ZnO Nanowire Radiation Detectors with High Spatiotemporal Resolution

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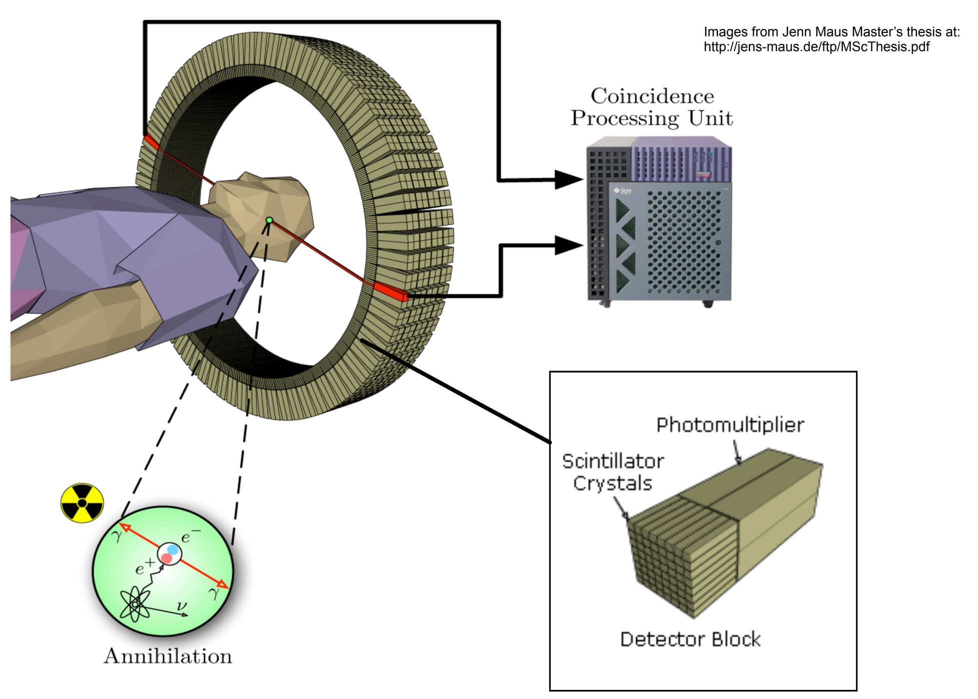
Motivation



- LYSO (cerium-doped lutetium yttrium orthosilicate) response time 100's of picoseconds -> spatial uncertainty of single-digit cm
- ZnO response time 10s of picoseconds -> spatial uncertainty of single-digit mm

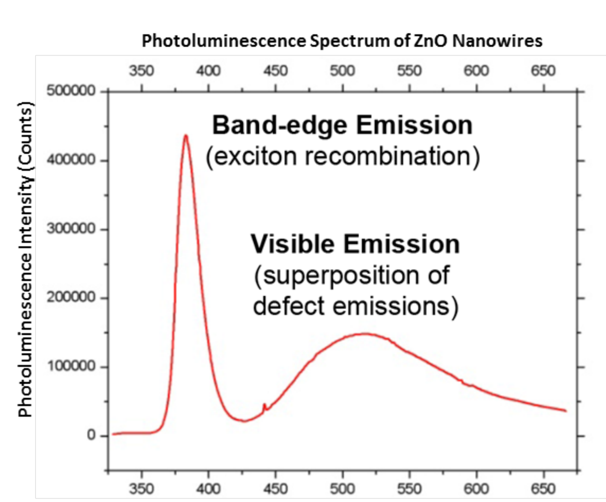
Faster scintillator response = greater spatial resolution for higher accuracy scans

- ZnO NWs are cheap to make, require little to no power, efficient, lightweight, and can be easily manufactured

