Characterizing Radiation Induced Color Centers in Lithium Fluoride

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BACKGROUND

Color centers are impurities in a crystal's regular lattice structure which can alter its optical properties. F-centers are a specific type of color center where an anionic vacancy gets filled with an electron, which can then be excited and re-emit light at wavelengths that the crystal originally did not emit.

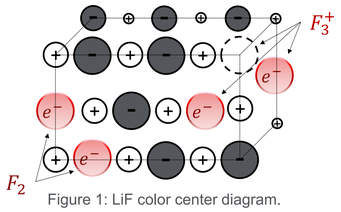


Figure 1: LiF color center diagram.

In this study of Lithium Fluoride (LiF), the two types of color centers of interest are F_2 centers (2 adjacent vacancies filled with 2 electrons) and F_3^+ centers (3 adjacent vacancies filled with 2 electrons). While these color centers can both be excited with 450 nm light, F_3^+ centers re-emit light at 525 nm and F_2 centers re-emit light at 670 nm, creating two distinct peaks in the emission spectra (Figure 4).

PURPOSE

- According to the PALEOCCENE concept[1]; neutrons, neutrinos, and, potentially, dark matter participate in nuclear recoil events which can damage materials like LiF, leaving behind color centers.

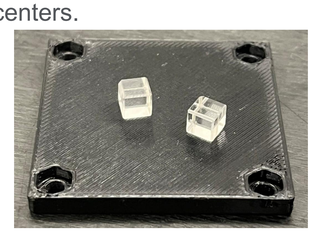


Figure 2: Picture of some measured LiF crystal samples.

- With improved characterization of how radiation damage influences color center formation in semi-pure, artificial LiF samples; long-lived natural samples could eventually be scanned for evidence of dark matter damage which may have occurred over their ~10^6 year lifespan.
- This study focuses on the time/temperature dependence of gamma and neutron irradiated LiF color centers through two imaging types: Bulk Fluorescence through spectrophotometry and individual Track Fluorescence through fluorescence microscopy.

BULK FLUORESCENCE

Time Dependence

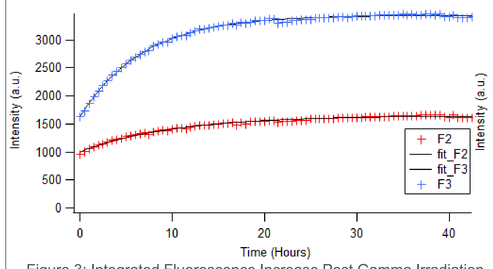


Figure 3: Integrated Fluorescence Increase Post Gamma Irradiation

- One sample was gamma irradiated for 3 hours and scanned repeatedly for 43 hours to measure the exponential increase in F_2 and F_3^+ fluorescence. The signals were integrated across the F_3^+ (495 - 585 nm) and F_2 (585 - 685 nm) spectral ranges after background subtraction to produce Figure 3.
- This increase in signal could be due to color center kinetics in the crystal, such as invisible F-centers combining to form F_3^+ and F_2 centers.

Temperature Dependence

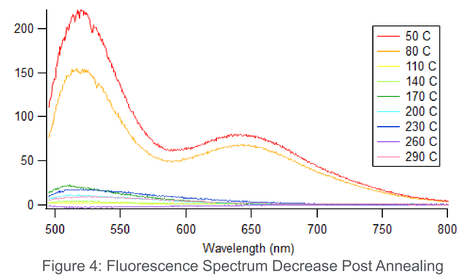


Figure 4: Fluorescence Spectrum Decrease Post Annealing

- Nine samples were gamma irradiated for 41.3 hours and annealed separately in 30℃ temperature steps from 50℃ to 290℃ for 1 hour.
- The samples were measured before irradiation, pre-annealing , and post-annealing. The pre- and post-annealing spectra were integrated over the F_3^+ and F_2 spectral ranges after background subtraction to calculate the relative decreases in fluorescence.

TRACK FLUORESCENCE

Figure 5: Benchtop mesoSPIM diagram. Retrieved from https://mesospim.org/design/.

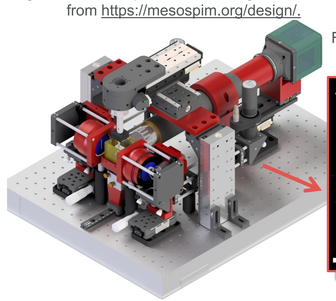


Figure 6: Sample slice from LiF sample after thresholding[2].

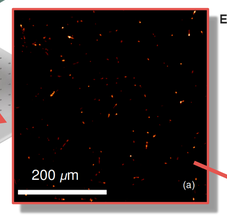
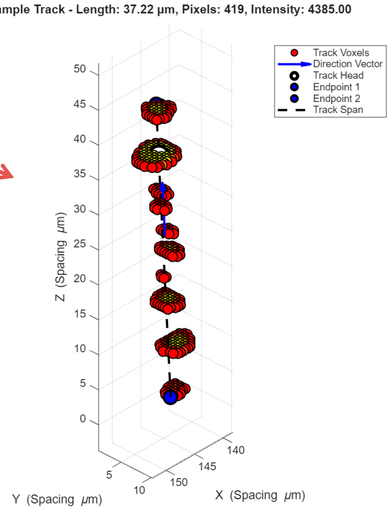


Figure 7: Calculated mesoSPIM Track.



Neutron irradiated LiF samples were scanned with a benchtop mesoSPIM Light Sheet Fluorescence Microscope (LSFM) with 0.42 x 0.42 x 6 μm^3 scan resolution[3]. Data processing was done in a custom MATLAB code which pre-processed data with gaussian blurring, identified radiation damage tracks with a custom clustering code, and stored information on track position, direction, length, and total intensity.

RESULTS

Bulk Fluorescence

Time Dependence

- The F_2 and F_3^+ centers' fluorescence curves fit time constants of 10.1 ± 0.3 hours and 6.8 ± 0.1 hours respectively, which were close to previous studies results[2].

Annealing Temperature Dependence

- The gamma irradiated samples showed no significant decrease in fluorescence at 50℃, about a 40-50% decrease at 80℃ and almost complete loss of fluorescence (>99% decrease) at temperatures at and higher than 110℃.
- These results indicate some level of fluorescence decrease at lower temperatures than previously used for complete annealing of LiF radiation damage (350℃).

Track Fluorescence

- Tracks in the z-axis direction are identified by the code well; however, improvements need to be made to better detect tracks in the xy-plane. Additionally, scanning the crystal in different orientations may provide enough data to detect these primarily non-axial tracks.

CONCLUSIONS

- **Lithium fluoride's fluorescence is heavily dependent on its thermal/temporal history.**
- **Track data from LSFM could help reveal more about color center properties and radiation history in comparison to bulk spectroscopy.**

REFERENCES

[1] Krystal Alfonso et al. Passive low energy nuclear recoil detection with color centers – PALEOCCENE. In Snowmass 2021, 3 2022.
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[3] N. Vladimirov et al. Benchtop mesoSPIM: a next-generation open-source light-sheet microscope for cleared samples. Nature Communications, 15:2679, 2024.

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