PN-ACD-236

Cooperation in Applied Science and Technology (CAST) Final Report

April 21, 1997

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Dates of Visit April 1, 1996 - February 28, 1997
Dr Matveev remains in the host laboratory, supported by other funding

Objectives

The goal of Dr Matveev's visit was to initiate a collaboration on resonance ionization spectroscopy, specifically the Rydberg spectroscopy of Hg, in order to finds ways to obtain a very high ionization efficiency for the purpose of ultrasensitive detection of Hg and the development of highly selective and sensitive optical (photon) detectors

Research Summary

Dr Matveev had a very productive year in our laboratory The studies which were proposed were completed, others were begun and several new topics finished on the side A total of 11 papers were published or are in press We prepared two major proposals (to DARPA and NSF/DOE), which are presently under review, involving the resonance ionization imaging work and we have submitted one patent application Dr Matveev is presently continuing this work, paid by funds from the University of Florida Division of Sponsored Research, while we await the reviews of the submitted proposals

Resonance Ionization of Mercury

We began our studies with an evaluation of a resonance photon detector based on laser excited ionization in mercury vapor Figure 1 shows the ionization scheme used The idea is to provide one or two pump lasers to excite and ionize any atom which reaches the first excited state A photon entering an atomic population of Hg of sufficient number density will be absorbed with unity efficiency and subsequently ionized The detection takes place by providing an electric field to detect the charged pair which results Our initial studies proved that the efficiency could indeed approach unity and that single photoelectron detection was possible [1 2]

In a subsequent project using a pulsed electric field for detection, Dr Matveev discovered that it was possible to detect the ionization by optical means as well, via a mechanism of collisional energy exchange with an inert buffer gas (neon) [3 4] The excitation process is identical, involving initial resonance absorption of photons at 253 7 nm, followed by one or two step laser induced ionization The charged species which are produced, when accelerated in a pulsed electric field,

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Date November 19, 1996

To USAID Center for Development, Information, Evaluation

From Sharon Vandivere

Subject CAST final reports

At the suggestion of John Daly of USAID's Bureau for Global Programs, I am sending the enclosed final reports of projects conducted under the Cooperation in Applied Science and Technology (CAST) program The CAST program is funded by USAID and administered by the National Academy of Sciences As I receive additional final reports, I will be sure to forward to you

If you have any questions regarding the reports or the program, please contact me at 202-334-2644 or <ocee@nas edu>

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transfer energy to the buffer gas causing it to emit characteristic spectral lines This emission can be optically detected and provided the possibility of using the device as a actual image detector rather than only as a spectrally selective detector of photons

In order to maximize the efficiency of ionization we undertook a study of the spectroscopy of the mercury Rydberg States [5] The spectral characteristics of the Rydberg states (n=10-42) were observed Each principal quantum number was observed as a triplet, and after observing a quartet of lines for n=10, 11 and 12, these lines were assigned, from red to blue, as belonging to upper levels $^1P_1^0$, $^3P_2^0$, $^3P_1^0$, and $^3P_0^0$ These levels were studied as a function of variable applied high voltage between the collection electrodes and variable buffer gas pressure In this way, broadening and splitting caused by the influence of Stark effects and of increasing buffer gas pressure were observed for different n values These observations permitted us to choose the optimum pressure and voltage and excitation level for the most efficient ionization of Hg Along with these studies, we also carried out an evaluation of the temporal behavior of the mercury laser enhanced ionization signal [6 7]

During the course of this work, we found that the sensitivity of the ionization process detection could be enhanced by up to 8000 fold by inducing an avalanche effect in the ionization cell This led to the development of a new method for the detection of laser enhanced ionization We studied the effect of temperature on the collisional ionization efficiency in both argon and P-10 gases Using this approach we achieved a limit of detection of ≈15 atoms of Hg in the laser probe volume [8]