ZnO Properties

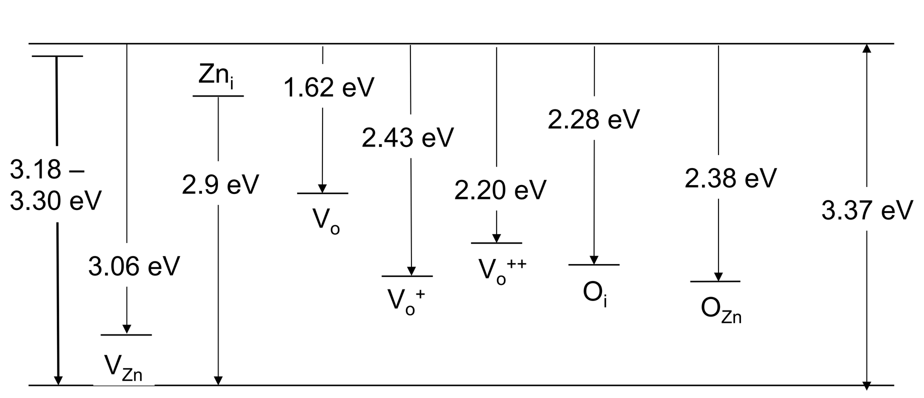
ZnO Material Properties:

- Efficient optoelectronic material
- Direct bandgap of 3.37 eV
- Very stable band-edge exciton ($E_{binding}$= 60 meV)
- Typical photoluminescent (PL) spectra:
  - Near UV (band-edge exciton) emission
  - Visible (donor-acceptor-pair) emission

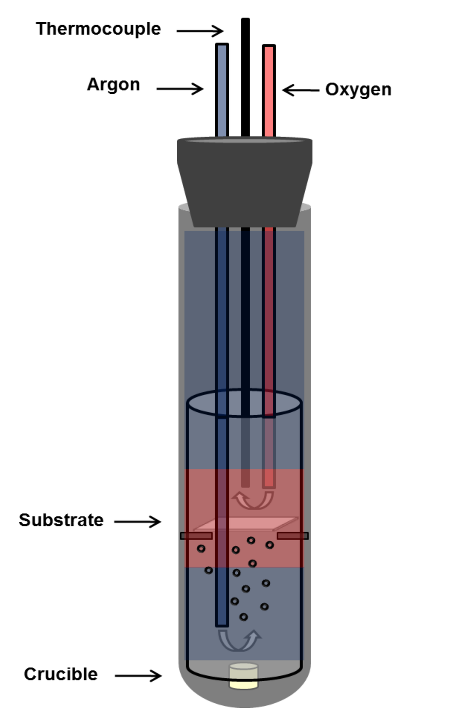


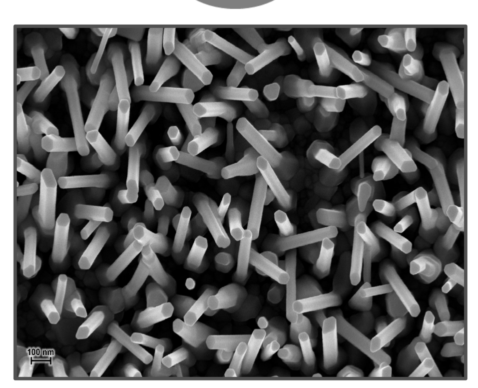
ZnO Nanowire Properties:

- Enhanced surface area-to-volume ratio compared to planar structures
- High crystallinity enhances band-edge emission
- Waveguiding effects allow for nearly all emitted light to be detected



