The Size Effect of Powdered Scintillator on High-Resolution X-ray Imaging System

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Introduction

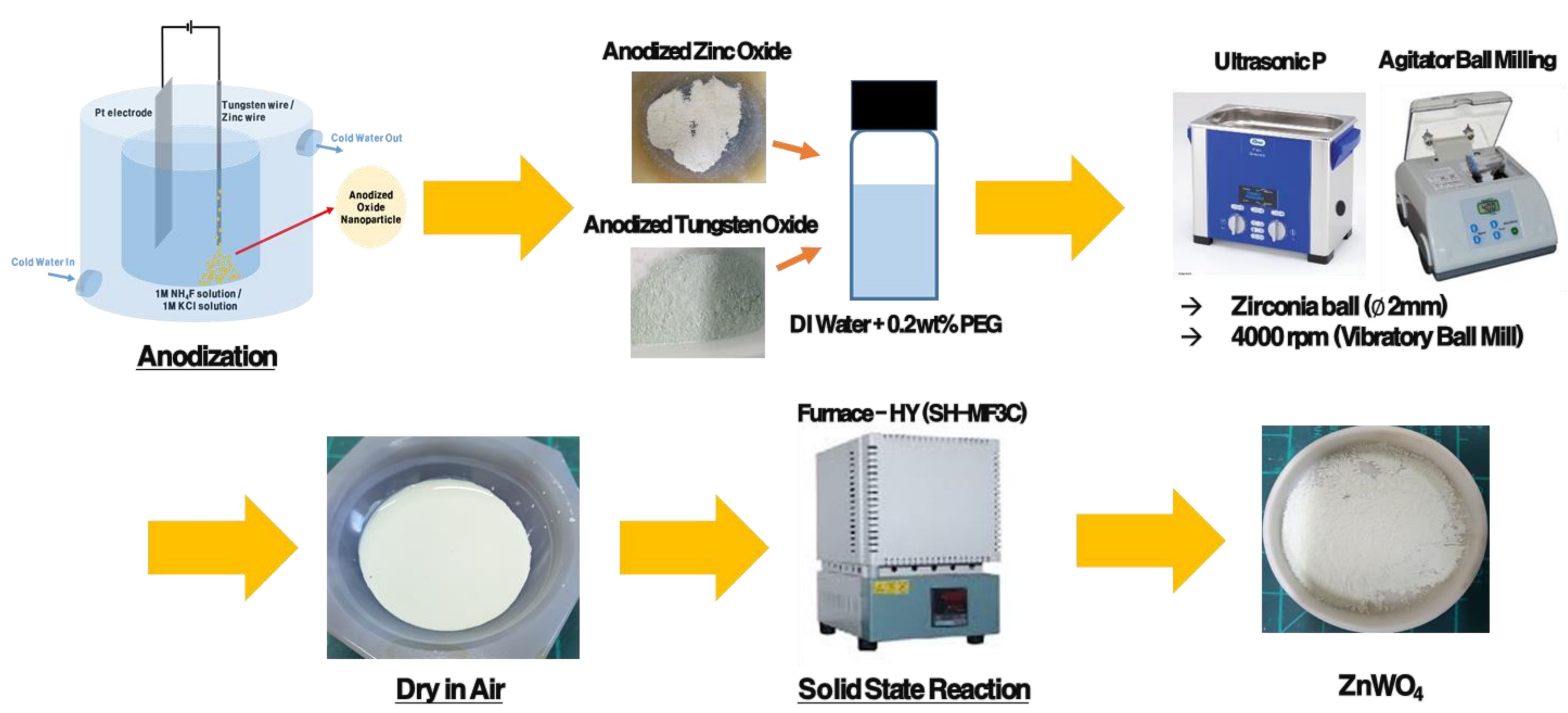
Digital X-ray imaging utilizes a converter which produces visible light (indirect) or electrons (direct) after absorbing X-rays. An indirect setup uses a scintillator as a converter coupled with a light detector [1]. A scintillator is a substance that emits visible light when exposed to X-rays or other forms of radiation. The structure and optical properties of scintillators affect the quality of X-ray images. Powder scintillators are used ubiquitously in various industries especially in those involving medical diagnostics and non-destructive testing [2]. With such scintillators, the generated optical light is optically diffused due to the presence of particles, reducing the spatial resolution of the produced X-ray images [3]. However, if the powder scintillators are composed of nanoparticles, high spatial resolution can be achieved due to minimal optical diffusion [4]. ZnWO4 is a material of great interest in regard to being used as ultraviolet, X-ray, γ-ray, electron beam and proton beam scintillators [5] as the material is of low price and possesses excellent luminescence property, high density, high chemical stability, short decay time, and low afterglow.

