

Quantum dots microstructured optical fiber for x-ray detection

By

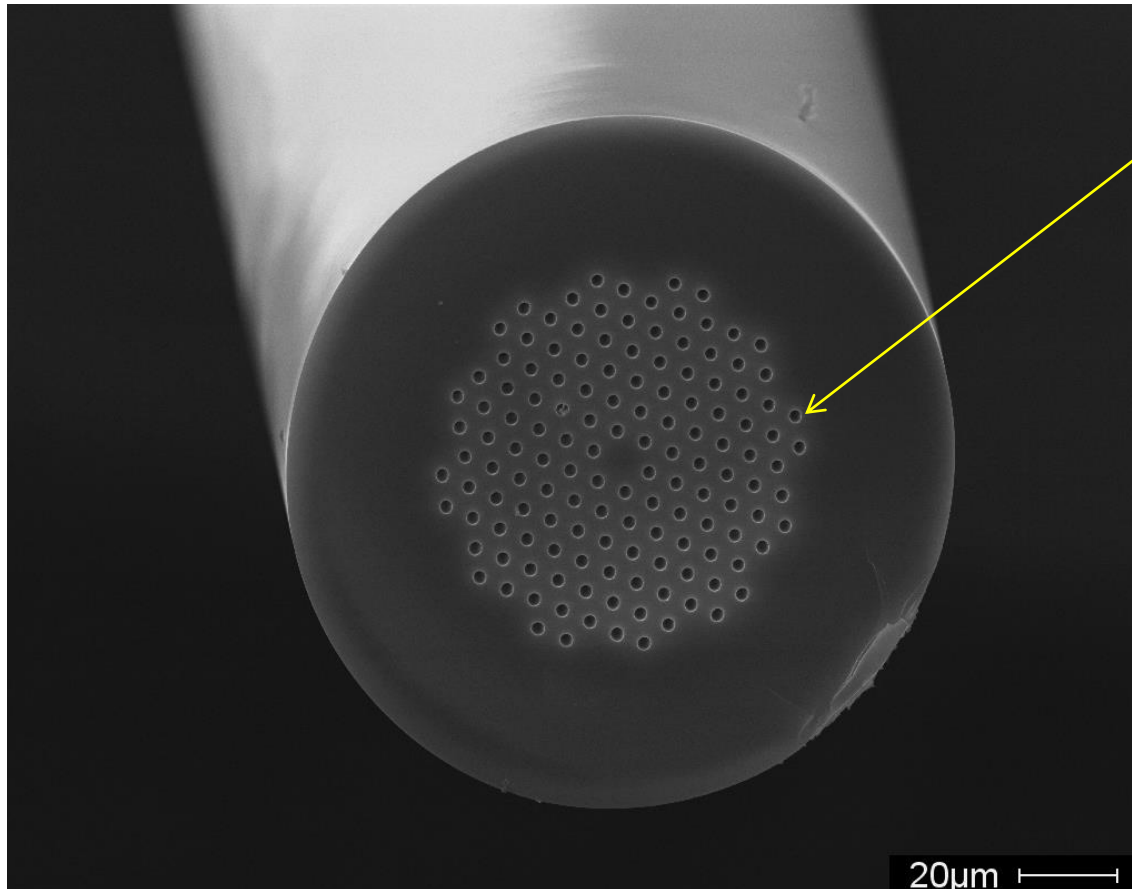
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Why incorporate Quantum Dots in a fiber to detect x-rays?

- Potential NDE applications
- Quantum dots offers a range of designer materials which are easily incorporated into microstructured optical fiber
- Directionality of detector may have other x-ray system uses
- Technology in fiber optic sensors and x-ray detection advancement
- Increased quantum dots output from fiber optics

Fiber microstructured geometry: quartz structure with inclusions



ϕ 2.5 μm
inclusion

20 μm 

Detectors Used for X-rays

- Scintillator Type
 - Organic (used in plastic, liquid filled, etc.)
 - Inorganic (standard: NaI(Tl) crystal, new: quantum dots)
- Semiconductor Type
 - Silicon (low energy $<20\text{keV}$)
 - CdTe (100% efficient $>10\text{keV}$ and $< 50\text{keV}$)
- Quantum dot scintillating fibers are compared to a commercial CdTe detector.

