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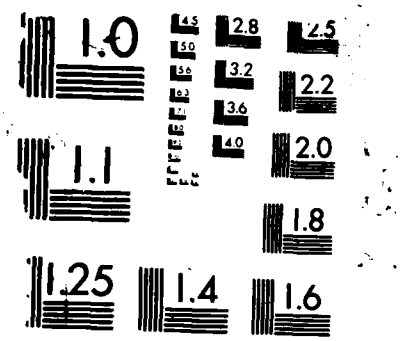

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Fundamental optical nonlinear processes based on X_2 and X_3 in different materials (liquids, polymers, and semiconductors) were investigated for size and speed. Ultrafast optical logic devices, switches, and processes based on these nonlinear optical materials were designed, built, and tested. Twenty one papers were published during this work in the period 1986-1987.

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Subpicosecond Optical Digital Computation using Phase Conjugate Parametric Generators

Senior Researchers: Professors R. Alfano, G. Eichmann, R. Dorsinville, and Y. Li

Ph. D. Graduate Students: P. Delfyett, L Yang.

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Progress Report

The purpose of the research program under grant AFOSR 84-0144 was twofold: to investigate basic fundamental optical nonlinear processes in different materials and use the acquired knowledge to design and build ultrafast optical logic devices, switches and processors. Substantial progress has been achieved in both areas.

A. Major Achievements

I. Device design and construction

(1) A fundamental logic switch, a nonlinear Sagnac interferometric switch has been proposed and experimentally demonstrated. The device improvement in auto-isolation of retroreflection has been noted.

(2) A modified switching device, a two port Sagnac interferometric switch (TPSIS) has been proposed. With two orthogonal polarization channels, the TPSIS can switch one of the two inputs to one of the two output ports. Various TPSIS based logic and arithmetic applications were described.

(3) For the reason that a ternary number set is an optimum set in terms of storage complexity, various binary coded ternary (BCT) optical arithmetic and logic computing methods have been investigated. The BCT representation has two advantages. First it allows the use of well developed binary optical components. Second, in comparison with other optical multivalued number encoding schemes, it conserves the optical space bandwidth product. Correspondingly, various BCT arithmetic and logic processing architectures and algorithms were introduced.

(4) A Fabry-Perot resonator with an active Sagnac interferometer as its retroreflector has been studied and the corresponding multistability results have been calculated. The device can be configured to be either an optical limiter, an amplifier, a logic or a memory element.

(5) An optical parallel computing method using polarization and hybrid encoded optical shadow-casting has been proposed. One major advantage of this technique over its conventional black/white and its theta modulation encoding counterparts is that it allows the multiple data operations that are essential to general purpose optical computing.

(6) An optical phase conjugation (OPC) logic device has been proposed. All three input ports are used to produce the spatially encoded logic output signal.

(7) A conditional symbolic modified sign-digit (MSD) arithmetic processing method using content addressable memory (CAM) has been proposed. Compared to other MSD processing methods, the new method has the faster processing speed.

(8) An electro-optical theta-modulation based A/D conversion technique has been proposed. Using an existing e-o waveguide deflector together with an array of precalculated geometrical masks, various non-cyclic binary codes can be generated. Other theta modulation based A/D conversion advantages found includes fast processing speed (ns or sub-ns), low conversion voltage (2-3 volts for each level), and compact geometry.

Fundamental research

The following highlights the major achievements during the past two years:

(1) We have demonstrated the use of the Raman induced phase conjugate technique (RIPC) both to obtain strong Raman signals and to measure relaxation times in liquids and solids using picosecond laser pulses[1-5]. We have obtained the picosecond RIPC spectra of carbon disulfide, benzene, nitrobenzene, nitrotoluene, calcite, and lithium niobate . This new time resolved spectroscopic method will not only allow to study the relaxation mechanisms of the materials used in new broadband switching devices but also can lead ultimately to the development of multispectral ultrafast optical processors.

(2) Using the phase conjugation and Kerr techniques we have measured, the magnitude and response time of the third order nonlinear coefficient χ^3 of polymers such as PMMI and 4BCMU (a polydiacetylene) at 532, 620, and 1064 nm. These measurements have shown that the nonresonant nonlinear optical coefficient of 4BCMU is at least two order of magnitude larger than CS_2 with a response time of less than 0.5 ps. At resonance the nonlinear optical coefficient can be several order of magnitude larger ($> 1000\ 10^{-11}$ esu) but an additional slow component (< 12 ps) appears in the Kerr relaxation process. These results confirm that polymers like 4BCMU appear to be perspective materials for future logic devices.

(3) Similar measurements were carried out with several semiconductors[2] such as ZnO, ZnSe, and CdS. The values of χ^3 measured were 5 to ten times larger than CS_2. However, the response times were in the nanosecond range.

(4) The decay time of the phase conjugate signal in ZnSe was observed to decrease with *increasing pump intensity*[2]. In wide band semiconductors several mechanisms are present and contribute to the transient four wave mixing process, i.e. bound electrons, free carriers and impurities. The decay dynamics will depend on which mechanism dominates. In ZnSe our measurements have shown that at relatively low intensities, near zero delay, the dynamics are due to the nonlinear response of bound and free carriers, while at long delay times, a slower decaying signal is observed due to recombination and diffusion of free carriers. The longer decay times at higher pump intensity indicates the presence of secondary impurity gratings which dominate the light scattering process. The impurity grating in ZnSe is due to the population of carriers in a shallow donor state which has a decay rate dependent on the population of carriers in a deep impurity level.

(5) A 2 ps real time four wave mixing technique was demonstrated to measure phonon lifetimes and nonlinear optical response times. In this technique three pulses of different frequencies, one very short < 2 ps pulse derived from a nonlinear supercontinuum at $\omega - \Omega$ (where Ω corresponds to a vibrational frequency) and two 30 ps laser pulses at ω

interact in the nonlinear medium to generate a fourth beam nearly phase conjugate to one of the laser beams at $\omega - \Omega$ The generated phase conjugate pulse is then sent to a streak camera and a video computer system to record its time profile. The decay time of the generated pulse is directly related to the phonon lifetime and the nonlinear response time. The resolution of the technique is limited by the streak camera and the duration of the short pulse (about 2 ps). The technique was used to determine phonon and vibrational lifetimes in carbon disulfide and calcite. The measured lifetimes agree with earlier measurements using different techniques. We plan to continue our investigations using this new method to determine the relaxation mechanisms in semiconductor and polymer samples.

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