Optical Magnetometry by Spectral Hole Burning the Ruby R1 Transition

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Introduction

Spectral hole burning of the R1 ($^4A_2 \rightarrow \overline{E}(^2E)$) transition in ruby has been a well-explored technique to isolate a homogeneous linewidth from the inhomogeneous spectrum. Zeeman splitting in the homogeneous linewidth has been measured in magnetic fields on the order of 100 Gauss, which suggests its potential for application in magnetometry [1]. The properties of ruby make it ideal for sepectroscopy inin pressures as a high as 150GPa and in millikelvin temperatures, where much research in the development and characterization of new materials occurs. [2][3]

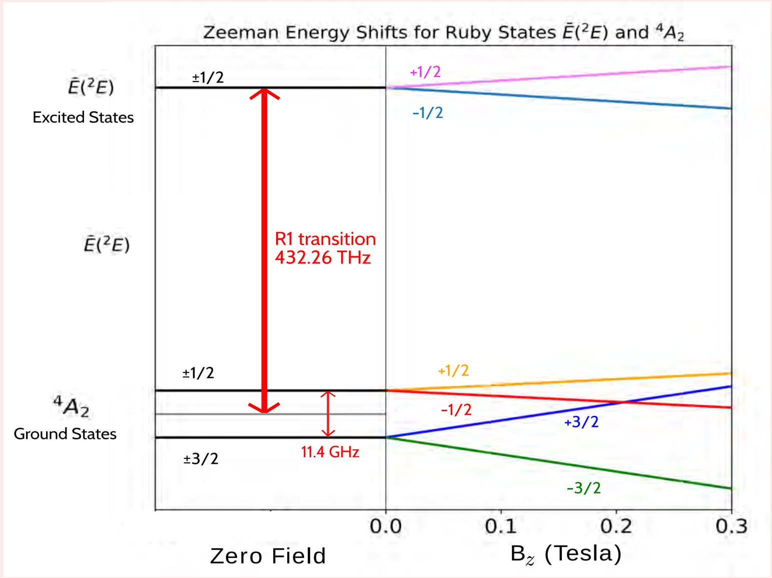

Figure 1. Energy diagram of the R1 transition in both a zero magntic field and in amagnetic field along the optical axis.

Cr:Al_2O_3 Properties

- Optically accessible transition frequencies, as measured:
  - R1: 432.25 THz (693.56nm)
  - R2: 433.11 Thz (692.19nm)
- Ruby is stable to pressures of at least 150Gpa and in millikelvin temperatures. [2][3]
- Cr3+ ion has 4 ground spin-states (± 3/2, ±1/2),and 2 excited spin-states (±1/2). [4]
  - In a zero B field, the ±3/2 and ±1/2 ground states are separated by 11.4 GHz. [4]
- The Hamiltonians for the Zeeman splitting of ruby are: [5][6]

$(^4A_2)$ state: $\hat{H}(\vec{B}) = g_{\parallel}\mu_B B_z S_z + g_{\perp}\mu_B(B_x S_x + B_y S_y) + D\left[S_z^2 - \frac{1}{3}S(S+1)\right]$

(^2E) state: $\hat{H}(\vec{B}) = g_{\parallel}\mu_B B_z S_z$

$g_{\parallel}, g_{\perp}$ are parallel and perpendicular Zeeman coefficients (1.9840, 1.9867)
μ_B is the Bohr Magneton
D is the zero-field splitting parameter
S is the spin state of the Cr^{3+} ion

The z axis (optical axis) is the axis around which Cr and Al sites have trigonal symmetry. [7]

SHB Processes and Application in Magnetometry

Isolating a homogeneous linewidth from the Inhomogeneous spectrum is achieved by spectral hole burning. The much sharper homogeneous linewidth can be measured with greater precision and has higher sensitivity to Zeeman shifting. Measurements of the width and splitting of spectral holes allows for recovery of the external magnetic field.

