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# Optical Characterization and Quantum Spin Control of Erbium Doped Cerium Dioxide



Photonic Quantum Technologies Group

Dr. Alisa Javadi

Adam Powell – June 11, 2026



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# Photonic Quantum Technologies Group



- **What are we interested in?** We are interested in trying to build solid-state systems (**quantum emitters**) that can interact efficiently with photons and preserve controllable quantum states long enough to store, process, or transmit quantum information (related to **quantum spin states**).
- **Why are we interested in this?** These systems are potential building blocks for quantum memory, quantum networks, and even quantum computation.
- Specifically, we are very interested in quantum emitters with transitions in the **telecom band** because those wavelengths propagate efficiently through existing fiber-optic networks. **Telecom band is 1260 nm to 1675 nm.**
- We work with both nano-structure emitters (like **quantum dots**) and rare earth **dopant-ion** emitters (like Erbium doped Cerium Dioxide).

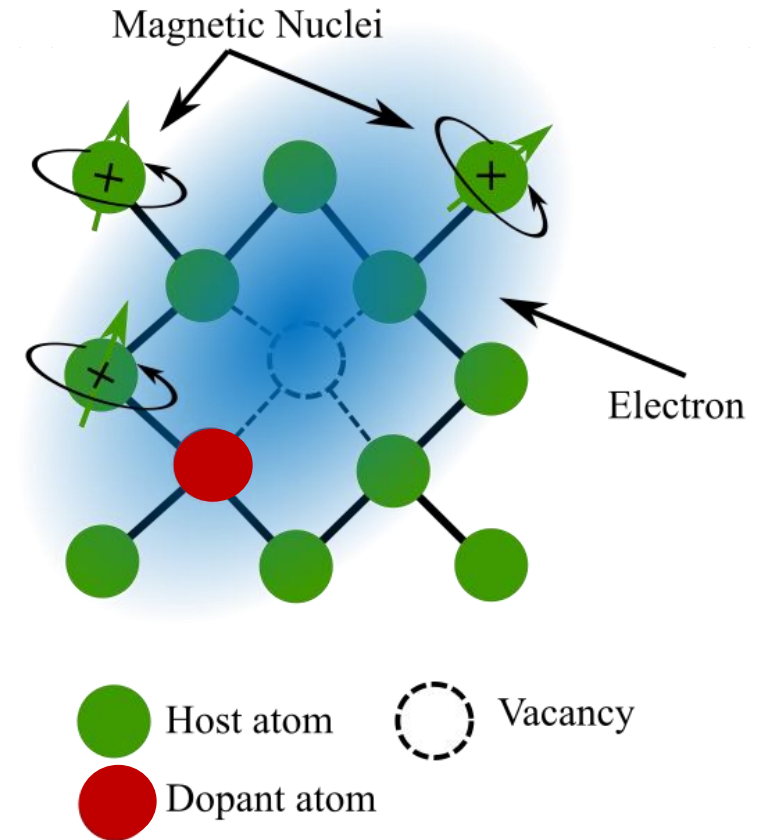
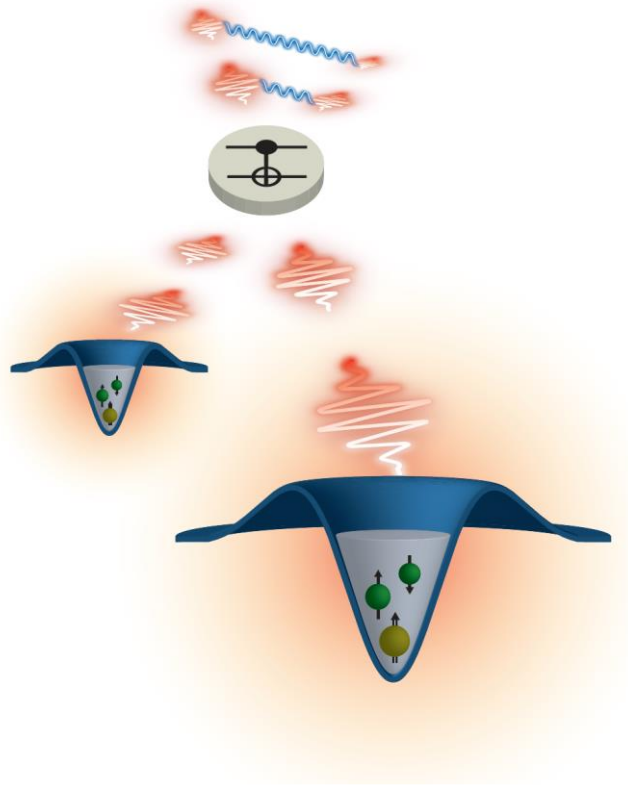


