Frequency Stability in a Wall-Coated Evacuated Cell: Preliminary Results

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ABSTRACT

Using a high-quality evacuated wall-coated sealed cell, first measurements on the frequency stability of the 6835MHz 0-0 rubidium 87 hyperfine transition are reported. The intrinsic linewidth in the 24cc cell was ~ 10 Hz FWHM. A saturated absorption locked diode laser provided a stable optical pumping light source. Available equipment showed a monotonic frequency drift rate of ~ + 1 x 10^{-12}/day. Additional experiments appear to confirm that light gas diffusion into the cell is the cause of this drift. The observed drift is closely matched by the calculated rate due to the diffusive influx of atmospheric helium through the cell wall. If such diffusion is the dominant cause of drift, improvement in frequency stability by orders of magnitude should be possible without penalties in size, weight, or cost.

INTRODUCTION

The hydrogen maser is a well-known example of a frequency standard using wall-coated cell technology. The device itself has been carefully researched and studied. A good understanding of limiting and systematic effects has been achieved; this provides the basis for the excellent performance of this frequency standard. Although use in viable frequency standards has yet to be demonstrated, wall-coated, evacuated cells can also be used with rubidium or cesium. The atom confinement mechanism is similar to that in the hydrogen maser. Wall-coated cell work at Duke University has previously reported observation of narrow linewidth 0-0 hyperfine resonances in Rb87, laser diode optical pumping for signal acquisition, and observation of various parameters affecting the 0-0 hyperfine transition in Rb87. [1-3] These

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promising results encourage further investigation, especially of the device's frequency stability and exploration of limitations on the stability. The area of frequency stability is a primary consideration toward use of wall-coated cells in frequency standards. Quite different systematic effects operate in the evacuated, wall-coated Rb device as opposed to the gas cell Rb frequency standard ... they are very different devices. In this paper, we report for the first time on the frequency stability measured with a high quality, wall-coated, evacuated, sealed cell using the Rb87 0-0 hyperfine transition.

APPARATUS

An evacuated, tetracontane wall-coated, sealed cell of ~ 24cc volume was placed in a TE011 mode cavity and illuminated with Rb D1 light tuned to the F -> F' = 2 -> 2' optical transition. The laser diode providing this radiation was locked to the optical transition by a separate saturated absorption package. [3] A magnetic field of 1.5G was applied along the axis of the cavity. A klystron phase-locked to an hp5100A frequency synthesizer provided the ~ 6835MHz frequency required to observe the 0-0 hyperfine transition. The synthesizer was frequency modulated at a 10Hz rate for the purpose of resonance interrogation. Lock-in detection of the 10Hz signal and feedback to the 5100A's search oscillator input locked the synthesizer to the 0-0 resonance. The search oscillator frequency was counted by an hp5245L and chart recorded using an hp580A D/A converter. The standard input to the synthesizer was derived from an Oscilloquartz Model 3200 Cesium Standard. [4]

In the absence of light and microwave power broadening, an intrinsic linewidth of ~ 10Hz FWHM was measured for the 0-0 resonance in the cell used. Virtually no Rb spin-exchange broadening contributed to the linewidth since all measurements were done with the Rb stem temperature maintained at 22^{o}C. The linewidth under operational conditions was ~ 30Hz. Major contributors to the operational linewidth were the optical pumping process (light intensity) and microwave power saturation. The wall shift, defined as the 0-0 frequency in the cell at zero magnetic field minus the free space hyperfine frequency, was determined to be ~ -80Hz at 40°C. The linewidth and wall-shift parameters indicate a wall-coating of high quality.

Our route to measurement followed the path of minimum cost, with an effort to maximize the information gathered using equipment available. Thus we term our results ´preliminary´ since the apparatus and measurement equipment/technique should be modernized and the data base expanded.

RESULTS

A measured frequency drift of ~ + 1 part in 10^{12}/day was obtained. This was determined by measuring the slope of the chart recorded search oscillator frequency over a several day time span. We were not able to characterize the Allan variance because of equipment limitations.

A question may be asked about the possible cause for such an observed drift. A number of parameters are known to affect the observed frequency of the 0-0 transition. Among these, applied magnetic field, light intensity, detuning of the optical transition from resonance, and cell wall temperature have been characterized previously. [3] The experimental conditions used presumably were under sufficient control to rule out these sources or, at least, make them unlikely prospects as the cause of the observed drift.

