This project examined the use of atomic vapors in an optical correlator for pattern recognition. The nonlinear optics of very thin atomic vapors was studied. This work allowed the demonstration of an optical correlator in a thin cesium vapor. This correlator was able to compare patterns of letters as well as random patterns. The patterns can contain up to $10^5$ pixel/cm$^2$ and the correlation is obtained in 10 microseconds. In addition, methods to improve the performance of the optical correlator were investigated. Experiments showed that motion of the atoms during the excited state lifetime of 30 nsec limited the smallest pixel size to about 30 microns. Two methods that were investigated to improve this resolution were the use of buffer gasses to confine the atoms and laser cooling the atoms to reduce their speed. One set of experiments showed that buffer gasses can either quench the excited state lifetime or limited diffusion of the excited state atoms. Another set of experiments began investigation of laser cooling techniques to slow the atomic motion.
Atoms For Logic

Final Progress Report

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The views, opinions, and/or findings contained in this report are those of the author and should not be construed as an official department of the army position, policy, or decision, unless so designated by other documentation.
A. Statement of the Problem:

The primary aim of this project is the use of atomic vapors for optical information processing. An optical correlator has many potential optical computing applications including; pattern recognition, military target identification, sorting of pharmaceutical pills or other parts, fingerprint identification, neural networks, matrix multiplication, etc. Atomic vapors have the ability to exhibit a sufficient optical nonlinearity so that a correlation containing $10^5$ pixels can be performed at a rate approaching $10^6$ per sec.

B. Summary of the important results:

There were a number of important results obtained during this grant period. The first result was a demonstration of building and using very thin atomic vapor cells with internal dimensions as small as 10 microns. Thin cells are important for use in an optical correlator since diffraction will limit the smallest pixel size. Most previous work with atomic vapors used cells that were at least 1 mm thick. A 1 mm cell can achieve a pixel density of $10^5$ cm$^{-2}$ while a 10 micron cell can achieve a pixel density that is 100 times larger. In addition, wall collisions become important in these thin cells. Wall collisions allow degenerate four wave mixing to be observed on transitions that are normally susceptible to optical pumping. Thin cells also allow the observation of light transmission in very dense atomic vapors for the first time, which will allow further investigations of a variety of predicted phenomena.

A theory of degenerate four wave mixing in a saturable absorber was developed for arbitrary input intensities. This theory can be used to examine the efficiency of using degenerate four wave mixing in a saturable absorber for use in an optical correlator.

An optical correlator was demonstrated using cesium atoms confined in a glass cell. This correlator operated at a power of a few mW/cm$^2$ and could perform a correlation on $10^5$ pixels/cm$^2$ in about $10^{-5}$ seconds. Correlation of letters and random patterns were demonstrated.

The pixel size in this correlator was limited to about 30 microns due to motion of the excited state atoms during their lifetime. We investigated the use of buffer gasses and laser cooling to reduce the excited state motion and therefore be able to achieve smaller pixel sizes and better efficiencies.

It was demonstrated that buffer gasses could quench and limit the diffusion of excited state atoms. One experiment showed that molecular gasses, such as nitrogen, could quench the excited state atoms. Another experiment demonstrated that it is possible to use degenerate four wave mixing to directly
measure for the first time excited state diffusion coefficients. Either of these buffer gas techniques can be used to increase the number of resolvable pixels in the optical correlator.

We are also looking into the use of cold atoms by laser cooling techniques. Cold atoms will have negligible motion; so that grating washout will not occur. This should allow a greatly improved the efficiency and pixel resolution in an optical correlator. Also, since cold atoms have negligible Doppler broadening, all the atoms will resonantly interact with the laser so that the efficiency may be able to be improved by one or two orders of magnitude. We investigated two techniques using laser-cooled atoms. The first method produces a cold cesium atomic beam using Stark effect compensation. The second technique is a new neutral atom trap that uses a focused CO₂ laser beam. This trap can confine cold atoms for very long periods of time due to low photon scattering rates.

C. LIST OF All PUBLICATIONs and TALKS:


9. "Enhancement of Degenerate Four Wave Mixing by Atom-Wall Collisions in Atomic Vapor", B. Ai,


21. "Measurement of the Potassium 4P Excited State Diffusion Coefficient in Xenon Gas using


D. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:
(1) Randall J. Knize, Principle Investigator, 1993-1997

Dave Glassner, 1993-1995
Bing Ai, 1993-1996
Jeng-Rong Yeh, 1993-1996
Tetsu Takekoshi 1993-1997

(2) Ph.D.'s Awarded,

Dave Glassner 1995
Bing Ai, 1996
Jeng-Rong Yeh 1996
Tetsu Takekoshi 1997

E. REPORT OF INVENTIONS (BY TITLE ONLY): None