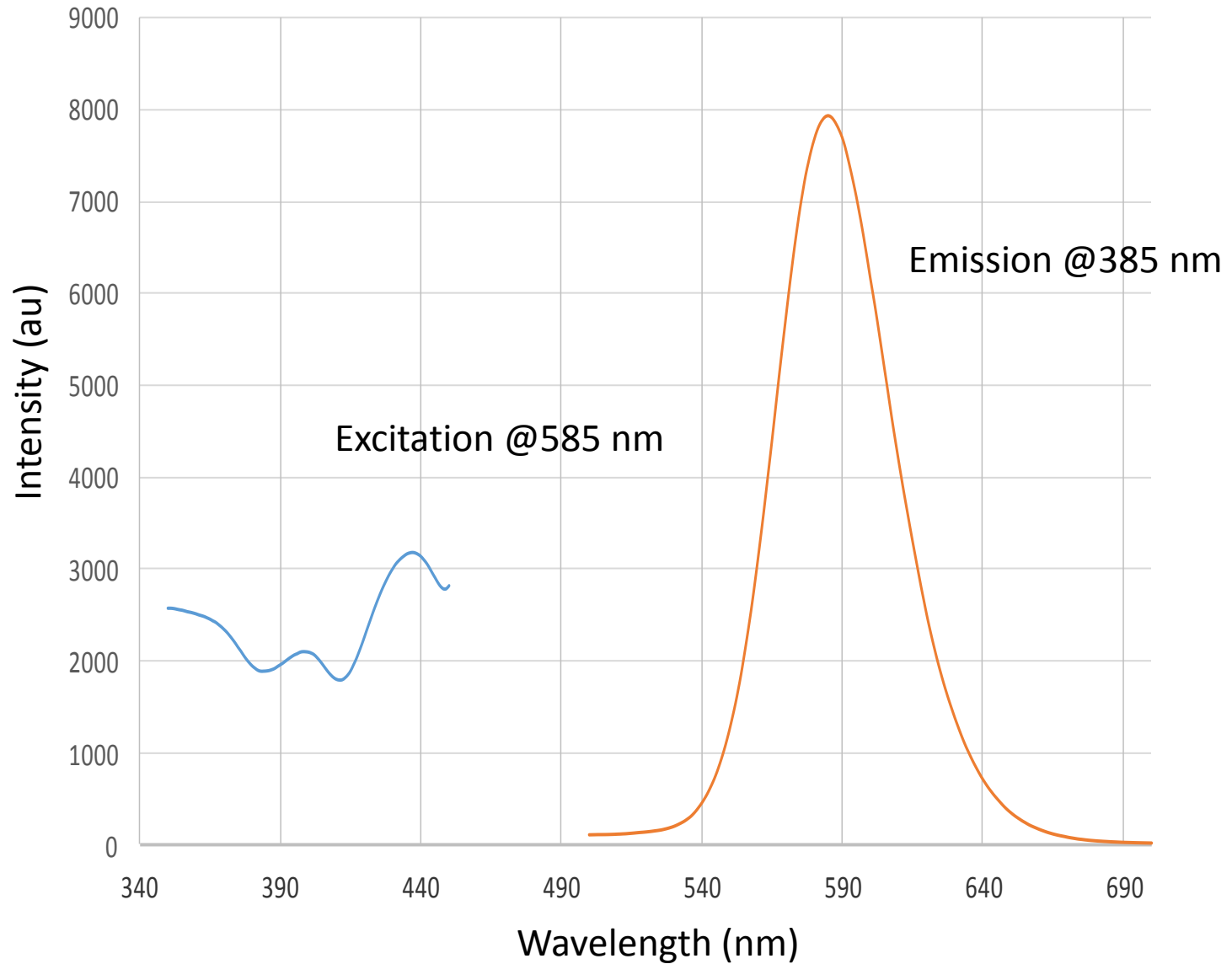
Scintillators

- Atomic energy change from x-rays releases visible photons from scintillator material.
- Photons are captured in waveguide structure and directed to a detector.
- NaI(Tl) and CsI(Tl) are the most common standard inorganic scintillators for x-ray detection but must be grown, typically from vapor deposition or the melt.
- Quantum dots, comprised of ZnS(MgS), is a new scintillating material used in the fiber.

Fluorescence and scintillation emission

- UV fluorescence gives the same scintillation emission as x-rays: this allows evaluating some fiber characteristics using UV.
- The quantum dots fluoresce using UV and can be analyzed using spectrophotometry.
- The ZnS(MgS) quantum dots yield a 580-610 nm peak emission from UV (385 nm) and x-rays.

Quantum Dots Excitation-Emission Spectra



Fiber preparation

- Inclusions hold quantum dots (QD).
- QDs are placed in fiber via capillary action.
- Fiber optic waveguide uses total internal reflection and scattering to carry scintillation light from QDs through quartz.

