A Study of Tungstate (WO_4^{2-}) Materials for Use in Quantum Transduction

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Introduction

Recently, companies have been investing in research towards the next step in computing, quantum computing. Although not something for the common person, quantum computing introduces the possibility of infinitely more data storage and problem-solving abilities than the modern computer of today.[1] These capabilities could provide the means to more easily discover useful drugs, as well as to create means of simulating the stock market.

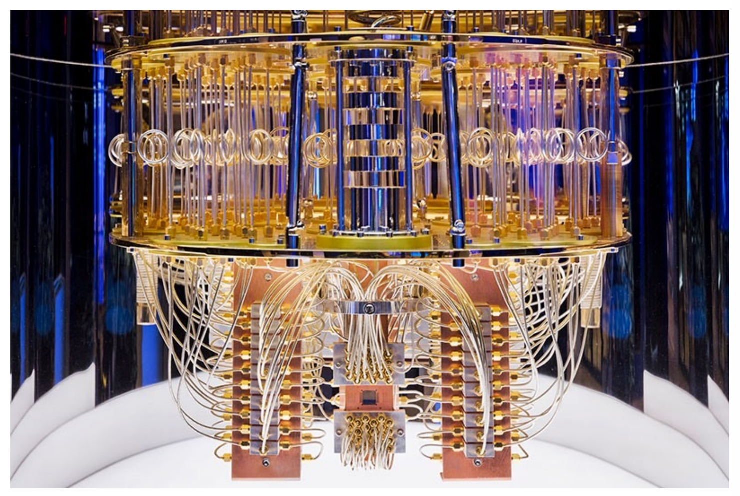


Figure 1. IBM's newest 127 qubit quantum computer (2021)

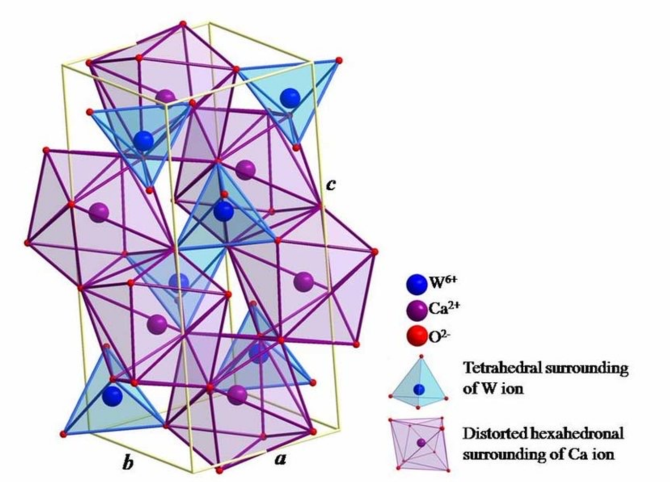


Figure 2. Crystal lattice of $CaWO_4$

One of the most important components for the future of quantum computing is the production of a quantum transducer. Transduction is the process of converting one form of energy to another, and in terms of quantum computing, the ideal conversion would be taking microwaves and converting them to the optical region of infrared radiation.[1,2] To do so, an ideal material will be one with no impurities, as well as a long coherence time, allowing for the access of quantum material for longer periods of time. Thus, the goal of my project has been to grow single crystals of $CaWO_4$ as well as Er^{3+} doped $CaWO_4$. Er^{3+} is the ideal ion to act as a transducer as it has energetic transitions in both the microwave region and optical regions, while $CaWO_4$ is capable of acting as a suitable host for the Er^{3+} ions while also having a wide enough bandgap to host the Er^{3+} energetic transitions.

Experimental Methods

Samples were prepared by combining starting materials in a mortar and pestle until well combined. Then, sample is placed in a crucible and heated from room temperature to 1,000° C back to room temperature. Powder XRD of each sample is then taken to ensure purity. Once this is done, material is made into rods, which then sinter at 1400° C to become hard. The rods are then utilized in a floating zone furnace to make single crystals.

