RPC 2020

Virtual Research Presentation Conference

CHIP SCALE LIGHT SOURCE FOR A COHERENTLY PUMPED MERCURY CLOCK

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Program: Spontaneous Concept

Assigned Presentation #RPC-199

Jet Propulsion Laboratory
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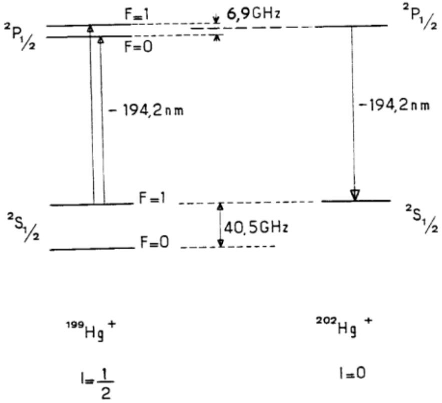
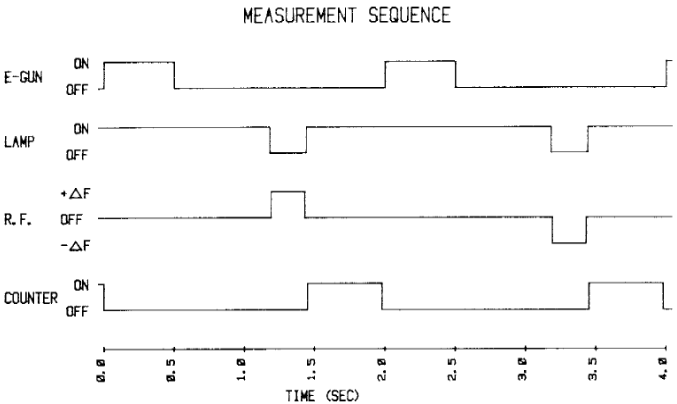
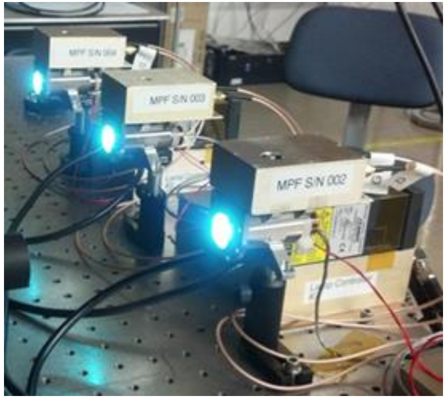
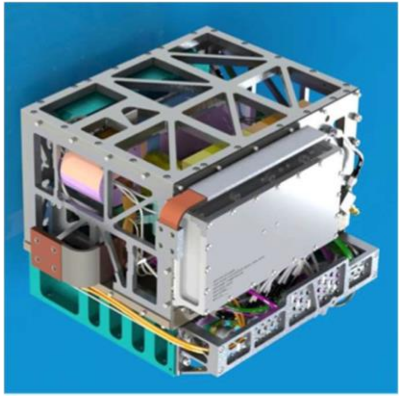
Tutorial Introduction



Energy levels of mercury 199 (clock) and 202 (lamp). [1] The mercury 202 lamp is used to prepare quantum state as well as interrogate the mercury 199 ions.



Operation of the mercury clocks [1]:
--Ion population refreshing
--Optical pumping
--Ion interrogation with RF
--Optical interrogation to generate error signal

DSAC mission parts and form factor [2]. Left: Three mercury discharge bulbs being tested for UV performance and lifetime. Right: An external view of the Deep Space Atomic Clock System

The clock can be improved and its size can be reduced if the lamp is replaced with a small laser operating at 194 nm