ZnO Nanowire Growth

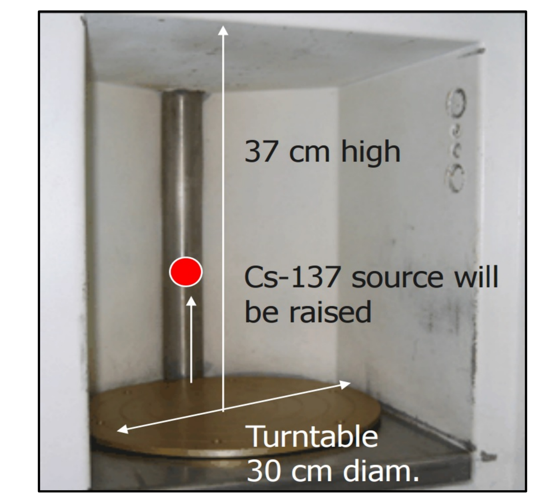


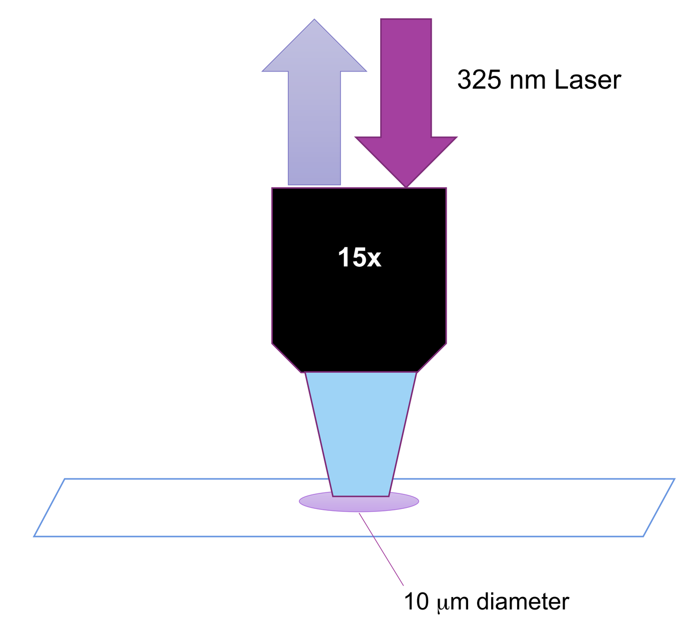


1. 500 µm thick fused silica substrate cut to approximately 1 cm x 2 cm with diamond saw
2. Electron-beam evaporation used to deposit 100 nm ZnO seed layer on substrates
3. Substrates placed onto two Si wafer shelves in quartz tube, Zn source placed in crucible at bottom
4. Ar gas (800 SCCM) used to purge system of ambient air
5. O_2 flow (30 SCCM) established and tube transferred to vertical furnace preheated to 690 ºC
6. After 5 minutes, Ar flow rate reduced to 350 SCCM to allow O_2 reach below the substrate
7. ZnO nanowires begin growing from seed layer

Experimental Procedure

- ZnO NW sample placed in irradiation chamber where it is bombarded with gamma rays from Cs-137 source
- Cs-137 emits 3.215 x 10^{12} 662 keV gamma rays per second per gram
- Rough calculation on number of events in irradiated ZnO NW sample





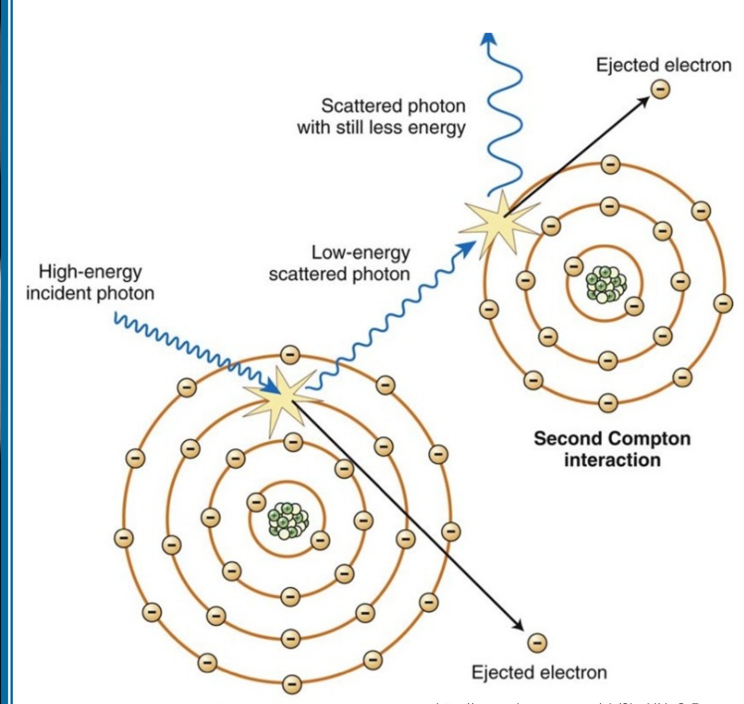
- Sample kept under dark conditions to minimize UV interaction
- Photoluminescence spectroscopy (PL) was performed each day following irradiation for 5 days
- Enabled analysis of changes in the band edge emission and visible emission as a function of time

F^+ Center Formation

- 662 keV gamma rays interact with matter predominantly through Compton Scattering