Quantum dot fiber emission from UV (365 nm) excitation

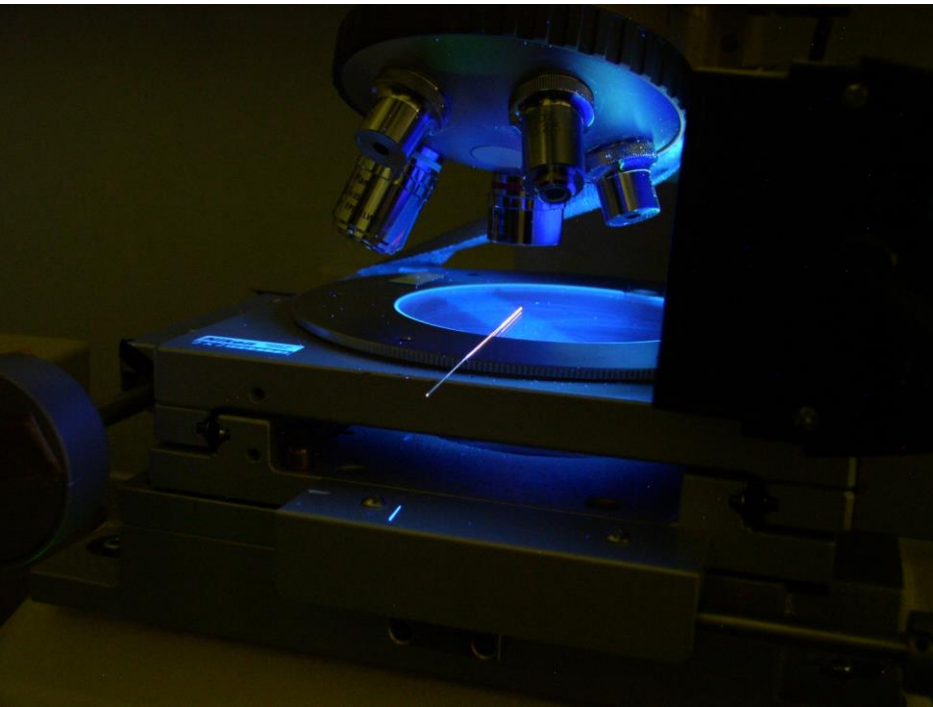
