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Author(s):

D. J. Vieira
R. Guckert
D. W. Preston
V. Sandberg
D. Tupa
J. M. Wouters

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Development of an optical trap as an ultra-sensitive analytical tool

D. J. Vieira¹, R. Guckert^{1,2}, D. W. Preston^{1,3}, V. Sandberg¹, D. Tupa¹ and J. M. Wouters¹

¹Los Alamos National Laboratory, Los Alamos, New Mexico 87545

²Justus Liebig University, 35392 Giessen, Germany

³California State University, Hayward, California 94542

ABSTRACT

The use of an optical trap for the quantitative detection of small numbers of radioactive atoms is featured. Presently under construction is a system consisting of a high-efficiency magneto-optical trap (MOT) coupled to a mass separator. Mass-separated samples will be implanted into a thin platinum foil, subsequently released from the foil by heating, and resonantly trapped in the MOT. The number of atoms in the trap will be quantitatively deduced from the amplitude of the fluorescence signal. Measurements for different isotopes are planned by appropriately shifting the trapping and repumping laser frequencies of the optical trap. Our initial investigations will concentrate on the determination of trace amounts of ^{135}Cs and ^{137}Cs .

1. INTRODUCTION

Since the magneto-optical trap was first invented¹ in 1987, great progress has been made in understanding and optimizing the trapping of atoms. Some 13 different elements (most of Group IA, 3 members of Group IIA, and most of the noble gases excited in the metastable state) have been trapped to date. In this morning's session alone we have heard about important breakthroughs in the trapping of radioactive atoms^{2,3}, the high-efficiency trapping using dryfilm coatings⁴, and the detection of a single atom in a trap⁵. Other work has recently shown that two isotopes of rubidium can be simultaneously trapped⁶. With these and other developments, optical traps have become a powerful tool for undertaking a wide variety of basic and applied research. Herein, we explore how a MOT coupled to a mass separator can be used as a new ultra-sensitive analysis method.

2. AN OPTICAL TRAP COUPLED TO A MASS SEPARATOR

Since the process of trapping atoms using a MOT involves the repeated resonant absorption and fluorescence ("scattering") of thousands of photons within a few milliseconds (that is within the time it takes for an atom to traverse the trap), the inherent isotopic and elemental selectivity of the trapping process is extremely high. Once the atoms of interest are trapped they are then concentrated into a small fluorescing cloud (typically a few mm or less in diameter) at the center of the trap where they can be held for several seconds depending on the quality of the vacuum within the trap (generally pressures of 10^{-8} torr or better are required). During this time the number of trapped atoms can be measured by imaging the fluorescent signal onto a photodiode. Since each trapped atom "scatters" millions of photons per

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second, this fluorescence determination is highly leveraged which makes the detection very sensitive. Taken together, the very high trapping selectivity and the high detection sensitivity of optical traps make them exceptionally well suited to the problem of ultra-sensitive detection and measurement.

One of the major concerns in using the MOT technology is how to introduce samples without degrading the ultra-high vacuum. Because we felt that chemical methods would cause too much gas loading, we chose a mass separation, ion implantation, and release scheme as a relatively straight forward and efficient method for introducing alkali and alkali earth elements in the trap. Such elements can be efficiently ionized and they diffuse out of materials relatively easily. The mass separator also provides an additional chemical and isotopic purification step with easy control over which isotope is introduced into the trap. A schematic of the system which we are presently building is given in Figure 1.

To understand how the system works, we will now outline each step in the analysis process. We begin by chemically purifying the sample and loading it into an ion source. For alkali and alkali earth elements we will use a high temperature surface source where high (10-50+%) ionization efficiencies are routinely achieved. Such sources are also known for their high elemental specificity. Once ionized, ions are pulled off the surface of the source by an electrostatic extractor and accelerated up to energies of 10-50 kV. The resulting ion beam passes through the magnet of the high-transmission mass separator and a single mass is selected using a mass slit. From there the mass-selected beam passes into the dryfilm-

Figure 1. A sketch of an optical trap coupled to a mass separator for the ultra-sensitive measurement of trace amounts of radioactive atoms. See text for a detailed discussion of separation and detection steps.

coated glass cell of the optical trap and is implanted into a platinum catcher foil. Although a variety of implantation materials could be used, previous work⁷ has shown that implanted Cs is released from platinum with high efficiency (~90%) upon heating to 1200°C for 2 s. Thus after a suitable accumulation period of several minutes, the MOT will be turned on and the catcher foil rapidly heated (by inductive or resistive heating) for a few seconds to release the sample as a vapor. A slight negative bias (~-40 V) will be placed on the catcher foil to suppress ionic emission. Also illustrated is a small trap door which would be closed during the heating and trapping step so that the sample is not pumped away. However, recent developments⁴ suggest that this trap door may be replaced by a small fixed aperture hole to effectively achieve the same purpose. Related to the lasers, we plan on using a Ti:Sa laser for the trapping beams and a home built laser diode system⁸ for the hyperfine repumping beams. The time profile of the number of trapped atoms will be recorded by imaging the fluorescing cloud onto a photodiode over a period of ~10 s to complete the measurement cycle.

In order to perform isotopic measurements, a time sequence controller will be used to jump shift the mass separator from isotope to isotope together with the appropriate frequency shifting of the trapping and repumping laser beams using acousto-optic modulators. Multiple measurements of each sample will be made to determine the reproducibility of the system. To the extent possible we will monitor and actively stabilize the key parameters associated with the implantation, release, and trapping process. These include, but may not be limited to, the position and intensity of nearby mass lines (in some cases the sample may be spiked), the temperature-time profile of the catcher foil upon heating, and the intensity and frequency of the laser beams. Our initial goal is to make quantitative measurements with accuracies on the order of 20% for samples containing as few as 10^4 atoms of radioactive species such as ^{135}Cs ($T_{1/2}=2$ Myrs) and ^{137}Cs ($T_{1/2}=30$ yrs).