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# Quantum Dot versus Rare Earth Dopant Ion

- Quantum dots produce discrete energy levels by quantum confinement: Think of a 3-Dimensional quantum well.
- Droplet etched GaAs (Gallium Arsenide) quantum dots
- Next generation InAs (Indium Arsenide) quantum dots with telecom band emission
- Dopant-ion emitters already possess discrete atomic energy levels. Embedding them in a wide band-gap host (such as Cerium Dioxide) allows their internal optical transitions to be excited at energies below the host band gap, so the surrounding host is not excited across its valence and conduction bands.

# Quantum Dot versus Rare Earth Dopant Ion





# Why Cerium Dioxide?

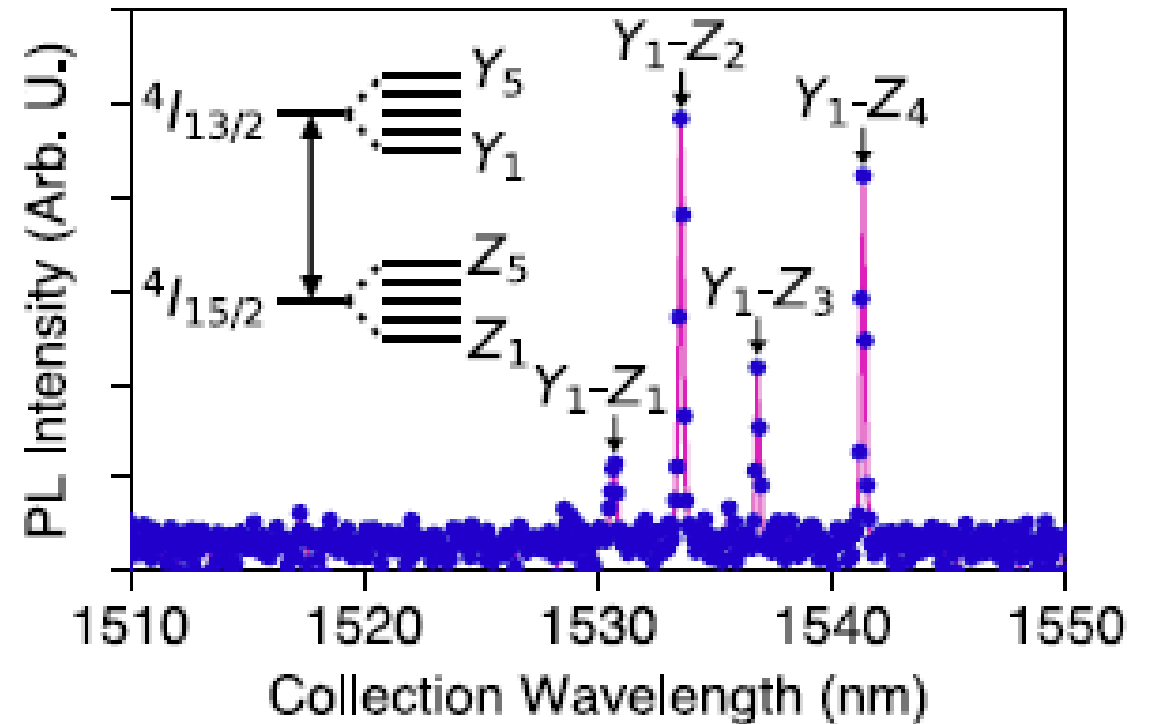
- Cerium Dioxide is a low magnetic noise host as seen by Magnetic Natural Isotope Abundance: Cerium Dioxide host has very few magnetic nuclei and produces a very quiet magnetic environment for Erbium ion spins.
- Stable crystalline structure
- Wide bandgap
- Compatible with wide range of substrates including silicon
- Easy growth tech