Our research team has previously developed a high-resolution X-ray inspection system (HRXIS) [6]. This system consists of a carbon nano-tube (CNT) based miniature X-ray tube, a scintillator, an optical lens, and a scientific complementary metal-oxide-semiconductors (sCMOS) detector. The system utilizes X-rays to generate images with the scintillator positioned directly under the object of interest. The images generated by the scintillator are magnified by the optical lens and then developed by the sCMOS detector. This system can not only produce X-ray images with high spatial resolution, but can also inspect for internal defects that are micrometers in size.

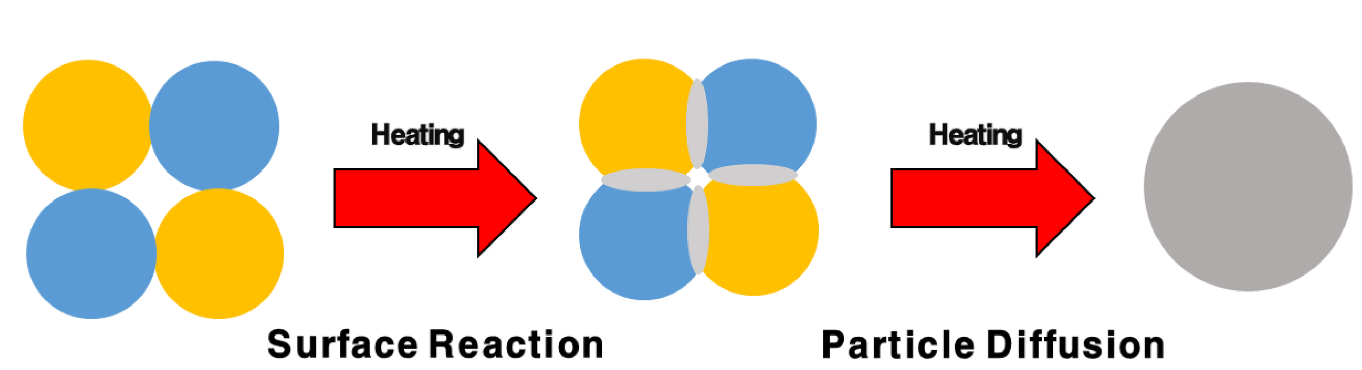
In this study, the zinc oxide and tungsten oxide nanoparticles, used in the solid-state reaction, were synthesized using anodization. Anodization involves applying a voltage of 10-100 V to a platinum electrode (-) and a metal wire (+) in an electrolyte solution, which leads to the oxidation and etching of the metal wire, resulting in the formation of metal oxide nanoparticles [7]. Subsequently, ZnWO4 nanoparticles were fabricated through the solid-state reaction between the as-prepared zinc oxide and tungsten oxide nanoparticles. The solid-state reaction was carried out at various temperatures to produce ZnWO4 particles of varying sizes. A thin layer of the particles was applied onto silicon glass substrates to be used as scintillators to obtain X-ray images.