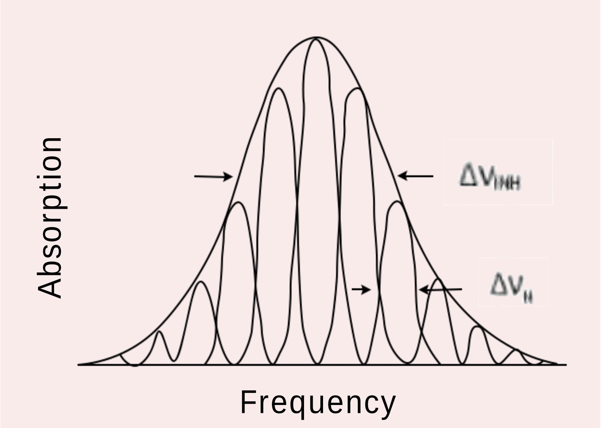

Figure 2. Sketch of inhomogeneous vs homogeneous linewidths [8]

Burn and probe sequence to acquire width of hole:

1) 15ms hole burning at constant frequency with 0.85mW lasing power
2) 100μs probe at variable frequency with 55μW lasing power
3) repitition of (1) and (2), varying the probe frequency across expected hole width

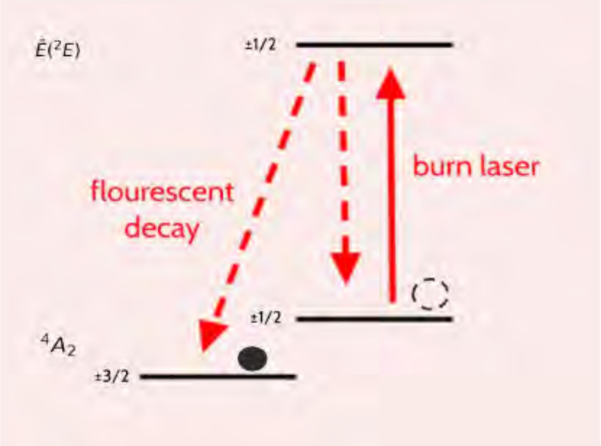

Figure 3. Diagram of the zero-field hole burning process

APPARATUS & RESULTS

- 694 nm external cavity diode laser with temperature, current, and piezoelectric controllers
- Doublepass AOM steup modulates laser frequency within 80MHz
- Vacuum cryostat cools sample to 77K at a pressure of 10 millitorr
- Future work includes transitioning to a 4.2K liquid helium cooled environment, where holes are expected to be sharper and longer-lived