Element	Magnetic Natural Isotope Abundance
Carbon	1%
Silicon	4.6%
Cerium	0%
Calcium	0.13%
Oxygen	0.04%

# Characterization: Photoluminescence

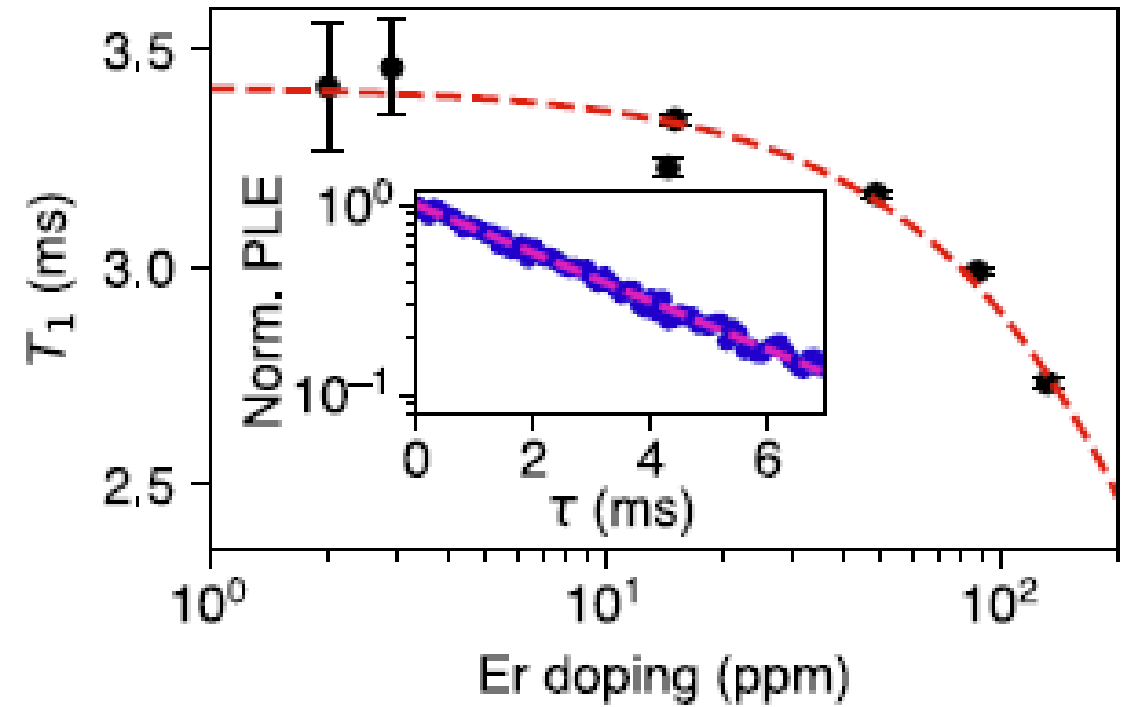
- Photoluminescence (PL): We excite our sample with a laser and measure the emitted light versus wavelength.
- This reveals which optical transitions are present and their relative emission strengths.
- In our experiment, we will have three different concentrations of Erbium ion doped Cerium Dioxide hosts. These samples were created by the fabrication half of our group.