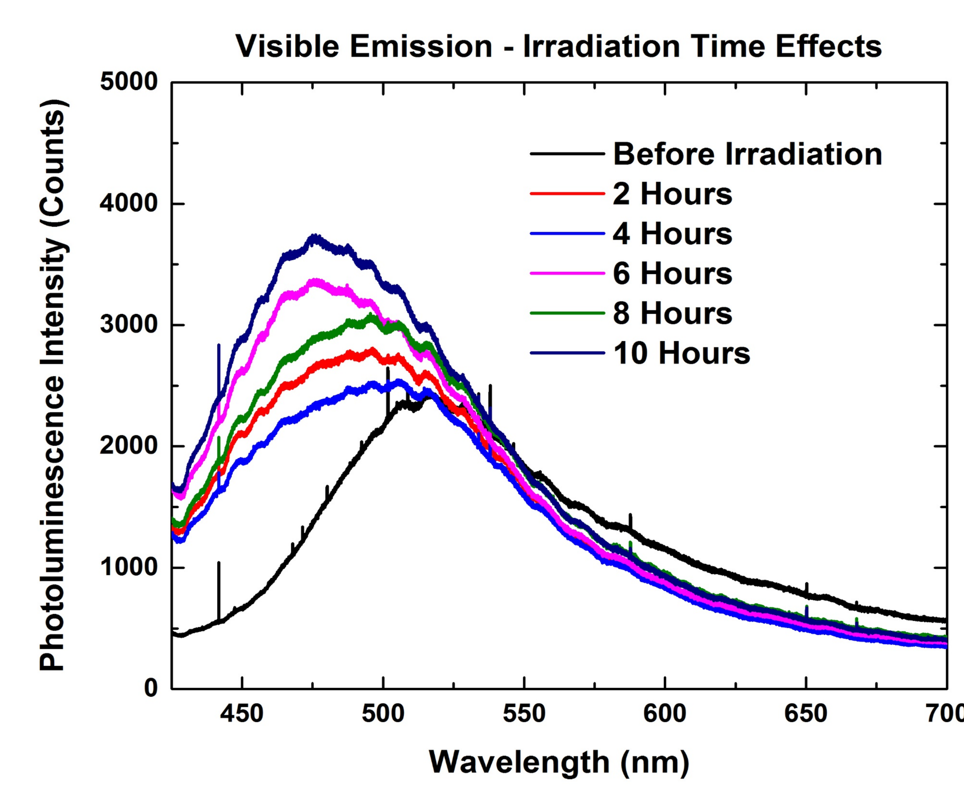
Compton Scattering:

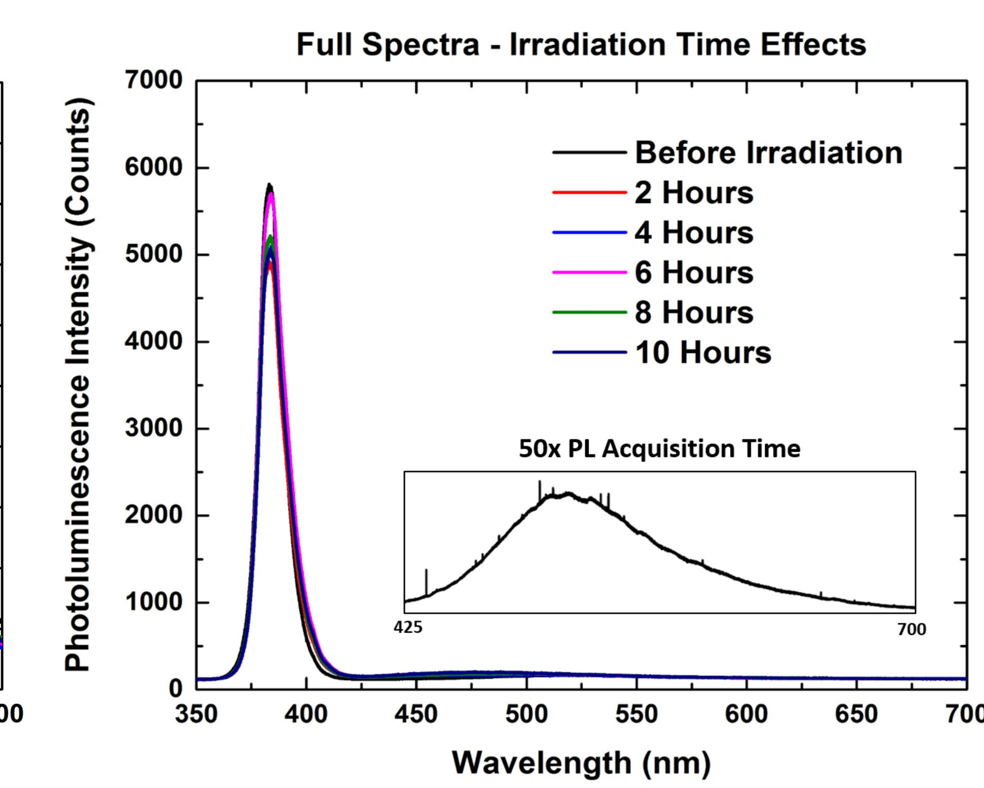
- High-energy photon incident upon an electron
- Electron emits a photon of lower frequency and is ejected from the atom, leaving a hole