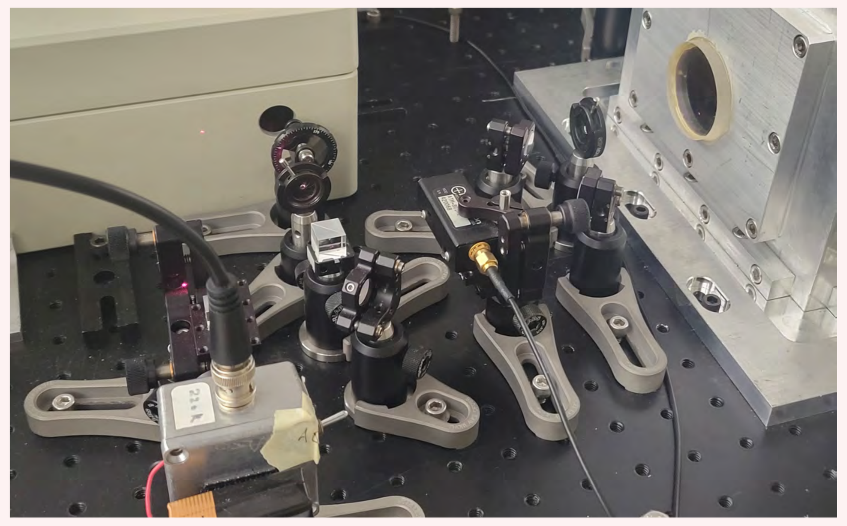

Figure 4. Image of optical table setup

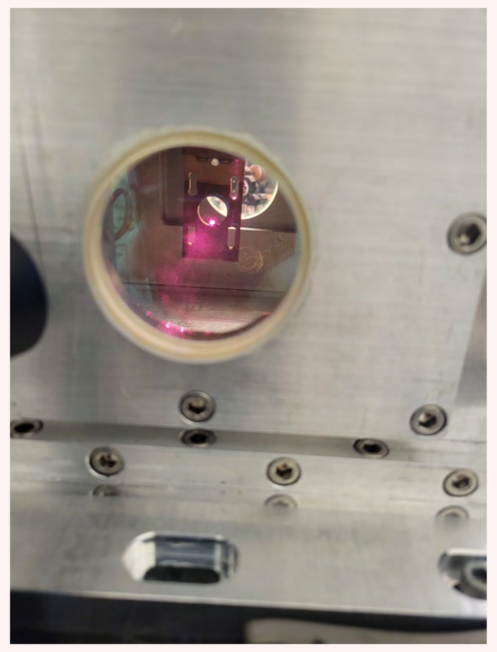

Figure 5. Image of laser passing through ruby sample in cryostat

SPECTRAL HOLE LIFETIME

- Spectral holes decay exponentially, with a on resonance flourescent lifetime of 3.4±0.4ms. This result aligns with measurements done by Chandler, D.E. et al. (1991). [9]
- Probe pulse is extended to 15ms and is conducted at same frequency as burn pulse.

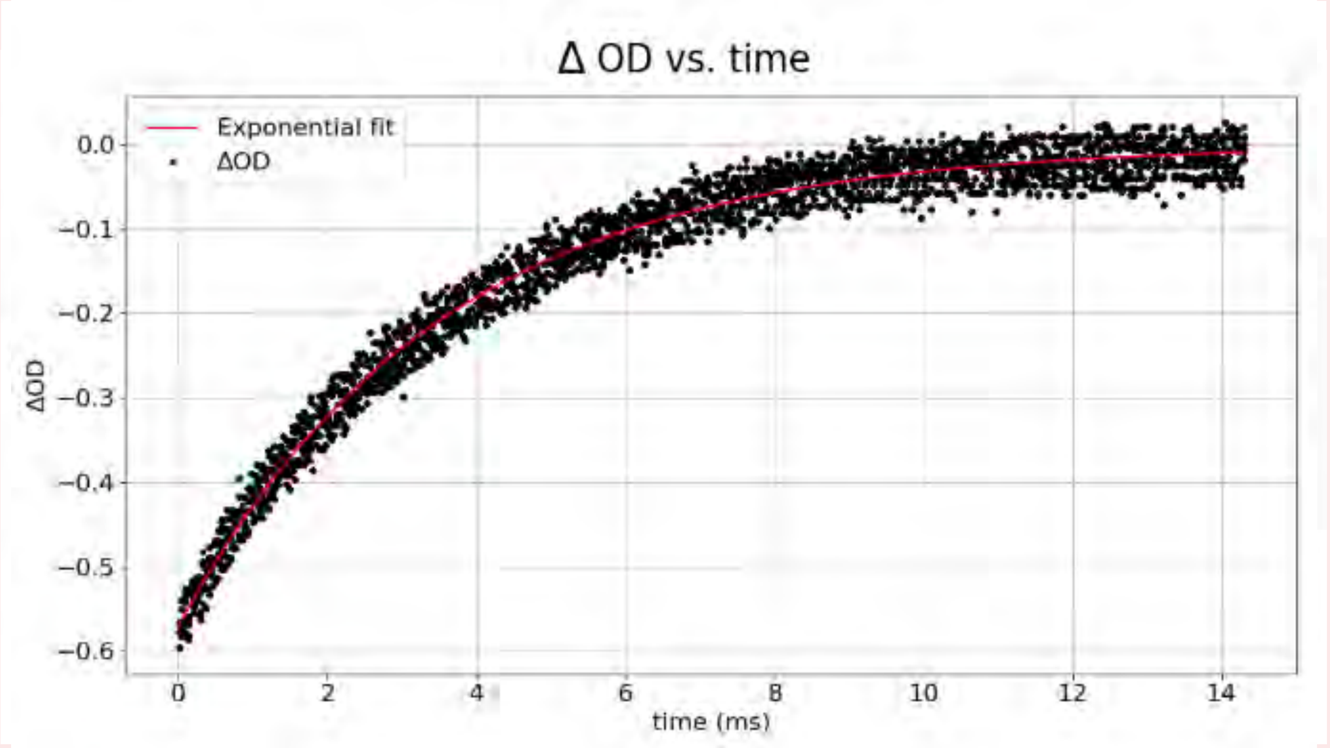

Figure 6. Graph of hole depth vs time at a frequency of 432.257THz. Lifetime fitted to be 3.4±0.4ms.

