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All-optical switching characteristics of metalloporphyrins

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Abstract

We present all-optical switching in Zinc (II) tetraphenylporphyrin (ZnTPP) and Vanadium (IV)-oxide tetraphenylporphyrin (VOTPP) using pump probe method. A cw probe laser beam of 633 nm passing through the dye solutions is switched by a 20-ns pulsed pump laser beam of 532 nm. Our results show that there is an optimum value of concentration of the medium for which maximum modulation of the probe beam can be achieved. Probe beam modulation saturates after a certain value of pump intensity. Switch 'off' and 'on' time for VOTPP are ~1.5 and ~2.5 μs, respectively and for ZnTPP, respective times are ~200 ns and ~3.5 μs. Experimental results have been explained by doing a theoretical analysis based on nonlinear intensity induced excited state absorption using the rate equation model. Our analysis indicates that in VOTPP the long switch off time could be due to the existence of an intermediate state between the first singlet and triplet state.

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1. Introduction

Considerable research efforts are directed towards all-optical molecular devices for information processing and storage that offer advantages of small size and weight [1,2]. Metalloporphyrins are interesting chromophores due to their large nonlinearity and amenability to tailoring of their properties by different techniques to develop better materials for device applications [3–12]. Use of metalloporphyrins due to its reverse saturable absorption (RSA) characteristics has lead to the development of optical power limiters [11–15]. An optical limiter is a device that strongly attenuates optical beam to a threshold level at high intensity while exhibits linear transmittance at low intensity [16]. Such devices are used for protecting human eye and optical sensors from damage due

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to exposure to intense radiation. For optical limiting at resonance the primary mechanism is RSA which is observed when absorption cross-section of the excited state is higher than that of the ground state [16,17]. Different metalloporphyrins have been studied so far for optical limiting properties. Vanadium (IV)-oxide tetraphenylporphyrin (VOTPP) and Zinc (II) tetraphenylporphyrin (ZnTPP) show enhanced nonlinear optical properties [12]. Nonlinear optical properties of ZnTPP have been analyzed in detail but there are fewer reports on VOTPP.

All-optical switch is a fundamental building block of information processing for the future. All-optical switching has been reported in metallophthalocyanines [18,19], fullerene (C_{60}) [20–22], polydiacetylene [23,24], bacteriorhodopsin [25–28], PVK and azobenzene dyes [29] using pump probe method. In this paper we experimentally present all-optical switching in ZnTPP and VOTPP in toluene solution using pump probe method. We used a pulsed laser of 532 nm as a pump beam and a cw laser of 633 nm as probe beam. Effect of variation of pump power and concentration of the medium on switching characteristics has been studied. Switching results have been explained by carrying out a theoretical analysis based on the rate equation model.

2. Experimetal results

The chemical structure and energy level diagram of metalloporphyrin are shown in Figs. 1(a) and (b), respectively [3,13]. The chemicals ZnTPP and VOTPP from M/s Aldrich Corporation were dissolved in toluene with concentration of 1.3×10^{-3} and 6.4×10^{-4} M, respectively, and placed in a 1 mm thick glass cell. Absorption spectra of ZnTPP and VOTPP show significant ground state absorption at 532 nm and lower absorption at 633 nm as shown in Fig. 2(a). Excited triplet state absorption spectrum of ZnTPP shows a broad absorption over a wide visible region [4,8]. We considered 532 and 633 nm as pump and probe wavelengths, respectively. For VOTPP, the excited state absorption spectra are not known. The fluorescence spectra of ZnTPP and VOTPP excited by a cw 532 nm vanadate YAG laser are also shown in Figs. 2(b) and (c) respectively. The measured fluorescence lifetime (full width at 1/*e* point of maximum) of ZnTPP and VOTPP are ~2.7 and ~45 ns, respectively, as shown in Figs. 3(a) and (b).

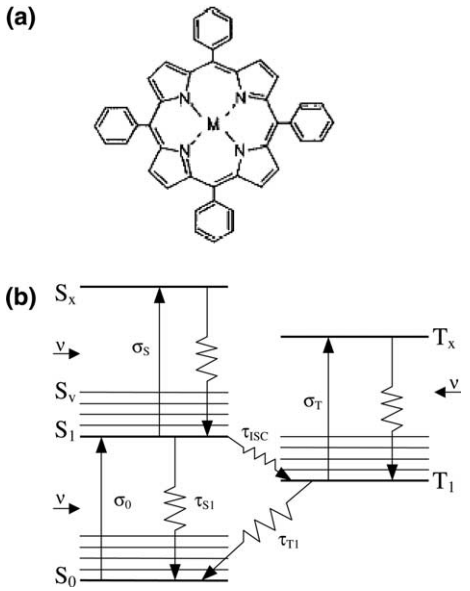

Fig. 1. (a) The chemical structure of metalloporphyrin, where M = Zn and VO and (b) energy level diagram of metalloporphyrin.

A He–Ne laser of 633 nm was used as probe beam and a flash lamp pumped frequency doubled Q-switched Nd:YAG laser of 532 nm, 20 ns pulsewidth and 1 Hz repetition rate was used as the pump beam. Pump and probe beams were focused by lenses L_1 and L_2, respectively of 20 cm focal length. To ensure pump and probe beam overlap on the sample, we kept sample before the focus of lens L_1 and at the focus of L_2. Probe signal was detected using photodiode. Pump and probe intensities on the sample are ~5 MW/cm^2 and ~5 W/cm^2, respectively. The detection instrument rise time is ~200 ns.

Figs. 4(a) and (b) show all-optical switching characteristics of ZnTPP and VOTPP, respectively. Initially, transmission of the probe beam is in switch-on state because of lower linear absorption. When the sample is pumped by a strong, pulsed laser beam, it excites molecules