As such the quantitative measurement of 10^4 atoms for such long-lived radioactive species would represent a significant breakthrough over current capabilities. In particular, the measurement of 10^4 atoms would represent a two orders of magnitude improvement over what can be measured with thermal ion mass spectrometer where cesium is one of their best cases. Compared to low-level nuclear counting, the improvements are expected to be as much as six orders of magnitude in the case of ^{135}Cs and between one and two orders of magnitude in the case of ^{137}Cs provided that 2-4 week counting periods are acceptable. Moreover, since far fewer than 10^4 atoms have already been detected in MOTs and rapid advancements in optical trapping are still being made, this method has the potential of increasing sensitivity levels significantly with time. Application of the MOT technique to the areas of environmental monitoring, nonproliferation, and treaty verification are currently of high interest. We are thus pursuing the development of this new ultra-sensitive analysis method as quickly as we can.

3. PROGRESS & PLANS

We have been working on optical trapping for approximately a year. Starting essentially from scratch we have built up several laser diode systems and successfully trapped stable cesium. We are currently in the process of improving our trapping diagnostics and bringing into operation a Ti:Sa laser. Our near term goal is to develop a high-efficiency trap using the higher powered Ti:Sa laser for the trapping beams, employing nonstick dryfilm coatings of the trapping cell, and by using a more optimized geometry between the trapping volume established by the overlapping laser beams and the total volume of the cell. Our intent is to achieve trapping efficiencies of 20-50%.

In parallel with the high-efficiency trap development, we are working to recommission one of our existing mass separators. This has taken much longer than we originally expected with essentially the entire front end and collection regions of the separator having to be replaced. We are working towards the

upgraded mass separator being made operational this summer. At that time we will begin the implantation and release studies using small amounts of ^{137}Cs as a radiotracer.

Among the many challenges which we face, perhaps the most difficult problem is the coupling of a high-efficiency MOT to a mass separator. The implantation and release scheme outlined above is relatively clean and straightforward to implement, but will the dryfilm coating survive the radiant heat from the 1200°C catcher foil and will the out-gassing rate be sufficiently low during the foil heated process that high-efficiency trapping is achieved? Can we get away with just a small hole leading into the trapping cell or must some type of trap door be used? These and other questions will engage us and other groups working in the optical trapping for some months. With a little luck we hope to demonstrate the first trapping of radioactive cesium, ^{135}Cs , by the end of 1995.

4. SUMMARY

The use of optical traps for the quantitative, ultra-sensitive measurement of selected long-lived radionuclides is outlined. In order to prevent the gas loading of the trap, samples will be introduced through an ion implantation and heated-foil release process using a mass separator. Construction of a MOT coupled to a mass separator is currently in progress. Demonstration of this new technology at the level of 10^4 atoms would represent a breakthrough, pushing detection limits down by two or more orders of magnitude. Moreover, with the implementation of continuing developments in optical trapping, this method has the potential of significantly lowering detection limits even further in the future. Application of this new technology to the areas of environmental monitoring and nuclear nonproliferation are foreseen.

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6. REFERENCES

1. E. L. Raab, M. Prentiss, A. Cable, S. Chu, and D. E. Pritchard, "Trapping of Neutral Sodium Atoms with Radiation Pressure," *Phys. Rev. Lett.* **59**, 2631 (1987).
2. Z-T. Lu, C. J. Bowers, S. J. Freedman, B. K. Fujikawa, J. L. Mortara *et al.* "Laser Trapping of Short-Lived Radioactive Isotopes," *Phys. Rev. Lett.* **72**, 3791 (1994); S-Q. Shang, S. J. Freedman *et al.*, these proceedings.
3. G. Gwinner, J. A. Behr, S. B. Chan, A. Ghosh, L. A. Orozco *et al.*, "Magneto-Optic Trapping of Radioactive ^{79}Rb ," *Phys. Rev. Lett.* **72**, 3795 (1994); G. D. Sprouse *et al.*, these proceedings.
4. M. Stephens and C. Wieman, "High Collection Efficiency in a Laser Trap," *Phys. Rev. Lett.* **72**, 3787 (1994); M. Stephens *et al.*, these proceedings.

5. Z. Hy and H. J. Kimble, "Observation of a Single Atom in a Magneto-Optical Trap," Opt. Lett. **19**, 1888 (1994); H. J. Kimble *et al.*, these proceedings.
6. W. Süptitz, G. Wokurka, F. Strauch, P. Kohns, and W. Ertmer, "Simultaneous Cooling and Trapping of ^{85}Rb and ^{87}Rb in a Magneto-Optical Trap," Opt. Lett. **19**, 1571 (1994).
7. W. Weibler, T. Schneider, R. Wallenwein, D. Dubbers, K. Wandelt *et al.*, "The Clean Deposition of Radioactive Isotopes on a Single Crystal Surface," Nucl. Instr and Meth. **206**, 299 (1983).
8. K. B. MacAdam, A. Steinbach, and C. Wieman, "A Narrow-Band Tunable Diode Laser System with Grating Feedback, and a Saturated Absorption Spectrometer for Cs and Rb," Am. J. Phys. **60**, 1098 (1992).