Telecom band: 1260 nm to 1675 nm

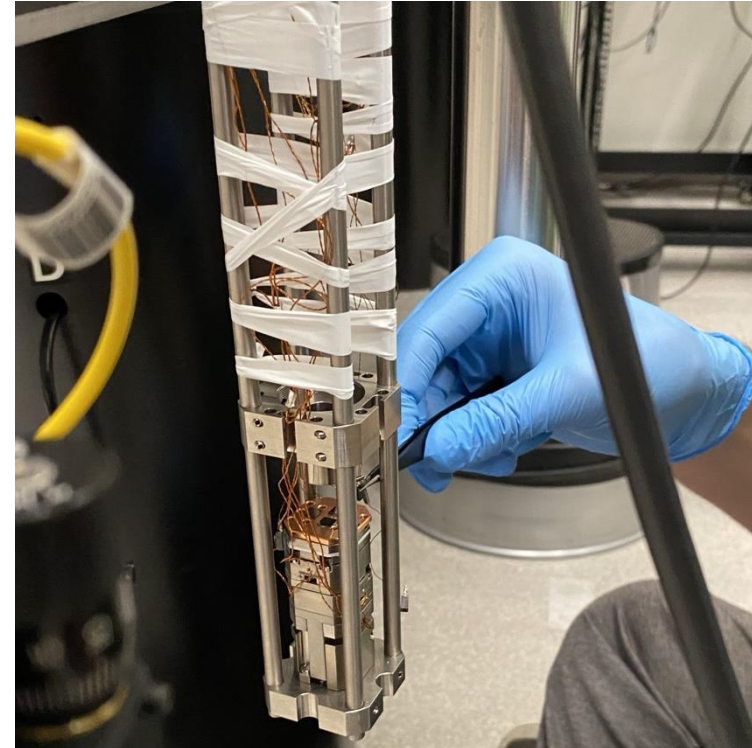
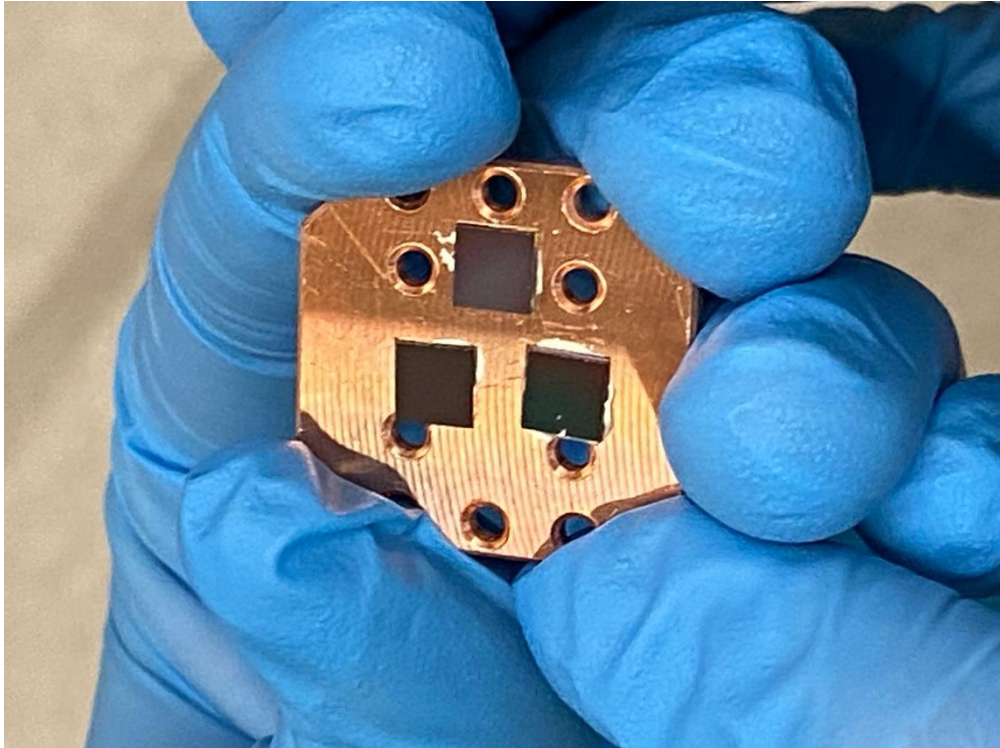


# Characterization: Lifetime Measurements

- Lifetime: We excite the sample with a pulse and then measure how the emission intensity decays over time.
- This reveals how long the excited state remains populated before decaying to a lower energy state.
- A longer excited-state lifetime is generally desirable because the quantum state persists longer before energy is lost. This is favorable for quantum memory applications.



