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High-contrast all-optical switching with Pt:ethynyl complex

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Abstract

We have theoretically analyzed all-optical switching in Pt:ethynyl complex based on nonlinear excited-state absorption. A detailed analysis for Pt:ethynyl complex has been presented based on rate equation approach. It is shown that a pulsed pump laser beam at 355 nm switches the transmission of a cw probe laser beam at 633 nm through a Pt:ethynyl sample. The effect of various parameters, such as pump pulse width, peak pumping intensity, normalized parameter $\beta(\sigma_{T_1P}\, NL)$, transition times of $S_1 \rightarrow S_0$ and $S_1 \rightarrow T_1$ states and lifetime of triplet state, on switching characteristics has been analyzed in detail. It has been shown that the probe beam can be completely switched off (i.e. 100% modulation) by a pulsed pump laser beam at 50 kW/cm^2. These results have been used to design all-optical NOT and the universal NOR and NAND logic gates with multiple pump laser pulses.

Keywords: Nonlinear optics; All-optical switching; Pt:ethynyl complex; Reverse saturable absorption

1. Introduction

Recent years have witnessed dramatic progress in the design of all-optical switching devices for ultrafast high-bandwidth optical communication and computing [1,2]. Current interest has focused on molecular devices that offer advantages of small size and weight, extremely low propagation delay, high intrinsic speed and ability to tailor properties to suit the specific device configurations [2–4]. A promising mechanism of all-optical switching is the nonlinear reverse saturable absorption (RSA), in which a cw probe beam corresponding to the peak absorption of an excited state is switched by a pulsed pump beam at the peak absorption of the ground state. Recently, all-optical switching based on nonlinear excited-state absorption has been demonstrated in different molecular configurations such as liquid crystals, rubidium vapor, organometallic phthalocyanines, polydiacetylene, poly (methyl methacrylate), PVK and azobenzene dyes, polymethine dye, 2-(2′-hydroxyphenyl) benzoxazole, fullerene C_{60} and naturally occurring retinal protein bacteriorhodopsin [5–14,20–27].

Organometallic compounds are prospective nonlinear materials, as they exhibit large optical nonlinearities. Organometallic compounds have a number of advantages over organic compounds. The addition of a metal contributes to the delocalized π-electron system and adds a number of optical transitions that do not occur in organic compounds such as d–d electronic transitions, metal to ligand charge transfer, intra-ligand and ligand to metal charge transfer, resulting in very large extinction coefficients [15–20]. These metals possess triplet levels that are coupled by inter-system crossing

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to singlet transitions, which leads to strong RSA [15–22].

Recently, we have shown all-optical spatial light modulation in Platinum:ethynyl complex [bis((4-(phenylethynyl) phenyl) ethynyl) bis (tributylphosphine) platinum (II)], which exhibits strong RSA over a wide visible range [15]. The structure of Pt:ethynyl molecule is as shown in Fig. 1. It also exhibits a large absorption cross-section of the ground state at its peak absorption wavelength (355 nm), fast transitions (~μs), no overlap between the ground state and the triplet state absorption spectra at their respective peak wavelengths, and the flexibility to tailor its properties [16–19]. Optical limiting response in Pt:ethynyl complex has been reported, which is both broad band across the visible and effective over pulse lengths ranging from picoseconds to hundreds of nanoseconds [17,18]. The above features make it a good prospective candidate for all-optical switching based on nonlinear excited-state absorption. Hence, the aim of this paper is (i) to theoretically analyze all-optical switching in Pt:ethynyl complex, (ii) to study the effect of various parameters on the modulation characteristics and (iii) to investigate its application to realize all-optical logic gates.

The simplified energy-level diagram of Pt:ethynyl complex is as shown in Fig. 2. This five-level model is adequate to explain nonlinear absorption over a wide range of intensities. For Pt:ethynyl complex, the linear absorption spectra show a strong absorption peak at 355 nm with a tail that vanishes at ~550 nm while the triplet state absorption spectrum shows absorption peak at 600 nm and negligible absorption at 355 nm [17,18]. A 355 nm laser radiation that corresponds to third-harmonic wavelength of Nd:YAG laser can be used to

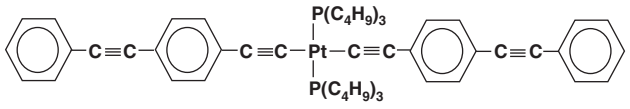

Fig. 1. Structure of Pt:ethynyl molecule.

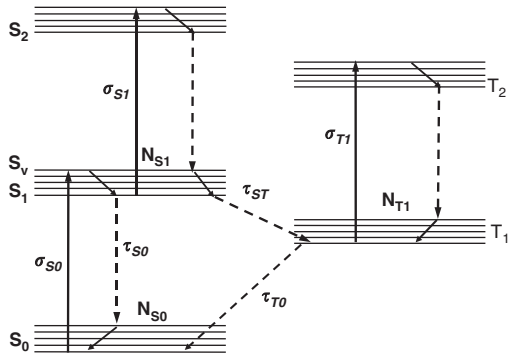

Fig. 2. Energy-level diagram of Pt:ethynyl complex.

excite molecules from ground state S_0 to a vibrational state S_v of the first electronic excited state S_1. The excited molecules rapidly decay in picosecond time scale to S_1 state from where they make a transition to the S_0 and T_1 state with a relaxation time of ~330 ps. The molecules in S_1 and T_1 states can be further excited to higher-energy states, but since their lifetimes are extremely short (<ps), the populations of these higher-energy levels is neglected in our analysis [16–19].

All-optical switching has been analyzed by considering the transmission of a weak cw probe laser beam at 633 nm that corresponds to the He–Ne laser wavelength, which is near to the peak absorption wavelength of the triplet state (T_1) through Pt:ethynyl complex, which is switched by a pulsed pump laser beam at 355 nm that corresponds to the maximum ground state absorption. The switching characteristics have been analyzed using the rate equation approach. The effect of various parameters, such as pump pulse width, peak pumping intensity, normalized parameter $\beta(\sigma_{T_1P}\,NL)$, transition times of $S_1 \rightarrow S_0$ and $S_1 \rightarrow T_1$ states and lifetime of triplet state, on switching characteristics has been analyzed in detail. Further, the results have been used to design all-optical NOT and the universal NOR and NAND logic gates with multiple pump laser beams, that are the basic building blocks of computing circuits. The proposed designs would be useful in all-optical information processing due to high switching contrast, fast operation, small size, simple digital operation and flexibility in optimizing the design.

2. Theoretical model

We consider Pt:ethynyl complex exposed to a light beam of intensity I'_m, which modulates the population densities of different states through the excitation and de-excitation processes. A schematic diagram of all-optical switching of a cw probe beam by a pulsed pump laser beam in the nonlinear medium is as shown in Fig. 3. These light-induced population changes can be described by the rate equations in terms of the photo-induced and thermal transitions of different levels

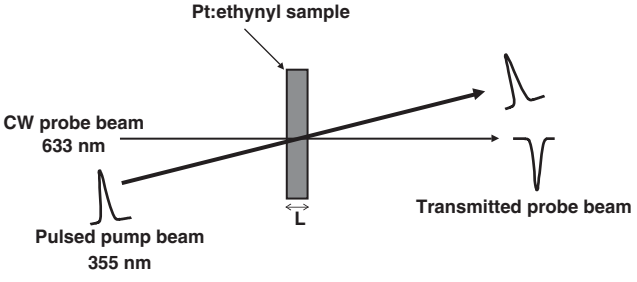

Fig. 3. Schematic diagram of all-optical switching.