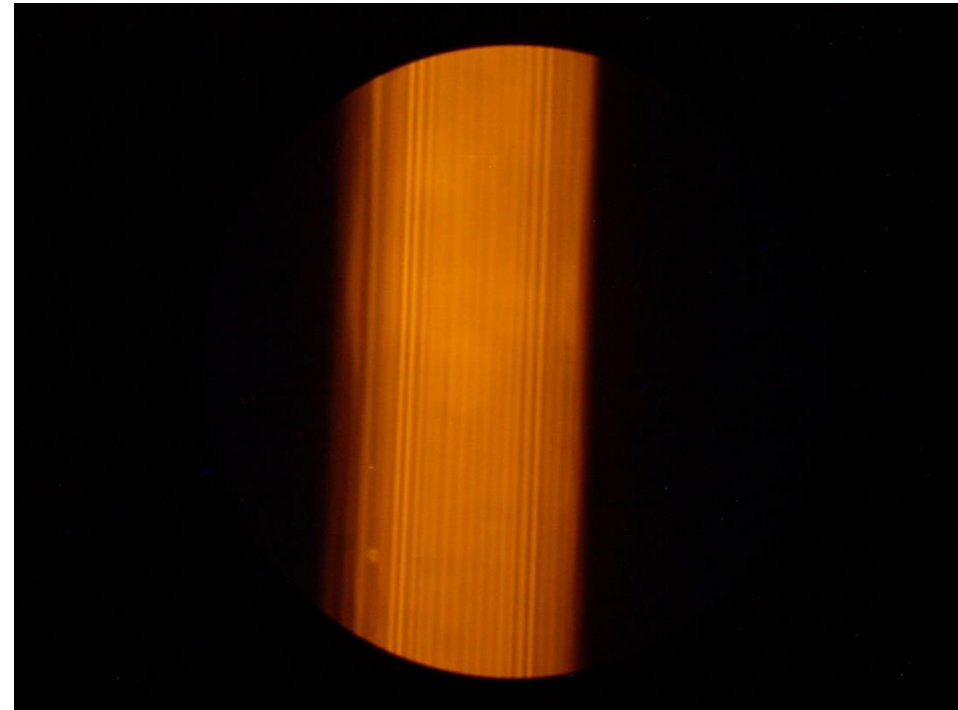
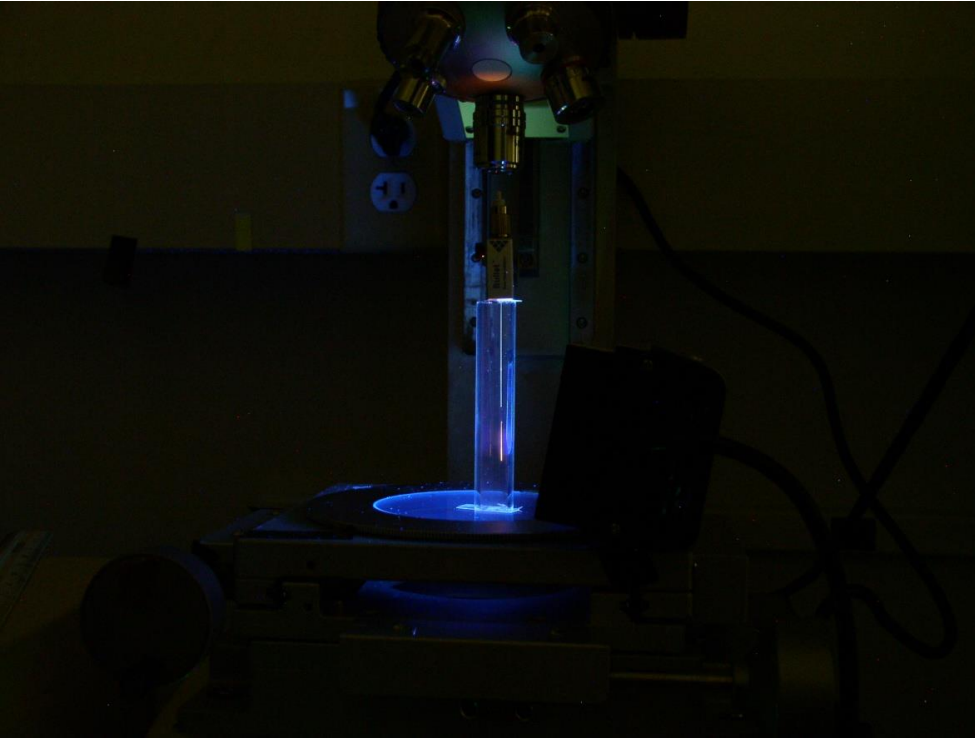