# Three Samples: Preparation for the Cryostat





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# Quantum Spin Control: A little background

- **Angular Momentum (Classical):** In classical mechanics, angular momentum describes a rotational momentum. (A spinning wheel has angular momentum.)
  - Depends on mass distribution and rotational speed
- **Angular Momentum (Quantum):** In quantum mechanics, angular momentum describes an intrinsic quantum property (analogous to mass or electric charge).
  - **Orbital angular momentum:** Can arise from a particle's quantum state of motion.
  - **Spin angular momentum:** Is intrinsic to the particle.
- **Quantum Spin Control:** We use microwave pulses to manipulate two magnetic quantum states of the Erbium ion. (We think of these as **Spin UP and Spin DOWN.**)



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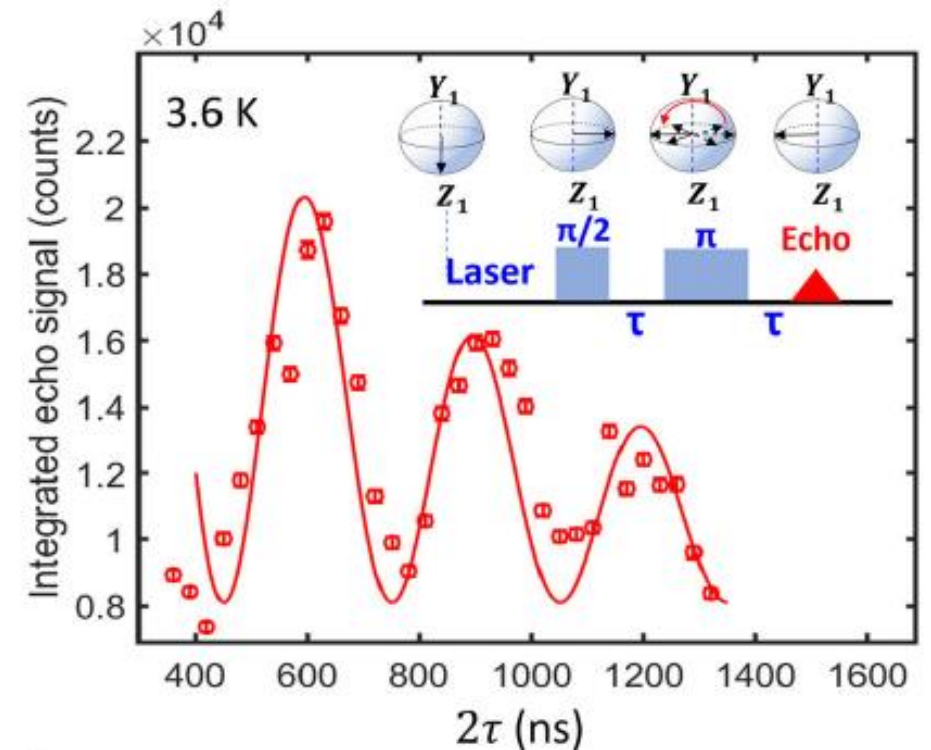
# Quantum Spin Control

- We treat two magnetic states of the erbium ion as an effective two-level system.
- Prepare a static magnetic field to define the quantization axis – the reference axis, or axis relative to which spin measurements are described.
- This magnetic field creates an energy gap between the two spin states.
- We then use a resonant frequency microwave pulses to drive transitions between states.
- That is, we tune the microwave frequency until its photon energy matches the energy gap created by the magnetic field.
- $E_{spin} = hf_{microwave}$



# Quantum Spin Control: Hahn Echo Sequence

- The Hahn Echo Sequence is a good litmus test for coherent spin control because it demonstrates that the microwave pulses are driving the Erbium ion spin transitions and that a spin ensemble is retaining phase information for a measurable time.



Zhang, Grant, et al.



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Thank you!

