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APPLICATION OF ORGANIC THIN FILMS TO A NEW ALL-OPTICAL DEMULTIPLEXING DEVICE

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Abstract We investigate the utilization an organic thin film of a phase II vanadyl phthalocyanine (VOPc), in a new high speed all-optical demultiplexer.

INTRODUCTION

Although many fundamental research programs are directed at developing organic materials with nonlinear optical properties suitable for applications in optical signal processing, there have been few material successes which have achieved commercialization. It is therefore important that efforts be made, in parallel to the fundamental studies, to either develop new devices which use nonlinear organic materials or improve existing devices by using organic materials

In this article we discuss how a new high speed all-optical demultiplexer known as a Terahertz Optical Asymmetric Demultiplexer (TOAD),[1,2] relaxes the constraint of ultra-fast recovery after photo-excitation, which is often assumed necessary for nonlinear materials used in high speed devices. We then discuss, and present some data on the possible application of organic materials in this device. In particular, we investigate the utilization of a phase II film of vanadyl phthalocyanine (VOPc), which has large optical nonlinearities at the communication wavelength 850 nanometers.

FOMs for Nonlinear Optical Materials and Device Design

There are various types of FOMs that are used to quantify the usefulness of nonlinear materials, or devices based on these nonlinear materials. However, care must be taken

when designing a device to not discard a candidate material based on a material FOM. For example the thermo-optic effect describes thermally induced refractive index changes when significant energy is optically absorbed by a material over a time which is short compared to the material's thermal relaxation time.[3] The magnitude of these index changes depends on the material's linear absorption, α, and heat capacity C_p.

Both organic and inorganic materials experience thermal index changes, however in many semiconductor devices, such as optical amplifiers or lasers, the thermal nonlineariites are avoided by heat-sinking the semiconductor material to a cooling element and thus effectively increasing the material's heat capacity. This is a simple example of how device design bypasses a problem implied by a material's optical constants

Another material figure of merit often used when describing an optically nonlinear material is $\chi^{(3)}/\alpha\tau$. Here $\chi^{(3)}$ quantifies the optical nonlinearity, and t is the relaxation time of the optically induced electronic nonlinearity. It is often assumed that for the case of high speed operation of a nonlinear optical device, the device's temporal resolution cannot be shorter than the relaxation time of the optical material the device is based on. The demultiplexer described briefly in the next section avoids this apparent limitation by virtue of its design.

The Terahertz Optical Asymmetric Demultiplexer (TOAD)

A TOAD is a new high speed all-optical demultiplexer which consists of an optical loop mirror, with an internal optically nonlinear element (NLE), such as a semiconductor structure or device, and an intraloop 3dB coupler which is used to inject an optical control pulse.[1] This device behaves as an optical gate which opens for a short time after receiving a control pulse, and after some reset time can operate again. The reset time is typically several hundreds of picoseconds, while the "open" time can be as short as about a picosecond. As explained in reference 1 it is only the TOAD's reset time which is limited by the NLE's recovery time. But in many optical communications applications,[2] where pulses in a given data channel are separated by hundred's of picoseconds or more, this is not a problem.

The resolution of the TOAD is approximately $2\Delta x/c$, where Δx is the distance from the loop center to the near edge of the NLE, and c is the speed of light in fiber (see inset fig. 1). However when temporally short pulses, and small Δx values (< 1 mm) are

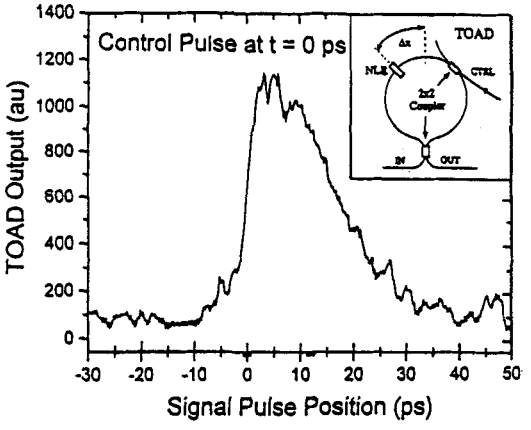

FIGURE 1. Time resolved transmission window of the TOAD. Inset: The TOAD.

used, the transit time of light through the NLE becomes a limitation. This can be seen in figure 1 which shows a time resolved measurement of the transmission of a TOAD that has a 1mm long DC-biased semiconductor optical amplifier (SOA) as the NLE. In this data 2 ps pulses were used, and the source of the nonlinearity was a control pulse-induced gain depletion of the SOA.[2] This gain depletion occurs on the order of a ps, and recovers in about 800ps. In the figure after the control pulse arrives the TOAD goes into a 10 ps long transmitting state. Note that this transmission "window" has a rising edge, a plateau, and a less steep falling edge. The length of the rising edge is 2 ps, and is limited by the pulses used. But the duration of the falling edge is equal to the transit time of light through the SOA. In this case the 1mm long SOA's refractive index of about 3.5 results in approximately a 12 ps falling edge.

There are several possible ways to improve the TOAD which was used to produce the data in figure 1. The first is to use a passive NLE rather than an active NLE. This eliminates the need for, and cost of, the sophisticated regulated current source and temperature controller used by the SOA. Second, by using a physically shorter NLE a smaller transmission window can be achieved. In the remainder of this paper we report some work in progress regarding the use of an organic thin film, VOPc, as a possible NLE in the TOAD.

