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COHERENT SPECTROSCOPY OF ULTRA-COLD MERCURY FOR THE UV TO VUV

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ARIZONA UNIV BOARD OF REGENTS TUCSON

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Final Report

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Narrow UV transitions in atomic Hg can be utilized for a high quality atomic frequency standard. The primary goal of the research supported by this grant was the development of a laser-cooled source of ultracold Hg atoms and the spectroscopic study of the doubly-forbidden "clock" transition to better understand its potential as a future atomic clock. During this funding period a novel UV laser system was developed to efficiently cool and trap atomic Hg to temperatures below 100 microKelvin. The narrow 1^S_0 to 3^P_0 clock transition was measured and used to determine the temperature of the Hg ensemble. The grant supported the PhD research of two students.

15. SUBJECT TERMS

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Final Report

Award Title:
"Coherent Spectroscopy of Ultra-cold Hg from the UV to VUV"

Award No. FA9550-09-1-0563

Program Manager: Dr. Tatjana Curcic

Reporting Period: 7/15/2009- 08/28/2015

The primary goal of the research supported by this grant was the development of a laser-cooled source of ultra-cold Hg atoms and the spectroscopic study of the doubly-forbidden "clock" transition to better understand its potential as a future atomic clock. During this funding period a novel UV laser system was developed to efficiently cool and trap atomic Hg to temperatures below 100 microKelvin. This work demonstrated that, unlike other alkaline earth-like systems that require 2-stages a laser cooing (e.g. Sr and Yb), a single-stage of laser cooling can be used to capture over 10^6 atoms and reduce their temperature to a range where it is feasible to directly load them into an optical lattice. The narrow $^1S_0 \rightarrow {}^3P_0$ clock transition was measured during this work and was used to determine the temperature of the Hg ensemble. The grant supported the PhD research of two students.

Two novel laser systems have been developed for this project. The primary challenge was in the development of the source at 254nm for laser cooling and trapping on the $^1S_0$ to $^3P_1$ transition. We designed and constructed a system based on optically-pumped semiconductor laser technology (OPSL). Details of this system can be found in [1]. The home-built OPSL provides >1 Watt of single frequency, narrow line radiation at 1016nm. This is frequency quadrupled with high efficiency using two successive cavity enhanced frequency doubling stages (LBO and BBO) to generate over 100mW of UV light at 254 nm.

This OPSL based system is used to reliably generate the Hg MOT (see Fig. 1). Characterization of the MOT temperature and atom number was completed, using standard computer automated imaging and time-of-flight techniques. Both fermionic and bosonic isotopes of Hg have been characterized. We were able to demonstrate temperatures at the ~100 microKelvin level.

We have measured the narrow "clock" transition of Hg using a fiber based cw laser source. The spectroscopy laser system utilizes a cw fiber laser that is amplified and frequency doubled in a single pass using periodically-poled lithium niobate (PPLN). This provides a reliable, nearly turn-key source of green light. A resonant doubling cavity is then used to generate >10mW of light at the clock transition of ~265nm. In order to resolve the narrow $^1S_0$ to $^3P_0$ transition, the laser system must be stable and tunable on the timescale of several seconds. To accomplish this, we first lock a secondary external cavity semiconductor diode laser to an ultrastable ULE reference cavity (which is vibrationally and thermally isolated inside a vacuum chamber- see

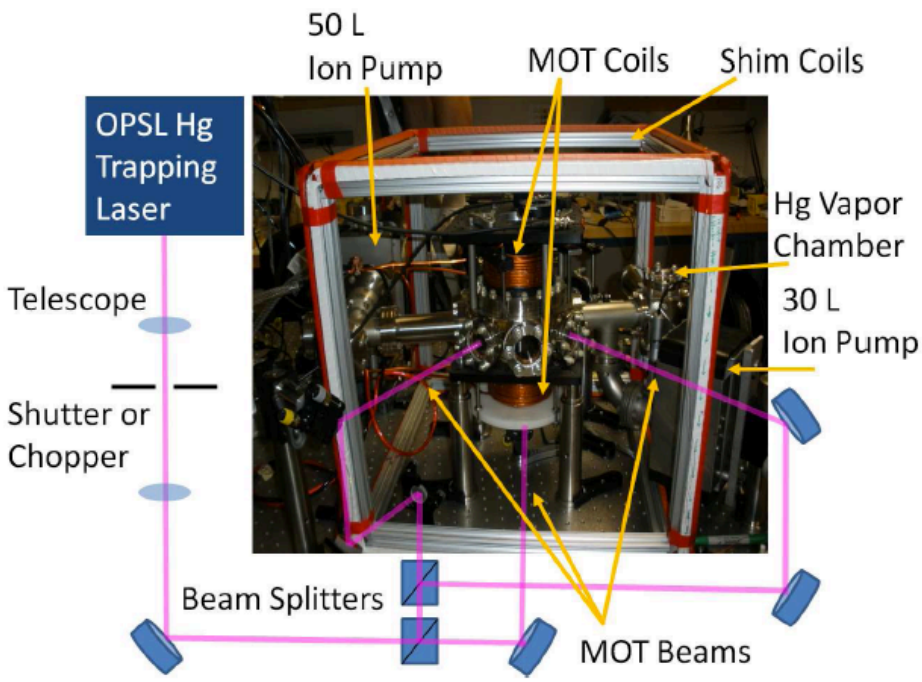

Figure 1. A photograph and diagram of the neutral Hg MOT chamber showing the locations of the Hg vapor chamber, MOT coils and shim coils.