Experimental

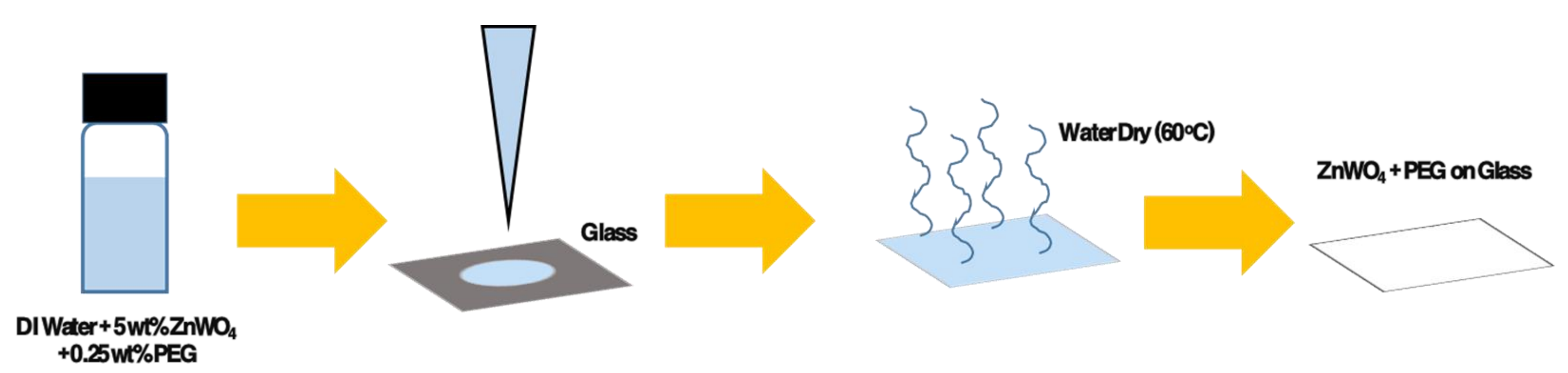
- **Fabrication of $ZnWO_4$**



- **Mechanism of Solid-State Reaction**



- **Fabrication of $ZnWO_4$ Thin Film scintillator**



- **Characterization**

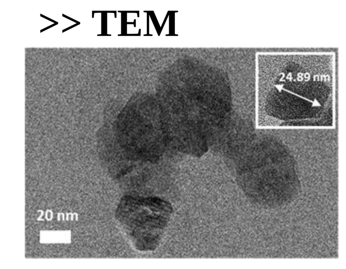
→ Surface Image : FE-SEM (Magellan 400) / TEM (Titan cubed G2 60-300)
→ XRD : High Resolution Powder X-Ray Diffractometer (SMARTLAB-RIGAKU)
→ PL spectrum in UV irradiation : MTS-150H Illuminator / Kimmon / Ramboss / Teem Photonics
→ MTF and PL intensity of X-ray Image : Home-made X-ray tube / s-Cmos Camera

