha_0/cos\theta] * [sin2(\pi dn_1)/\lambda cos\theta) + sinh2(d\alpha_1/2cos\theta)] \tag{2}$$

The nonlinear saturation behavior is introduced into n_1 and α_1 through the equation

$$\alpha_1 = \alpha_{1o}[I_s/I_s + I_{in}]^{1/2} n_1 = n_{1o}[I_s/I_s + I_{in}]^{1/2} \tag{3}$$

Then the simplified nonlinear diffraction efficiency is given by the equation

$$\eta_{nl} = exp|-2d\alpha_0/cos\theta| * d2[\pi 2nl0_2 + (\lambda\alpha_{10}/2)^2]/4\lambda_2 cos2\theta * I_s/(I_s + I_{in}) \tag{4}$$

where,
α_o = absorption coefficient of the material in dark,
d = thickness of the film,
λ = wavelength of the incident beam,
I_{in} = input intensity,
I_s (= h $v/\sigma\pi$) is the saturation intensity of the upper state in the film,
σ = absorption cross-section of lower state,
τ = upper state lifetime,
α_{lo} = effective amplitude absorption coefficient at low intensities,
n_{lo} = effective refractive index coefficient at low intensities.

3 Results and Discussion

The optical power limiting characteristics of bR and azobenzene are shown in figures 3 (a) and 3 (b) respectively. The dots are the data points and the solid line indicates the second order polynomial fit. In the case of bR, the clamping

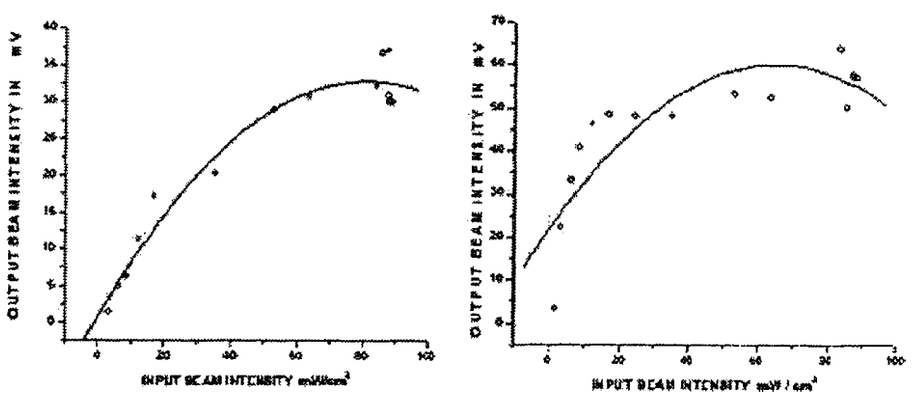

Fig. 2. Optical power limiting characteristics of (a) bR and (b) Azobenzene.

intensity was found to be 0.05 mW/cm^2 (= 32.3 mV) for a threshold intensity of 83.67 mW/cm^2. For the azobenzene case, the clamping intensity was found to be 0.13 mW/cm^2 (=58.02 mV) for a threshold intensity of 87.478mW/cm^2. Since bR has maximum absorption at 532 nm, the clamping intensity in the case of bR is small compared to that of azobenzene (maximum absorption at 487 nm). The threshold for limiting the output depends on two parameters.
(i) Saturation intensity of upper state which in turn depends on its lifetime. Therefore films with different lifetimes can be chosen to obtain different threshold levels.

(ii) The ratio of the intensities of the two beams. This is an important factor because the diffraction efficiency is maximum only when the intensities of the two beams are equal. So this parameter can be varied to obtain the desired output limiting levels easily.

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References

1. Yuhua Huang, Georgios Siganakis, Moharam M G and Shin-Tson Wu, Appl. Phy. Lett, 85 (2004) 5445.
2. Jin Z, Huang L, Goh S H, Xu G and Ji W, Chem. Phys. Lett. 352, (2002) 328.
3. Hollins R C, Current opinion in Solid State and Material Science. 4 (1999) 189.
4. Sun Y P and Riggs J E, Int. Rev. Phys. Chem. 18 (1999) 43.
5. Joshi M P, Swiatkiewicz J, Xu F, Prasad P N, Reinhardt B A and Kannan R, Opt. Lett. 23 (1998) 1742.
6. Hernandez F E, Zang S, Van Stryland E W and Hagan D J, Opt. Lett. 25 (2000) 1180.
7. Narayana Rao D, Chandra Yelleswarapu S, Sri-Rajasekhar Kothapalli, Rao D V G L N and Brian Kimball R, Optics Express, 11 (2003) 2848.
8. Wu P, Reji Philip, Laghumavarapu R. B., Devulapalli J, Rao D V G L N, Kimball B, Nakashima M and DeCristafano B.S, Appl Opt, 42 (2003) 4560.
9. Rao D V G L N, Aranda F J, Chen Z, Akkara J A, Kaplan L D and Nakashima M, J. Nonlinear Opt Phys, Mat 5 (1996) 331.
10. Birge R R, Parsons B, Song O W and Tallent J R, Department of Chemistry and Keck W M Center for Molecular Electronics, Syracuse University, Syracuse
11. Kogelnik H, Bell Sys. Tech. J. 48 (1969) 2902.