

# Optogalvanic Spectroscopy of the ${}^2F_{7/2}$ - ${}^1D[5/2]_{5/2}$ Repumper Transition for $\text{Yb}^+$ Optical Frequency Standards

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## Abstract

Due to interest in the  ${}^2S_{1/2}$ - ${}^2F_{7/2}$  transition of  $\text{Yb}^+$  for applications as a frequency standard, we have applied optogalvanic spectroscopy on the 638 nm  ${}^2F_{7/2}$ - ${}^1D[5/2]_{5/2}$  transition of  $\text{Yb}^+$  in a DC discharge in order to measure isotope and hyperfine splitting of the line. We have observed optogalvanic signals at multiple pressures of Ne buffer gas, finding linewidths of approximately 2 GHz at 5 Torr and 1.5 GHz at 500 mTorr. Showing that Doppler broadening is dominant below 1 Torr, we have set up sub-Doppler optogalvanic spectroscopy and are working on applying this to resolve the splitting of the transition line.

*Keywords:* Optogalvanic; Discharge; Sub-Doppler; Ytterbium; Isotope shift; Hyperfine

## Introduction

The  ${}^2S_{1/2}$ - ${}^2F_{7/2}$  transition of  $\text{Yb}^+$  is being investigated as an atomic clock transition, being of interest due to the estimated 6-year lifetime of the  ${}^2F_{7/2}$  state, resulting in a  $\sim$ nHz natural transition linewidth. In a clock based on this transition, ions are repumped from the F state to the ground state using the 638nm transition to the highly excited  ${}^1D[5/2]_{5/2}$  state (Hosaka et al., 2005). Excited-to-excited state transitions in complex ions such as  $\text{Yb}^+$  provide a challenge to theory, necessitating experimental methods for accurate determination of the isotope shift and hyperfine structure constants for the  ${}^2F_{7/2}$ - ${}^1D[5/2]_{5/2}$  transition.

The  ${}^2F_{7/2}$  and  ${}^1D[5/2]_{5/2}$  states each have two hyperfine states,  $F=3$  and  $F=4$ , causing splitting of the transition line. The hyperfine splitting has been estimated at 1.12 GHz. Also, the transition frequency is shifted for the different isotopes, where the isotope splitting has been estimated at 594 MHz. Optogalvanic spectroscopy was chosen to experimentally determine these quantities.

## Experiment and Results

We have performed optogalvanic spectroscopy on  $\text{Yb}^+$  generated in a DC discharge, using a solitary 35 mW diode laser operating at 638 nm. Optogalvanic spectroscopy allows for the detection of electronic spectra through measurement of the change in conductivity of a plasma discharge induced by laser radiation resonant with the transition (Barbieri et al., 1990). A Fabry-Perot etalon with a free spectral range of 300 MHz provides a frequency scale for the laser scan. An 80 MHz acousto-optic modulator was used to amplitude modulate the probe beam by directing the first order deflected mode through the discharge. Lock-in detection of the discharge current provides an optogalvanic signal with a high signal-to-noise ratio.

We observed an optogalvanic signal at the desired wavelength, in a commercial hollow cathode Yb discharge with 5 Torr of Ne buffer gas (Fig. 1). At this buffer gas pressure, the linewidth is expected to be dominated by pressure broadening. We constructed a second hollow cathode Yb discharge, which was built using a vacuum system in order to allow for adjustment of Ne buffer gas pressure within the chamber. Stable plasmas in the purpose-built discharge have been observed at Ne pressures down to  $\sim$ 200 mTorr. We found the broadened linewidth of the signal in the 5 Torr discharge to be approximately 2 GHz, and that of the signal in a discharge at a pressure of 500 mTorr to be approximately 1.5 GHz.

We have measured saturation curves of the optogalvanic signal in both discharges and determined that pressure broadening is not significant below  $\sim$ 1 Torr. The relevant saturation intensities were measured to be  $0.37 \pm 0.03 \text{ W cm}^{-2}$  at 5 Torr, and  $0.16 \pm 0.02 \text{ W cm}^{-2}$  at 500 mTorr. Also, by measuring the linewidths at varying optical powers, we have also ruled out saturation broadening, determining that Doppler broadening is the primary source of broadening of the transition linewidth.

