Shelving Spectroscopy and Atomic Clock Development of the Strontium 689 nm Intercombination Line

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Abstract

Precise timekeeping is crucial for a myriad of applications, including GPS, telecommunications, financial transaction time-stamping, and more [20]. The burgeoning demand for increasingly accurate clocks at a smaller scale has driven significant progress in atomic clock miniaturization over the past two decades [8][10]. Chip-scale atomic clocks have emerged by employing micro-fabricated vapor cells containing atomic species conducive to high-precision timekeeping [20][12]. Strontium has emerged as an exceptional candidate for atomic clocks, with the development of clocks exhibiting deviations of less than 1 second in 300 billion years [5]. However, a chip-scale strontium clock remains to be realized.

This paper delineates the advancements made toward the development of a strontium atomic clock utilizing a micro-fabricated vapor cell. The proposed design involves implementing a shelving spectroscopy scheme that employs the 1S0-3P1 transition as the clock transition. Further refinement of the shelving scheme and the associated laser lock systems is necessary prior to the establishment of a functional clock. All components of this proposed design, encompassing both optical and electrical elements, can be miniaturized to chip scale, rendering it a promising solution for a wide range of applications with stringent weight and volume constraints.

The strontium clock design outlined in this paper incorporates frequency and phase lock systems, which are critical for achieving precise resonance between the shelving and intermediate lasers with their respective transitions. This paper discusses the current limitations of these locking systems and proposes potential improvements. Once the frequency and phase locks are optimized and an additional frequency lock is employed, a clock is created by pairing a frequency counter with the laser resonant with the clock transition.

Lay Summary

I completed the work for this thesis under the supervision of Dr. Yang Li and Dr. Matthew Hummon at the Time and Frequency Division of the National Institute of Science and Technology. One of the aims of this research group is to produce increasingly precise and small clocks. High-precision timekeeping is essential to many sectors of the economy, from finance to telecommunications. However, a lot of new technology that requires the highest precision clocks does not have the space to accommodate the large atomic clocks of the past. The first atomic clocks occupied an entire laboratory. Today, the most precise atomic clocks can be as small as a dining room table. This research group hopes to make a clock that is the size of a computer chip.

My thesis documents the progress I made in the pursuit of this goal. I primarily discuss the techniques used to measure and stabilize light. Light is essential for this atomic clock because it serves as the oscillator used to measure time, just like the pendulum for a grandfather clock.

The name atomic clock comes from the use of atoms to stabilize the light. A group of atoms absorbs some of the light used for the clock. We then use a technique called shelving spectroscopy to amplify this absorption signal. This amplified absorption signal allows for better stabilization of the light through a technique called a phase lock. The phase lock prevents the frequency of the light from drifting too much, leading to a more reliable clock. My work contributes to the eventual development of a strontium-based atomic clock that is as small as a computer chip yet remains as precise as much larger clocks.

Works Cited

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