Image showing end emission from UV excitation of quantum dots in MOF

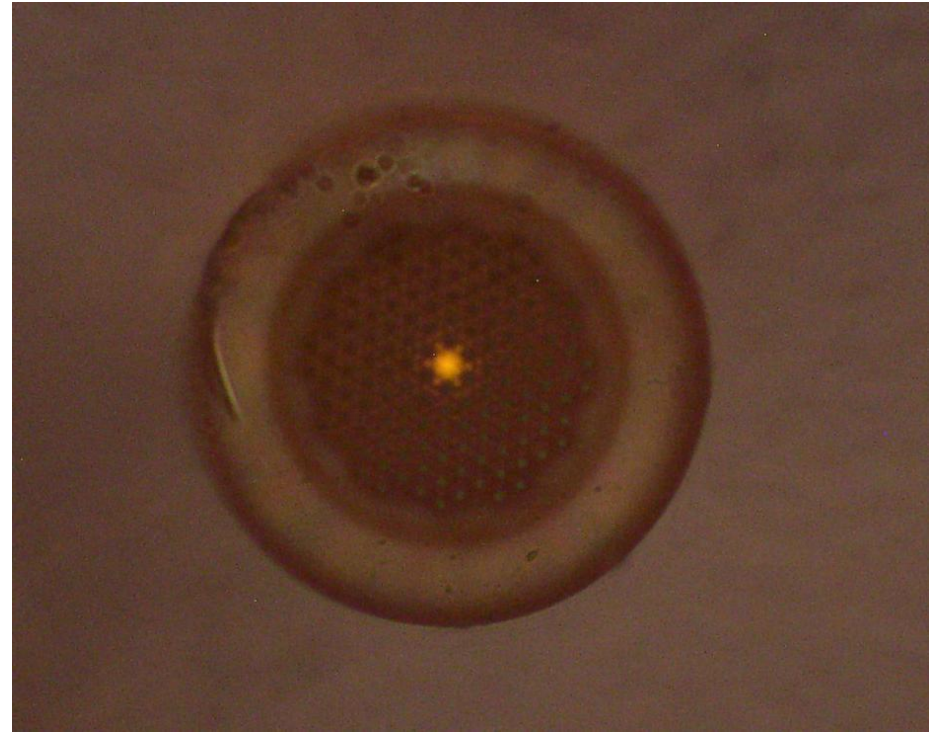


500x image of MOF showing quantum dots deposited along longitudinal axis of the fiber

Quantum dot fiber emission in MOF from UV (365 nm) excitation



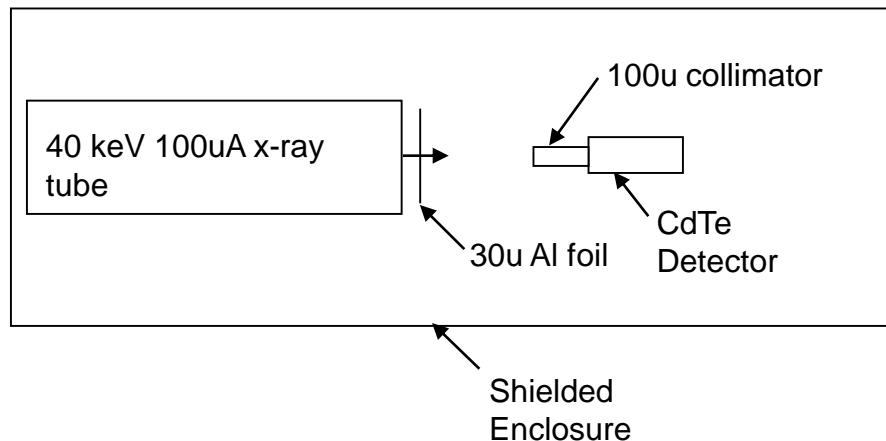
Illumination of MOF with quantum dots with the fiber oriented vertically for viewing through a microscope