INHOMOGENEOUS SPECTRUM

- Inhomogeneous spectrum gaussian fit has peak at 432.26±0.01THz)
- Inhomogeneous FWHM of our sample is 43GHz

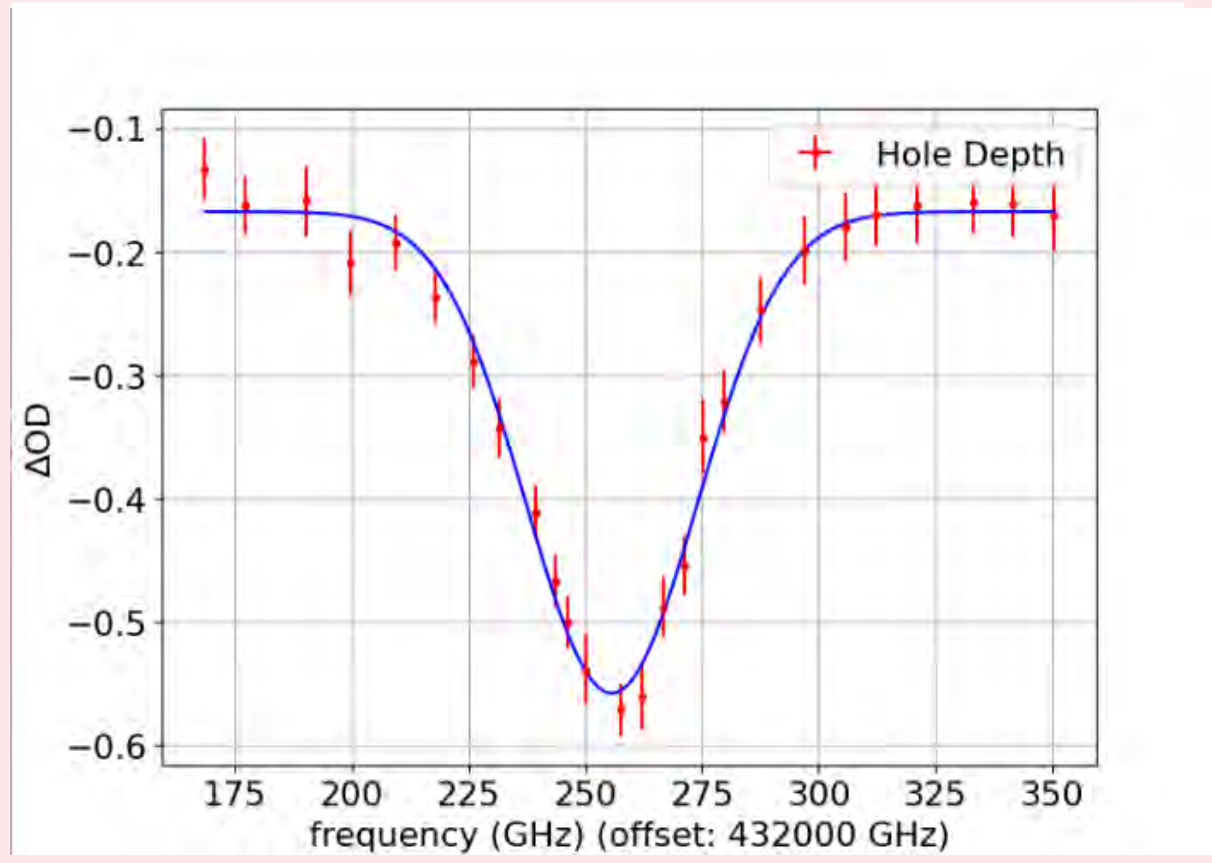

Figure 7. Graph of R1 Inhomogeneous Spectrum

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