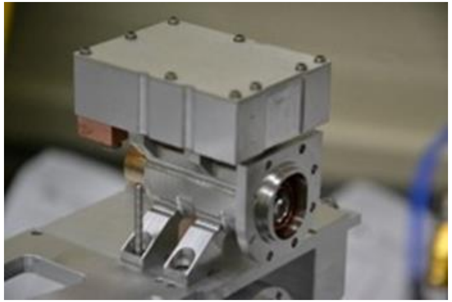
Problem Description

a) Our team has launched a linear ion-trap-based trapped mercury ion atomic clock, referred to as DSAC (Deep-Space Atomic Clock) developed under NASA's Technology Demonstration Mission program. The technology used by the DSAC clock is expected to provide a new capability with broad application to space-based navigation and science. For instance, the DSAC low-drift technology will enable one-way navigation, relieving the load on the Deep Space Network and improving precision. It is also important for the ESA/NASA Atomic Clock Ensemble in Space (ACES) Mission as well as a JPL/NASA DSAC-space clock follow on mission. The clock performance is at least an order of magnitude better than any other space clock demonstrated so far.

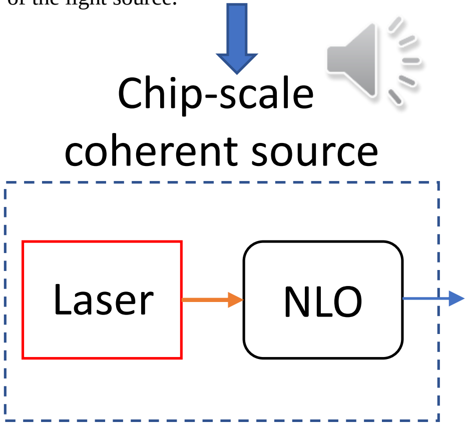
b) Further reduction of the clock size and power consumption and increase of the signal-to-noise ratio can be achieved by replacing the mercury lamp currently used, with a coherent light source. A compact laser or a nonlinear light source could provide much higher brightness while consuming much less power. A trade study as well as numerical simulations are needed to determine if a chip scale 194 nm light source can be created using state-of-the-art nonlinear optics. The study was performed in this Task.

c) Generation of the needed coherent light is fundamentally feasible but undeveloped. A table top (~m^3 volume) 194 nm laser system is manufactured by a US-based company and is commercially available for a few hundreds of thousand dollars. The technology is not fieldable or space qualified and the ruggedness is obscure or unlikely.)

d) The compact UV sources that can be developed based on the findings of the current effort can advance several technical aspects mentioned in the Instruments and Sensors section in the JPL's 2019 Strategic Technologies and benefit future flight mission. The sources are particularly important for atomic clocks.

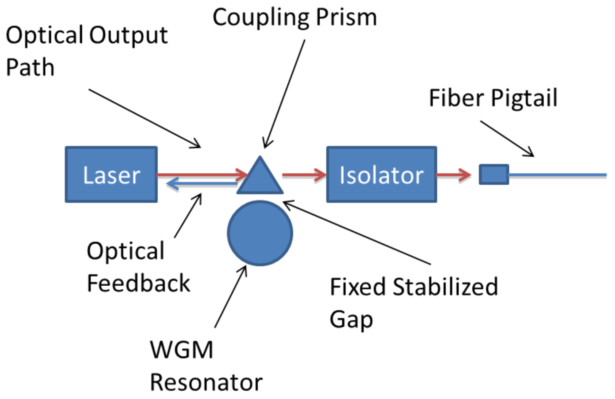


UV mercury lamp currently utilized in the Deep Space Atomic Clock. The lamp can be replaced with a chip-scale optical coherent source. The objective of this project is to confirm feasibility of the light source.