VOPc Steady State and Transient Optical Spectra

Figure 2 shows the thin film absorbance spectra of an evaporated VOPc thin film, prepared using a Knudsen cell, before and after 16 hrs of thermal treatment at 160C in a dry nitrogen atmosphere.[4] The shift in the peaks is due to a phase transition in which the molecules go from a cofacial alignment along the metal-oxo bond (phase I), to a slipped stack arrangement (phase II). Most importantly, this second phase has a larger absorption at 850nm. This structure also possesses long term stability.

The inset in figure 2 shows VOPc pump-probe data taken on an approximately 200 angstrom thin film. This spectrum has the required features for use in the TOAD. That is, it has a sharp rise time on the order of the exciting pulse (600 fs), and a relatively long, slow decay. These data were taken using a 1 KHz amplified femtosecond Ti:S laser system. This low repetition rate of 1 KHz ensured that no thermal component was present in the VOPc optical response. The experimental setup for this measurement, as

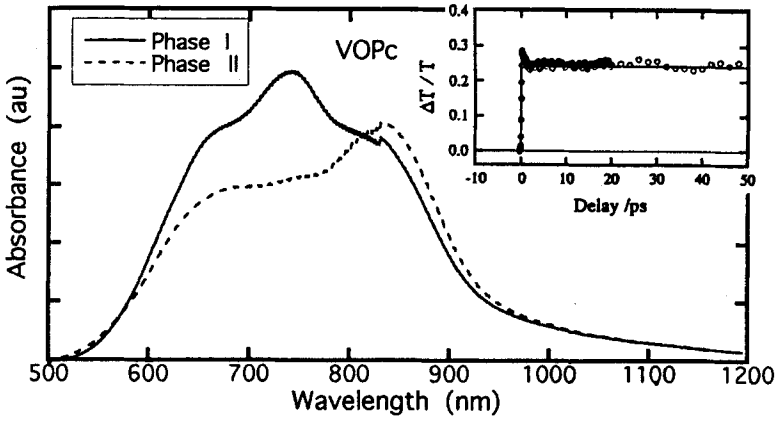

FIGURE 2. VOPc absorption spectra before (phase I) and after (phase II) heat treatment. The inset shows the samples's transient transmission changes.

well as the detailed temporal spectral features, such as the sharp peak centered at zero time delay, are discussed in detail elsewhere.[4] To check that the optical response was significant at the communication wavelength 850 nm, the pump wavelength was tuned nearby to about 820 nm and the sample was probed at 830 nm.

Thermal Nonlinearity and Average Power Constraints

Pump-probe measurements usually involve energies on the order of a micro-joule, spot sizes of 50 - 200 microns, and beam qualities which are not always Gaussian in their intensity distribution. Scaling arguments must then be imposed to gauge the suitability of the nonlinearity in an optical system where picojoule energies are available in waveguides with several micron cross sections, and well-defined optical modes. In an effort to make measurements more directly meaningful for optical systems, the simple setup shown in the inset of figure 3 was used. Here the 82 MHz output of the femtosecond laser was input directly into a 2X2 fiber-optic coupler. The coupler splits the light into two equal intensity pulse trains, with one going to a reference detector, and the other focused to approximately a 10 micron diameter spot on the VOPc thin film. By changing the input intensity the sample's transmission as a function of input intensity was determined. This is shown in figure 3. Notice that the transmission begins to increase at pulse energies of just a few picojoules, also at about 30 pJ thermal damage occurred so that as the input energy was decreased (downward arrow in fig. 3) the upward curve was not reproduced.

To determine whether the transmission changes were due to thermal or electronic nonlinearities we input a CW beam of the same average power as the modelocked beam, into the fiber. When the input intensity was then increased the curve of figure 3 was

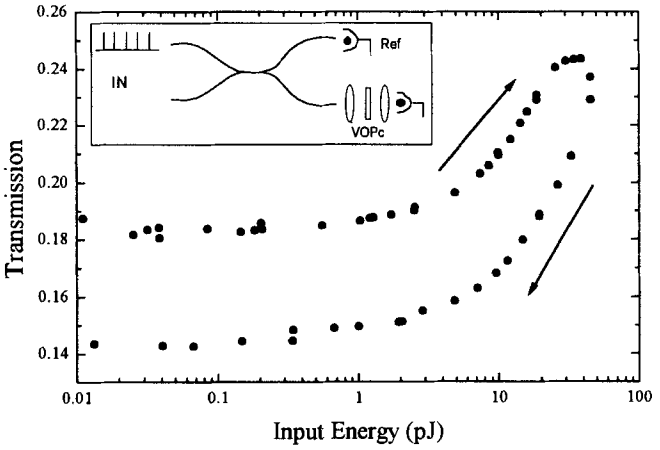

Figure 3. Fiber transmission measurement. Inset: Experimental setup.

reproduced. This indicates that the nonlinearity responsible for the data in figure 3 is thermal, and not electronic in nature. However, it is not clear whether or not this thermal nonlinearity is masking an additional electronic nonlinearity.

Future Work and Conclusions

In this paper we have described a new ultrafast all-optical demultiplexer called the TOAD. Due to its design, and not the use of some exotic material, this device has a resolution that depends on the optical response of the nonlinear element it uses and not on this element's optical recovery time. Thus the TOAD relaxes the constraint of ultra-fast recovery after photo-excitation often assumed necessary for nonlinear materials used in high speed devices.

We also presented some data from work in-progress concerning the use of VOPc as the nonlinear element in a TOAD. Currently we have identified that even at the very low pulse energies used in optical communication systems thermal nonlinearities are present. In the future we intend to suppress these thermal nonlinearities which will then allow us to have access to the material's optical nonlinearities.

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