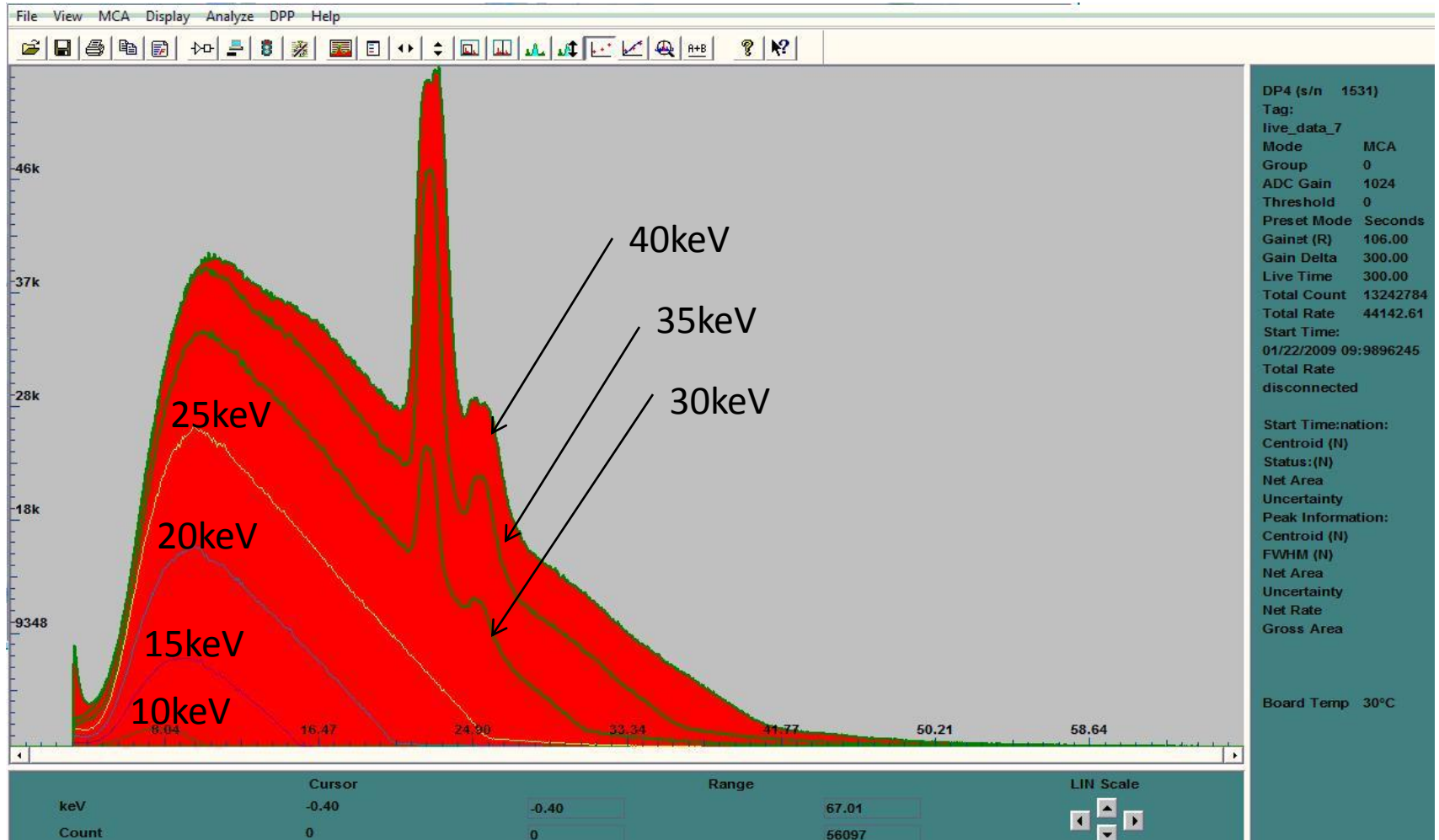
End view of MOF with quantum dots at 500x showing the transmission of 590 nm light at the end of the fiber