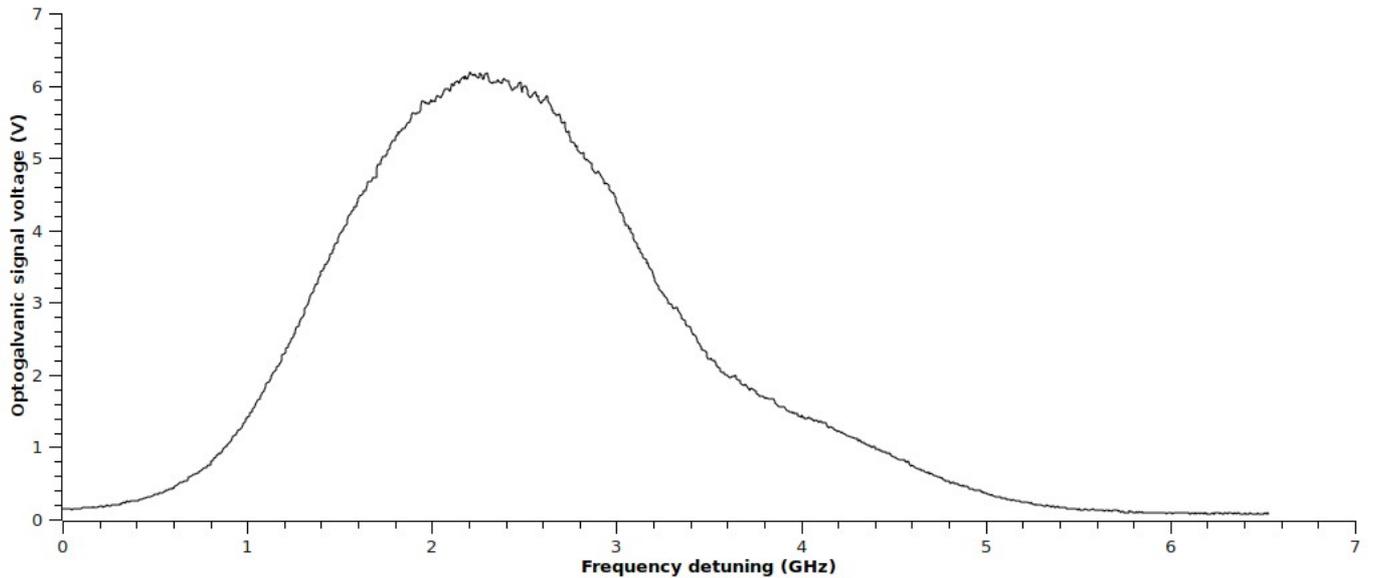


Figure 1: Optogalvanic signal of  ${}^2F_{7/2}-{}^1D[5/2]_{5/2}$  transition of  $\text{Yb}^+$  in a DC Yb discharge with 5 Torr of Ne buffer gas.

As the linewidths stated above are too broad to observe adequate resolution of isotope and hyperfine splitting, we have set up and are working on applying sub-Doppler optogalvanic spectroscopy in the low pressure discharge. By measurement of the saturation curves of the two discharges, we have determined that adequate optical power is present for saturation of the  ${}^2F_{7/2}-{}^1D[5/2]_{5/2}$  transition to occur, allowing for a saturation-based form of optogalvanic spectroscopy, similar in principle to saturated absorption spectroscopy, to be performed on the discharge.

### Conclusions

We have employed optogalvanic spectroscopy to study the splitting of the 638 nm  ${}^2F_{7/2}-{}^1D[5/2]_{5/2}$  transition line in  $\text{Yb}^+$ , with an estimated 594 MHz isotope shift and 1.12 GHz hyperfine splitting. Having observed optogalvanic signals in discharges with varying Ne buffer gas pressures, we have determined broadened linewidths of approximately 2 GHz and 1.5 GHz for pressures of 5 Torr and 500 mTorr, respectively. This broadening was found to be due primarily to Doppler broadening at pressures below 1 Torr. We have set up, and are now applying, sub-Doppler optogalvanic spectroscopy in order to resolve the splitting.

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