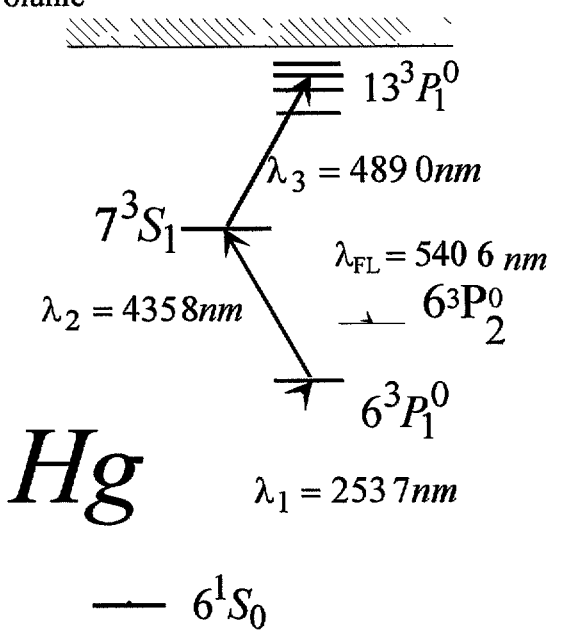
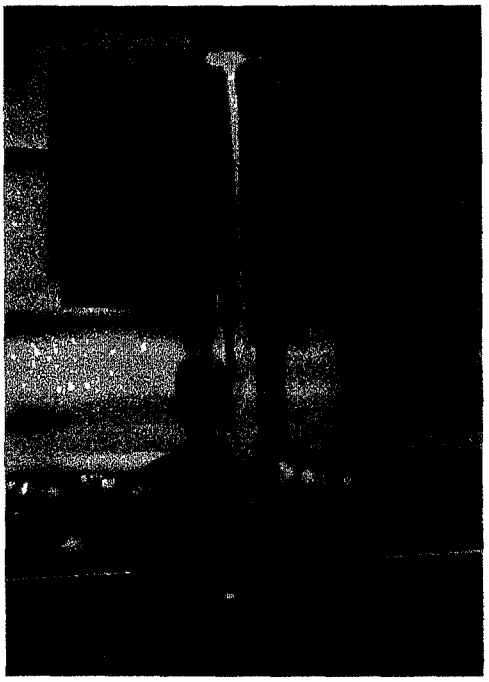


Figure 1 Excitation scheme for a Hg resonance ionization detector (RID)

These studies led to the development of the resonance ionization imaging detector which we will briefly describe This is a new concept for a spectrally selective optical imaging method, based on the resonance absorption of photons in an atomic vapor and subsequent laser resonance ionization of the excited atoms Calculated figures of merit show that it has the potential for improved spatial, spectral and temporal resolution, compared to available techniques Our preliminary experiments demonstrated the ability to detect single photons within an atomic resonance line using laser induced photoionization and excellent image quality has been obtained for a fluorescence-based system using Hg Numerous potential applications exist such as the imaging of moving objects and ultrasonic fields, high energy particle detection, high resolution microscopy in the vacuum UV, satellite tracking and optical communications The concept is general and can be applied to a wide variety of elemental and spectroscopic schemes throughout the uv-visible spectrum We have begun the development and evaluation of a prototype imaging system based upon resonance absorption in mercury vapor A cell filled with the optimum density of Hg vapor and a buffer gas is illuminated with two pulsed dye

lasers tuned to sequential excited state transitions of Hg (see Fig 1) A photon entering the cell with an energy within the spectral bandwidth of the 253 7 nm Hg ground state transition will be absorbed and excited by this two-step scheme into a Rydberg level from which ionization takes place with near unity efficiency The charge pair which is thereby created is accelerated in an electric field and can be detected with excellent spatial resolution by a variety of means, including a conventional charge coupled device The goal of this research is to develop a practical prototype based upon resonance absorption in Hg, to optimize its performance with respect to the important figures of merit and characterize its usefulness for one type of application, the selective imaging of moving objects



Picture 1 Photograph of the RIID cell

Preliminary experiments in a 25 mm diameter cell containing ~10^{13} atoms/cm^3 of Hg in 100 Torr of neon (see Picture 1) have shown that the position of the charged particles created by laser radiation can be detected simultaneously by measuring the images of fluorescence (λ_{FL} = 546 nm) and the optical emission signal of the neon discharge created by electrons in the cell The pink neon emission is generated by energy transfer from the ions, which are produced along the path of the laser beams, as they accelerate through the neon towards the exterior electrodes We have described the detailed experimental setup in the literature [3 8] As can be seen, there is a clear correlation of the green fluorescence and red neon discharge intensity along the axis of propagation of the laser beams This intensity is much higher close to the window of the cell and substantially reduced at a distance of 30-50 mm, where the laser radiation was absorbed by mercury atoms This experiment showed that in principle the same cell