Fig 2). An optical phase-lock loop is then used to stabilize the fiber-based system to the diode laser. This enables linewidth narrowing of the fiber laser system to 100's Hz levels while simultaneously allowing for a broad and controlled tuning range. In this way we are able to slowly scan the UV laser system to locate the clock transition (using the standard technique of MOT depletion).

As a secondary frequency reference for the lab, we have built a saturated absorption iodine system. This was needed in order to initially locate the Hg clock transition. Iodine reference lines near the green laser wavelength of 531nm (1016nm/2) are fortuitously located within ~2GHz of the Hg transition (after the final doubling stage 531nm -> 265.5nm). Using these transitions as reference, we calibrated the frequency of the ultra-stable reference cavity and slowly tuned to the clock transition frequency. In order to measure the clock transition in the absence of Stark shifts from the cooling laser light, we strobe the MOT beams and probe beams on and off at different time intervals using AOM's. The measured clock transition is shown in Fig. 3. The measured Doppler-broadened linewidth was consistent with the temperature estimates from time-of-flight measurements.

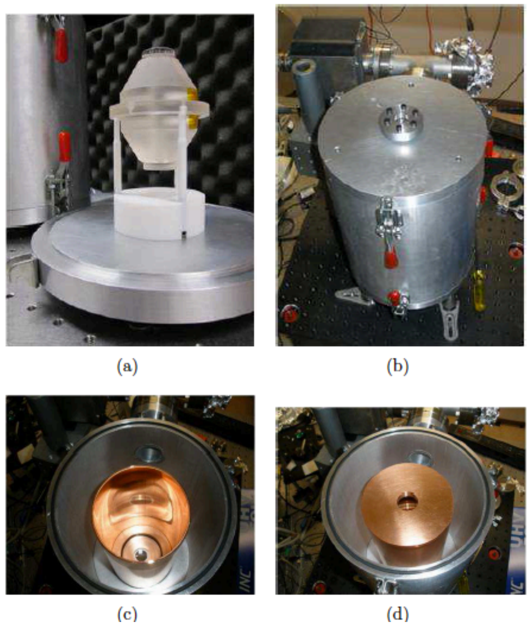

Figure 2. (a) The UHF cavity made of ULE glass is place (b) inside a vacuum chamber to provide environmental isolation. (c),(d) An additional heat shield within the chamber provides further isolation between the UHF cavity and thermal radiation from the chamber walls.

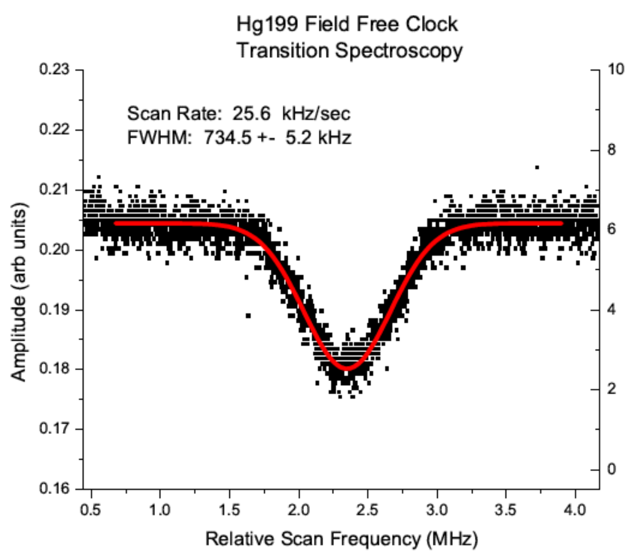

Figure 3. Spectrscopy of the Hg^{199} clock transition in the absence of the MOT beams.

Publications

[1] J. Paul, Y. Kaneda, T.-L. Wang, C. Lytle, J.V. Moloney, and R.J. Jones, "Precision spectroscopy of atomic mercury in the deep ultraviolet based on fourth-harmonic generation from an optically pumped external-cavity semiconductor laser," *Opt. Lett.* **36**, 61 (2011).

[2] Justin R. Paul ; Christian R. Lytle ; Yushi Kaneda ; Jerome Moloney ; Tsuei-Lian Wang, R. J. Jones, " Optically pumped external-cavity semiconductor lasers for precision spectroscopy and laser cooling of atomic Hg ", *Proc. SPIE* 8606, Vertical External Cavity Surface Emitting Lasers (VECSELs) III, 86060R (February 18, 2013); doi:10.1117/12.2004351; **http://dx.doi.org/10.1117/12.2004351**

[3] J. Paul, C. Lytle, S. Fang, R.J. Jones, "Characterization of a Hg MOT and measurement of the $^1S_0$ to $^3P_0$ clock transition," *in preparation for PRA (2015).*

1.

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R. Jason Jones

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Tatjana Curcic

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Abstract

The primary goal of the research supported by this grant was the development of a laser-cooled source of ultra-cold Hg atoms and the spectroscopic study of the doubly-forbidden \"clock\" transition to better understand its potential as a future atomic clock. During this funding period a novel UV laser system was developed to efficiently cool and trap atomic Hg to temperatures below 100 microKelvin. This work demonstrated that, unlike other alkaline earth-like systems that require 2-stages a laser cooing (e.g. Sr and Yb), a single-stage of laser cooling can be used to capture over 106 atoms and reduce their temperature to a range where it is feasible to directly load them into an optical lattice. The narrow 1S0 → 3P0 clock transition was measured during this work and was used to determine the temperature of the Hg ensemble. The grant supported the PhD research of two students.

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Laboratory Task Manager

Program Officer

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Funding Summary by Cost Category (by FY, $K)

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