The diffusion of light gases into the cell interior provides a possible mechanism for slow frequency drift in the evacuated, sealed cell. [5] For example, consider the diffusion of helium gas due to the natural pressure of helium in the atmosphere (4 parts in 10^{6}) through a pyrex glass wall of 0.1mm thickness. The known pressure shift coefficient of 0-0 hyperfine frequency, 720Hz/Torr [6], provides an initial frequency drift rate of ~ + 2 x 10^{-12}/day. The characteristic time of the process with the assumed parameters is 176 days. If gas diffusion is the dominant cause of frequency drift, a cell wall thickness of ~ 0.2mm would give agreement with the measured drift rate. The actual cell wall thickness was not known.

An ancillary experiment was performed by suddenly surrounding the cell with an atmosphere of pure helium while observing the frequency locked to the 0-0 transition. Cell temperature remained at 40°C. As expected, the observed 0-0 frequency eventually began to increase. After the helium was flushed out of the microwave cavity with nitrogen, and the frequency drift re-stabilized, a net shift of ~ +30Hz had resulted. With an overpressure of helium in the cell relative to that in the atmosphere, the frequency of the 0-0 transition should be observed to decrease with time. This was the case. Thus the sign of the frequency drift was reversed in the experiment.

CONCLUSION

The preliminary results on drift rate for the wall-coated evacuated sealed cell are encouraging toward use of such technology in a Rb frequency standard. If, as it appears to be, gas diffusion is the dominant frequency drift mechanism, control of this process would produce drift rates orders of magnitude smaller than 1 part in 10^{12}/day. This would be possible without a penalty in size, weight, or cost. Clearly, more research on this wall-coated evacuated cell device is justified and desirable. Work currently in progress under the auspices of the Naval Research Laboratory will characterize the long-term drift in several cells.

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QUESTIONS AND ANSWERS

JIM CAMPARO, AEROSPACE: I actually have two questions. First, is that one of the older cells, the first cell that you showed?

MR. ROBINSON: No. It is a recent cell. It hasn't set around a year. The characteristic time for a tenth of a millimeter cell is about 180 days for pyrex, that is the e to the minus one point, for helium. These cells are probably o.2 millimeter, so the characteristic time would be doubled. These cells were made within a month of the time that they were actually measured.

MR. CAMPARO: The other question was that in some of (unclear) papers looking at coatings, she actually finds that the vapor pressure is below the saturated vapor pressure of rubidium, so you probably have even less rubidium than a saturated vapor a 22 degrees. That would give you even more room for improvement.

MR. ROBINSON: I think that that is probably true. There are some interesting things that happened when you melt the wax. The wax actually puddles. It appears that it doesn't wet the glass. That is one of the problems of coating these cells. In fact, though, there must be a mono-layer or several layers there because the line width is fine. The amount of wax in the cell is probably grossly too large.

RICHARD KUNSKI, JOHNS HOPKINS: You mentioned at the beginning that your result for different lines for optical pumping. You were able to hold the laser on any one that you wanted. In an absorption cell there is very wide line width due to Doppler broadening. That is not the case here?

MR. ROBINSON: You are talking about the optical line. The optical transitions here were shown during the PTTI of 1984. We showed the saturated absorption resonances along with the Doppler curves.

MR. KUNSKI: And you were able to sweep the laser through these lines?

MR. ROBINSON: Yes. If you can get a copy or have a copy of that, we had in that paper those particular pictures. (Mr. Robinson sketched the curves on the overhead projector.) The curve widths are determined by the width of the laser, which was in this case about ten MegaHertz.

LUTE MALEKI, JET PROPULSION LABORATORY: You mentioned that your laser is stabilized in frequency. Is it stabilized in power?

MR. ROBINSON: Yes. It is stabilized every way that you can think of stabilizing it. The intensity changes the frequency as well as the frequency of the laser changing the frequency.

MR. MALEKI: At what level do you start seeing that?

MR.ROBINSON: I have the curves here of shift versus light intensity. We use the microamperes detected at the photodetector as a measure of the light intensity. It is essentially a 100% quantum efficiency device. The parameter is about a half a Hertz per microampere on this particular transition. If you go to the other transition, it is a negative amount about the same magnitude.