Measurement Setup: x-ray tube

- X-ray tube characterization
 - CdTe MCA detector with 100 μ m collimator
 - Be window, evacuated, Peltier cooled
 - Collimator placed 5mm from tube end

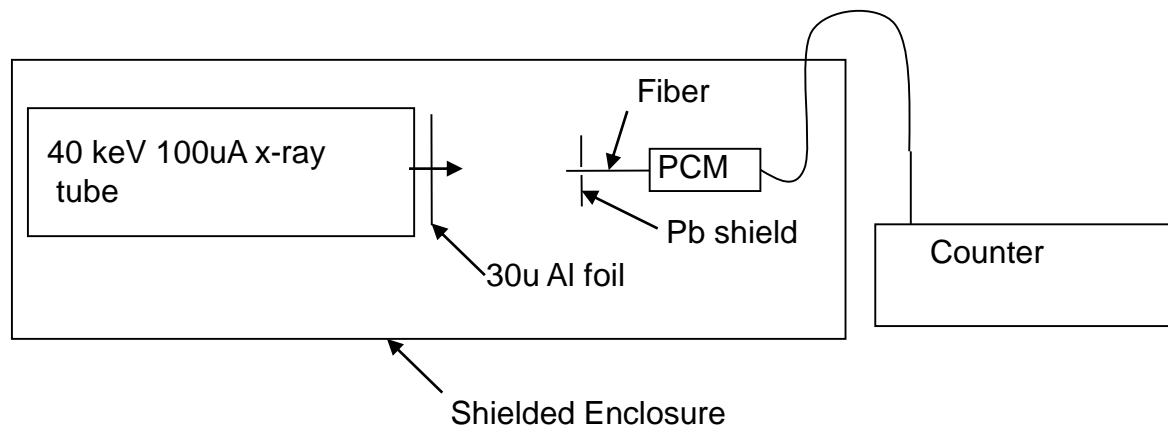


X-ray (Ag anode) tube characterization

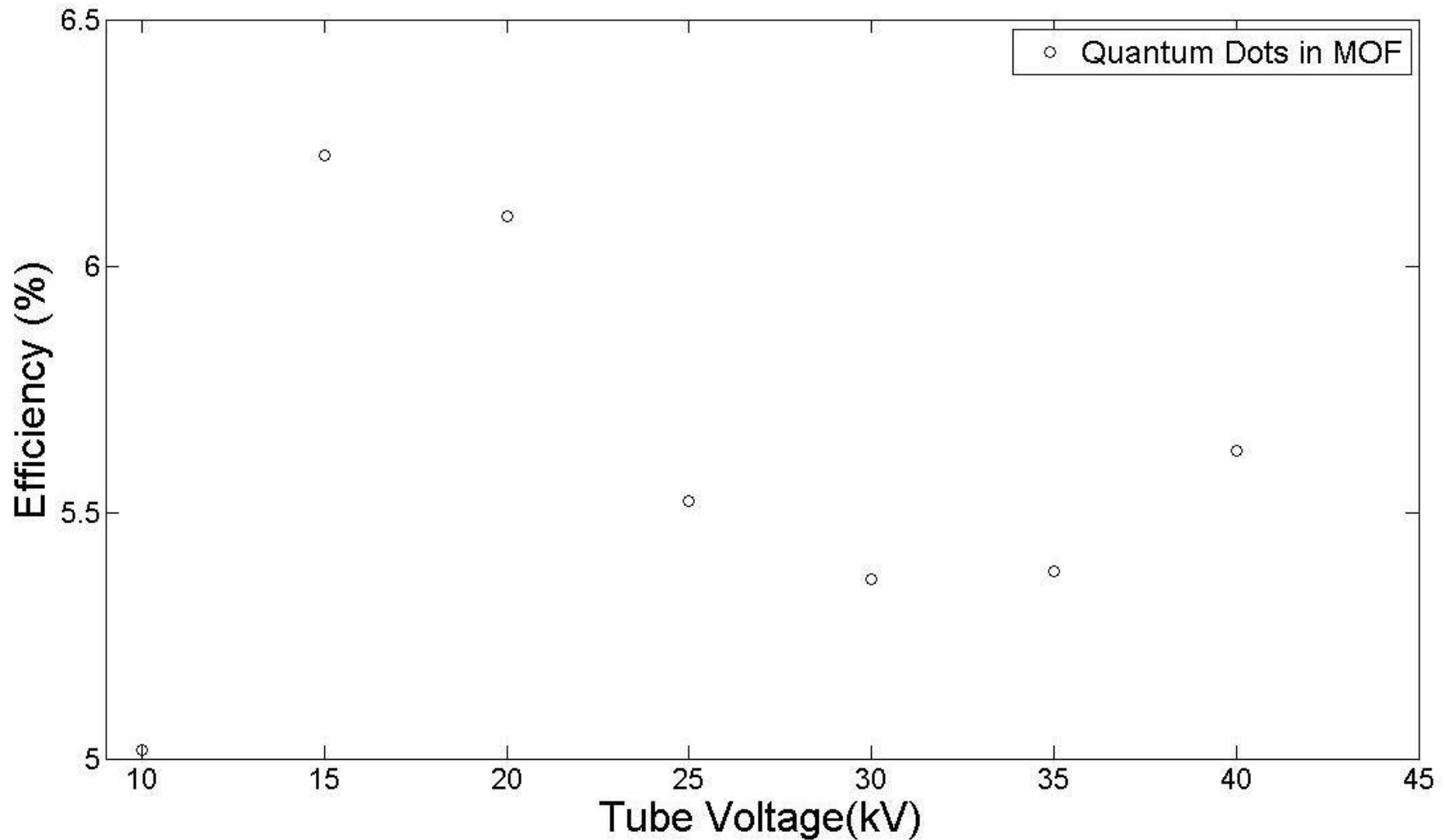


Measurement Setup: quantum dots in microstructured optical fiber

- Microstructured fibers photon counting
 - Fiber output to photon counting module (PCM) and counter
 - PCM $\eta_e \approx 65\%$ @ 585 nm
 - Fiber placed 5mm from tube end



Quantum dot measured efficiency in microstructured optical fiber vs. Tube voltage



Results

- Quantum dots in MOF show efficiencies between 5-6%.
- Quantum dot efficiencies are non-linear.
- CdTe detector is considered 100% efficient for counting x-ray photons in the energy range used.

Considerations

- Photon counting module used to measure Quantum dots efficiency is $\sim 65\%$ efficient.
- Quantum dots fill 2.5 cm of the microstructured fiber 12 cm length; fiber length is associated with collimator length for CdTe detector.
- Fiber preparation uses capillary action to draw quantum dots in toluene into fiber.

Conclusions

- The Quantum dots Microstructured optical fiber containing ZS(MnS) quantum dots can be used to detect x-rays at 5-6% efficiency.
- A specific fiber length is required for comparing fiber output to the CdTe detector.
- Other inorganic scintillator quantum dots could be similarly substituted and evaluated for relative efficiency.

Questions?