$CaCO_3 + WO_3 \longrightarrow CaWO_4$

Figure 3. $CaWO_4$ component mixture

Figure 4. Pellets of Er^{3+} doped $CaWO_4$

Experimental Results

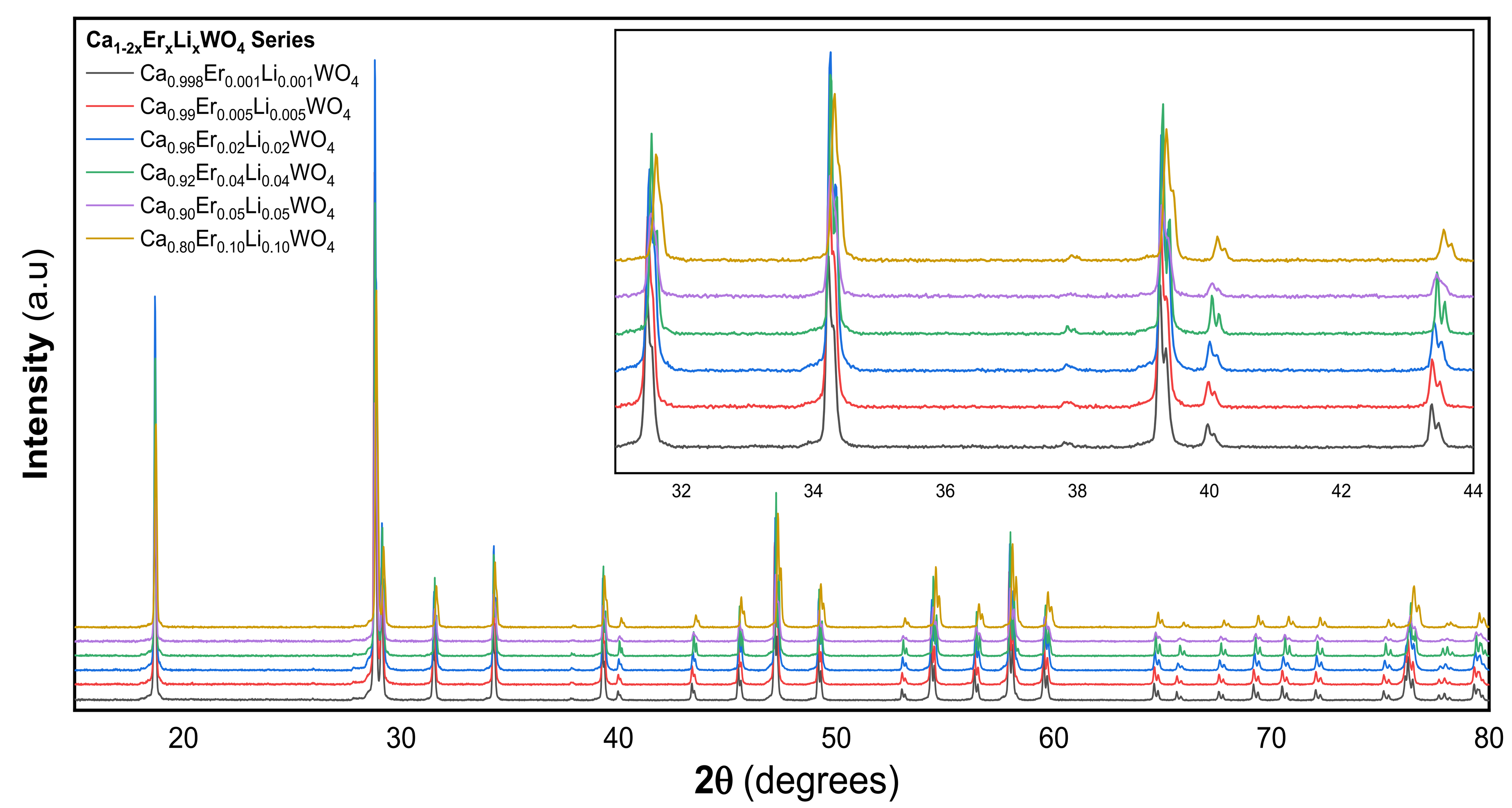


Figure 5. Er^{3+} doped $CaWO_4$ powder XRD pattern

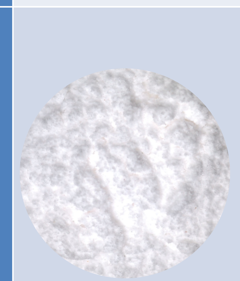
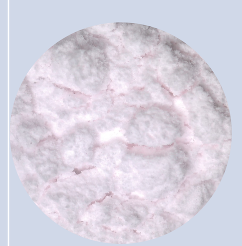
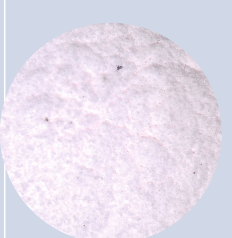
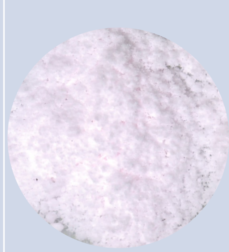
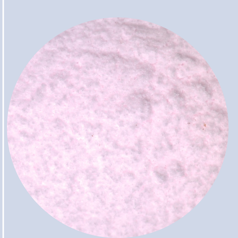
Chemical Formula	$Ca_{0.998}Er_{0.001}Li_{0.001}WO_4$	$Ca_{0.99}Er_{0.005}Li_{0.005}WO_4$	$Ca_{0.96}Er_{0.02}Li_{0.02}WO_4$	$Ca_{0.92}Er_{0.04}Li_{0.04}WO_4$	$Ca_{0.90}Er_{0.05}Li_{0.05}WO_4$	$Ca_{0.80}Er_{0.10}Li_{0.10}WO_4$
Percent Erbium Doping	0.1%	0.5%	2%	4%	5%	10%
Appearance						