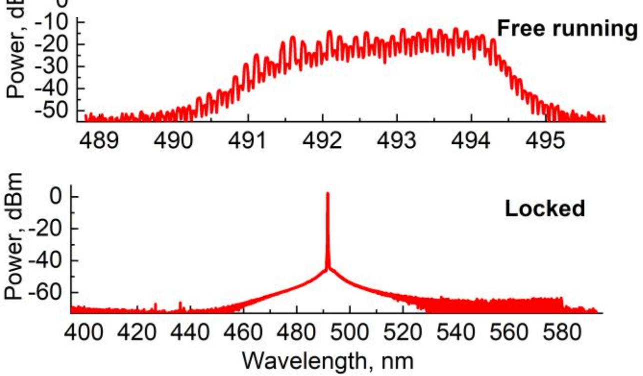


Methodology

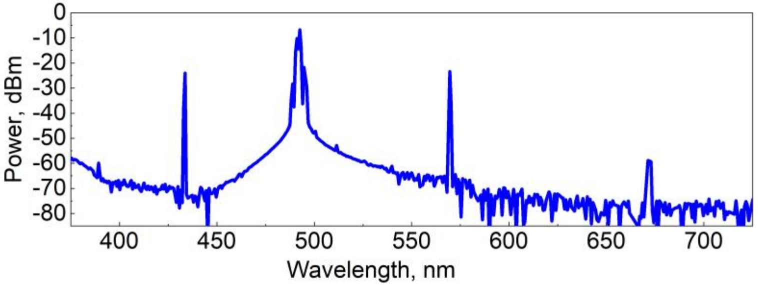
- ✓ **Prerequisites:**
  - ➢ There are no vacuum UV semiconductor sources
  - ➢ There are good visible and near-IR laser chips
  - ➢ There are good nonlinear crystals
- ✓ **Problem:** How to achieve power efficient generation?
- ✓ **Solution:** Resonant structures and self-injection locked pump light are promising here.
- ✓ **Technical issues:** Non-monochromatic laser chips & phase matching in the resonant structures
- ✓ **Methods:** Demonstrate self-injection locking and select proper geometry of nonlinear optical crystalline structures.



Demonstration of self-injection locked 493 nm laser. The polychromatic coherent emission becomes monochromatic [E]. The emission power is ~100mW.



Parametric generation of UV light using 493 nm optical pump [C]



Results

a) The goals of the effort were i) to perform a trade study of the commercially available nonlinear optical crystals suitable for generation of 194 nm coherent light with the sufficient power and ii) to suggest a conceptual design of the compact light source based on these crystals and semiconductor laser chips.

Both goals were accomplished.

In addition, a few auxiliary results were obtained:

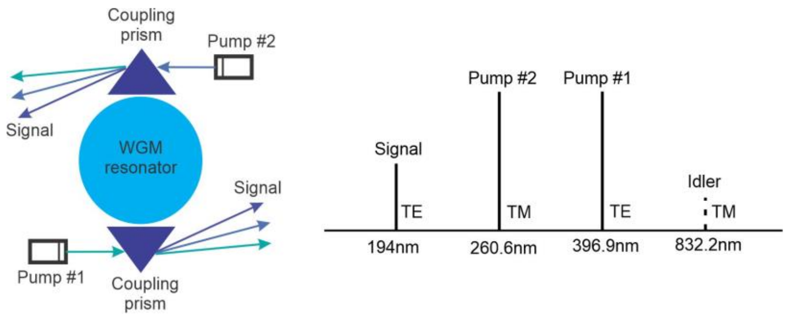
i) A high power monochromatic blue laser was demonstrated experimentally;

ii) Strongly nondegenerate four-wave mixing was demonstrated experimentally;

iii) A few papers were published

b) Significance: The study performed in the current project will allow us to design a specific scheme resulting in generation of 194 nm light on a small platform. Once realized, the source will result in improvement of the mercury atomic clocks.

c) Next steps: Apply for Topical R&TD as well as reimbursable grants



Left: A possible scheme of the experiment. Pumps #1 and #2 are coupled to the MgF_2 resonator via evanescently coupled prism elements. The lasers are orthogonally polarized. The coupling angles are optimized for the refractive index of the material at the pump wavelengths. The outputs of the both couplers contain signal light that can be separated from the pumps using an optical filter and a polarizer. Spatial filtering is also feasible as the light will leave the couplers at different angles. **Right:** Scheme of harmonics involved in the FWM process. Only the harmonics shown by the solid lines are phase matched. The phase matching is achieved by proper selection of the WGM resonator host material. (details will be disclosed in [A]) The signal is generated via process $2\nu_{pump2}$-ν_{pump1}.

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