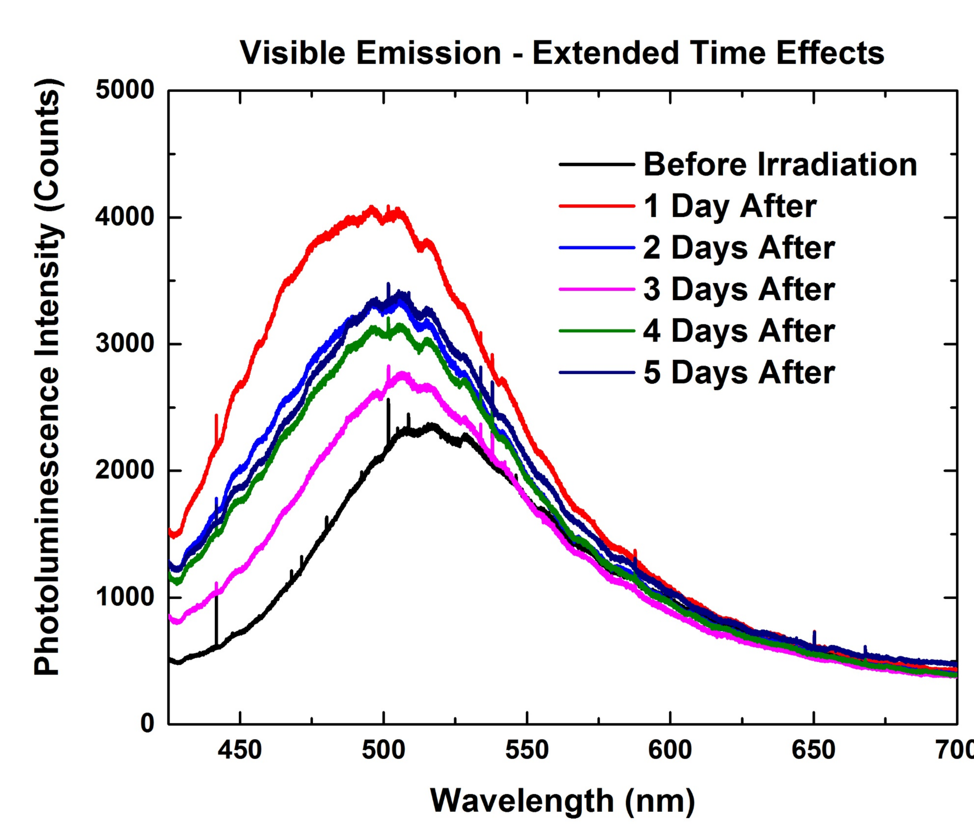


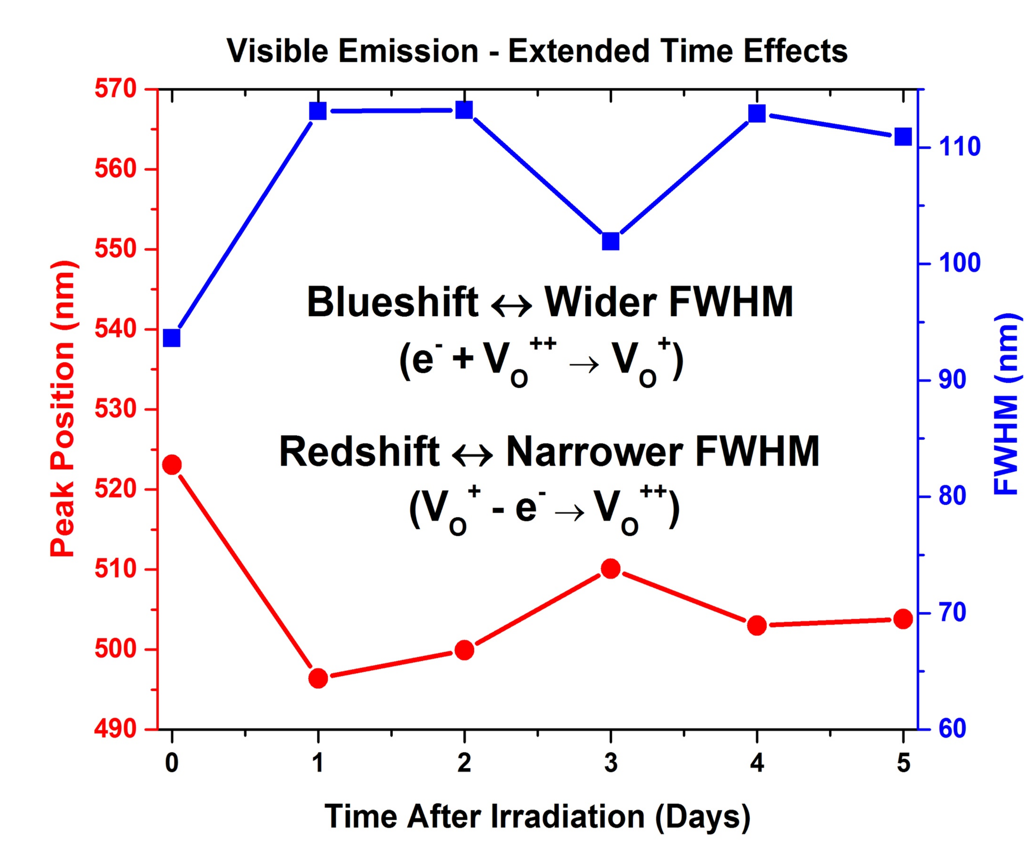
- Emitted photons attenuate with each Compton interaction
- **More energetically favorable for ejected electrons to combine with an O_2 vacancy in ZnO than with hole – leading to formation of F^+ centers**

Photoluminescence Results







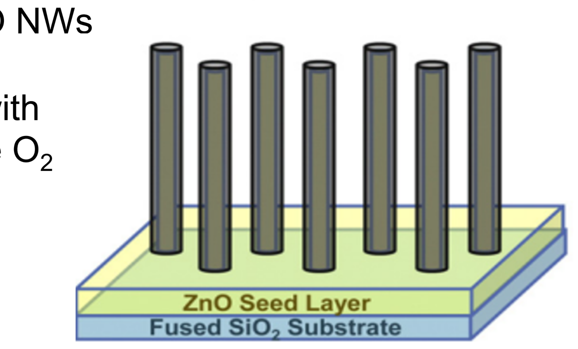


Conclusions

- **F^+ centers (V_o^+) were generated in ZnO NWs by gamma radiation and migrated by diffusion to the surface**
- **The increase in F^+ centers initially caused a blue shift and an increase in intensity in the PL visible emission**
- **Over time visible emission peak red shifted and lowered in intensity, eventually returning to near baseline**
- **Electrons are being freed from F^+ centers, resulting in stable V_o^{++}**
- **There was no significant change in the band-edge emission as a result of gamma radiation**
- **ZnO NWs show the ability to 'heal' themselves of radiation damage, making them a promising gamma radiation detector**

Future Work

- Examine effects of UV exposure on visible emission of irradiated sample – potential fast "healing" of F+ centers
- Irradiate sample for much longer time to determine if gamma irradiation causes unhealable damage
- Compare ZnO NW gamma ray detection efficiency with typical detectors such as LYSO
- Study the damage effects of charged particle irradiation on ZnO NWs
- Coat ZnO NWs with MgO to passivate O_2 vacancy surface states



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Acknowledgements

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