Table 1. Comparison of Er^{3+} doped $CaWO_4$ pellet results

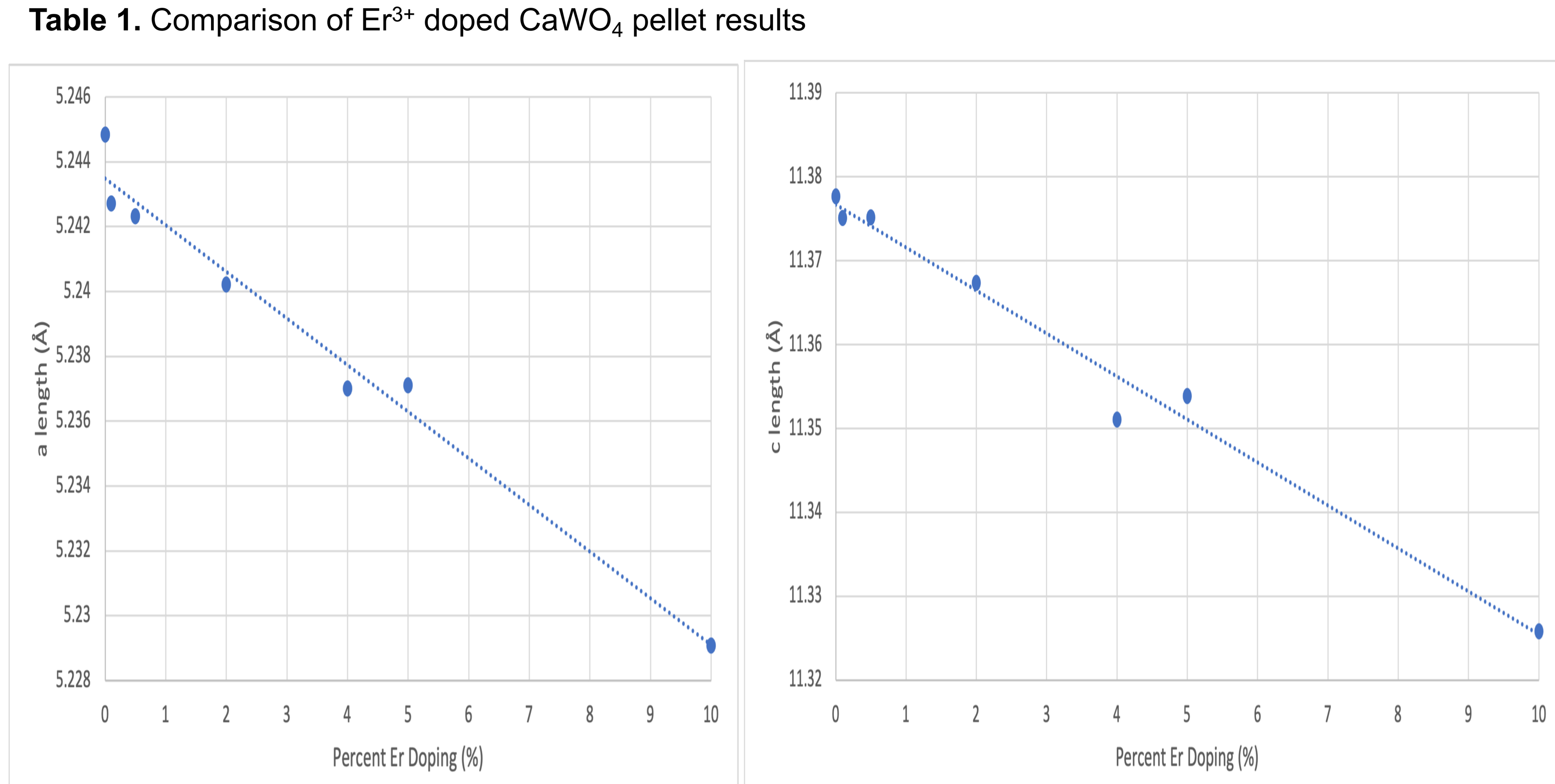


Figure 6. Lattice parameter shift with increase in Er^{3+} doping

Discussion

Initial rods made out of pure $CaWO_4$ seemed to not be dense enough to make a pure single crystal of $CaWO_4$. As crystal growth occurred in the Xenon furnace, there appeared to be many impurities in the rod, as well as the rods not being very dense, causing lots of fluctuations in furnace settings in order to keep the zone stable. By doing this, a wobbly crystal was formed with several different zones of crystal made, with the middle part of the growth being obviously tungsten rich as it appeared slightly green in color. In order to combat these issues for the next growth, denser rods were made by packing the powder in, as well as sintering at a temperature of 1,400° C. There were still difficulties at the start of the growth, causing power levels to fluctuate until a stable zone was kept. However, there is a very obvious transparent portion of the crystal near the end of the growth, demonstrating a potential to grow a very pure single crystal of $CaWO_4$ in future work.

As for the Er^{3+} doped samples, the style of formula $Ca_{1-2x}Er_xLi_xWO_4$ demonstrates a very clear trend in increased doping, as pellets will become a deeper pink color as doping levels are increased. Although optically very apparent that doping levels increase, lower concentrations of Er^{3+} doping are needed for use in functional transducers for the future.

Figure 7. First floating zone single crystal of $CaWO_4$

Figure 8. Second floating zone single crystal of $CaWO_4$

Future Work

For my future work, I think the next course of action will be to grow single crystals of my Er^{3+} doped samples and look at the most ideal concentration of doping. Also, I hope to eventually analyze MPMS data of each of my Er^{3+} doped samples to look at the different levels of magnetism in each sample. Also, the ability to look at EPR data for the Er^{3+} samples would be very beneficial to have an idea of the microwave transitions of these samples. Another important piece of data would be to look at Laue XRD in order to observe the purity of single crystals grown, as well as to look into different areas of the crystals within the growth. Finally, insight into the strain present in the Er^{3+} doped samples can be ascertained through performing Raman spectroscopy on the different samples and looking at the different lattice modes present in the spectra.

Acknowledgements and References

1. Nikolai Lauk *et al* 2020 *Quantum Sci. Technol.* **5** 020501
2. Mirhosseini, M., Sipahigil, A., Kalaee, M. *et al.* Superconducting qubit to optical photon transduction. *Nature* **588,** 599–603 (2020).

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