Figure 2 Image of 253 7 nm photons in Hg vapor

with or without electrodes can work simultaneously as a resonance ionization imaging detector or a resonance imaging monochromator

In another experiment to demonstrate the imaging capability of these devices we have

illuminated a Hg cell, 3 x 5 x 0 2 cm, with an image produced by a mask having the characters "UF" The second excitation at 435 8 nm, provided by a pulsed dye laser, was made to illuminate the Hg cell using a circle-to-line fiber optic bundle and enters the cell from the left in Figure 2 The green 546 nm image of the mask, formed in the Hg vapor, was clearly visible to the eye and was easily captured on photographic film, shown in Figure 2 We have also recorded this image using a conventional video camera and observed the appearance and disappearance of the image as one tunes the 435 8 nm laser across the fine structure of the Hg excited state Figure 3 shows a schematic of the present design for the resonance ionization imaging detector

Dr Matveev also participated in several other research projects, including the development of a technique based on laser enhanced ionization with electrothermal vaporization, to detect very low levels of Pb and Mg [9 10 11] Various two-step excitation schemes were examined and a limit of detection for Pb of 42 fg was achieved in diluted whole blood

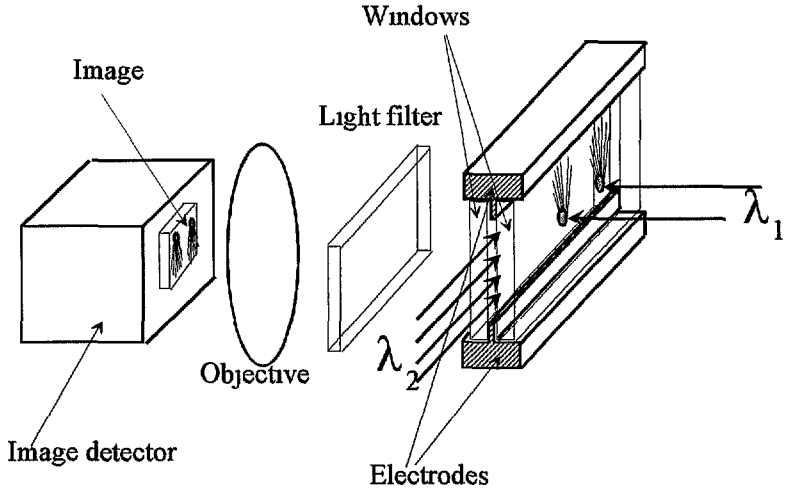


Figure 3 Experimental embodiment of the RIID

Benefits

Clearly, Dr Matveev's time in our laboratory has been exceptionally productive and beneficial to the research group Several new research directions were begun and Dr Matveev was able to pursue projects which would have difficult, if not impossible, in Moscow As can be seen from the authorship of the published papers, several undergraduate and graduate students worked closely with Dr Matveev during the past year and benefitted enormously from his broad experience in laser spectroscopy and optics

The projects involving the ultratrace detection of Hg and the development of resonance ionization imaging detectors will certainly be continued if funding can be found As mentioned above, two new proposals have been submitted in this regard If funding can be found, Dr Matveev will remain in the host's laboratory to continue this work

We have maintained connections with Moscow State University and during the past year submitted a joint proposal, with Prof Nikita Zorov, Chairman of the Department of Analytical

Chemistry, to the Civilian Research and Development Foundation Cooperative Grants Program This proposal was not funded

There is considerable possibility for commercialization of the resonance ionization imaging technology As mentioned above, we have submitted a patent application through the University of Florida Division of Sponsored Research and we have also submitted a Phase I SBIR proposal through a small high technology company, J&D Scientific, to DARPA

Funding Aspects

We were able to supplement Dr Matveev's salary to a level of $3000/month for the duration of his stay Because his family (wife and two children) accompanied him here, this was deemed essential Funds for this additional pay came from several ongoing research grants in the host's laboratory, including an NIH grant and a DOE grant Financial assistance was also provided by the University of Florida Division of Sponsored Research

The provision of this CAST grant initiated an enormously beneficial collaboration which is sure to continue for some time Dr Matveev is an exceptionally creative scientist and has been a wonderful addition to our laboratory His coming here would not have been possible without the assistance of the CAST program

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