Results

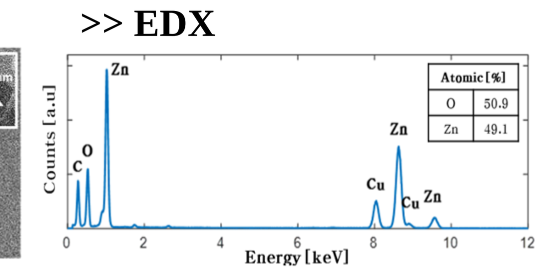
- **Zinc oxide nanoparticle**

Applied Voltage	15 V
Solution	1M KCl
Temperature	5 °C

\>> TEM



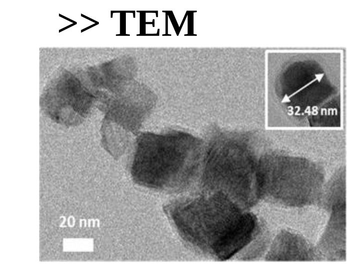
\>> EDX



- **Tungsten oxide nanoparticle**

Applied Voltage	80 V
Solution	1M NH_4F
Temperature	5 °C

\>> TEM



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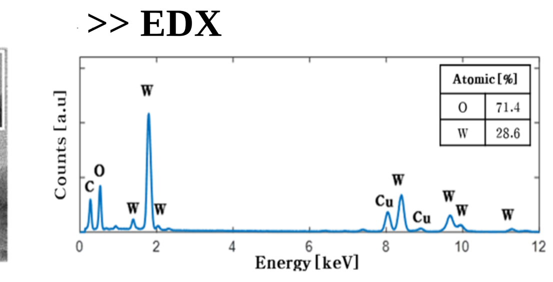
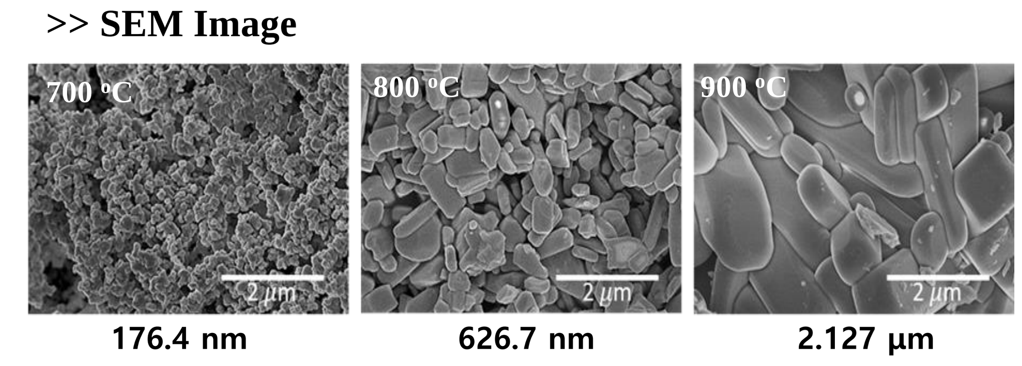
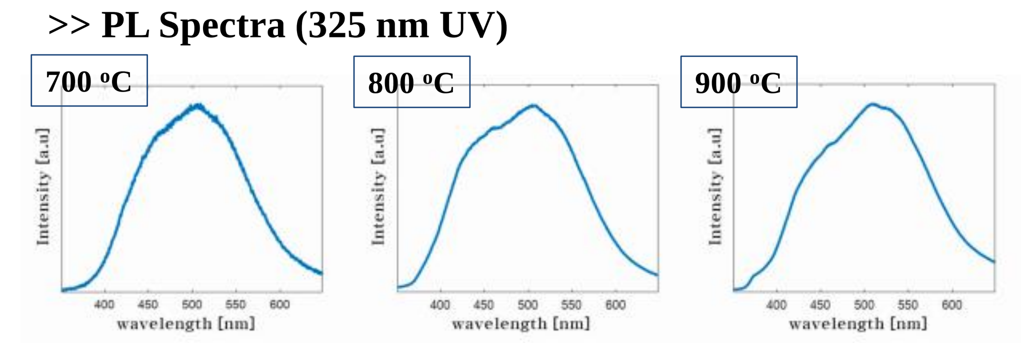


- **$ZnWO_4$ Powder Fabricated by Solid-State Reaction**

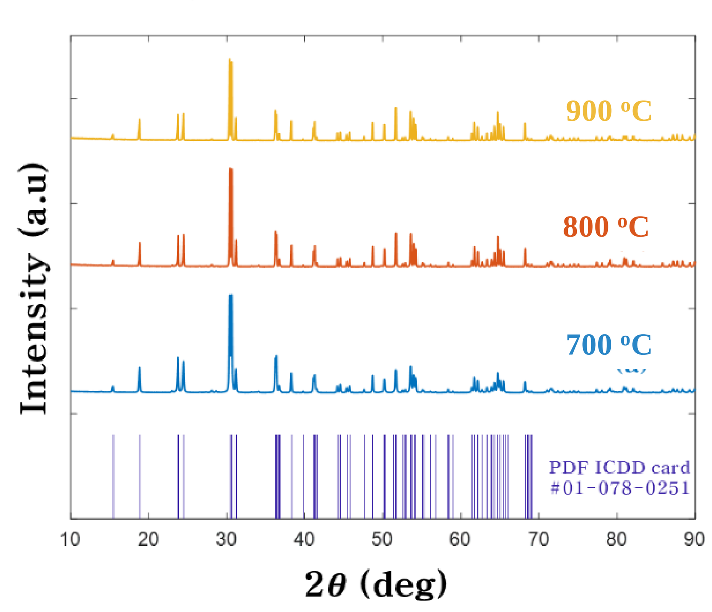
\>> SEM Image



\>> PL Spectra (325 nm UV)

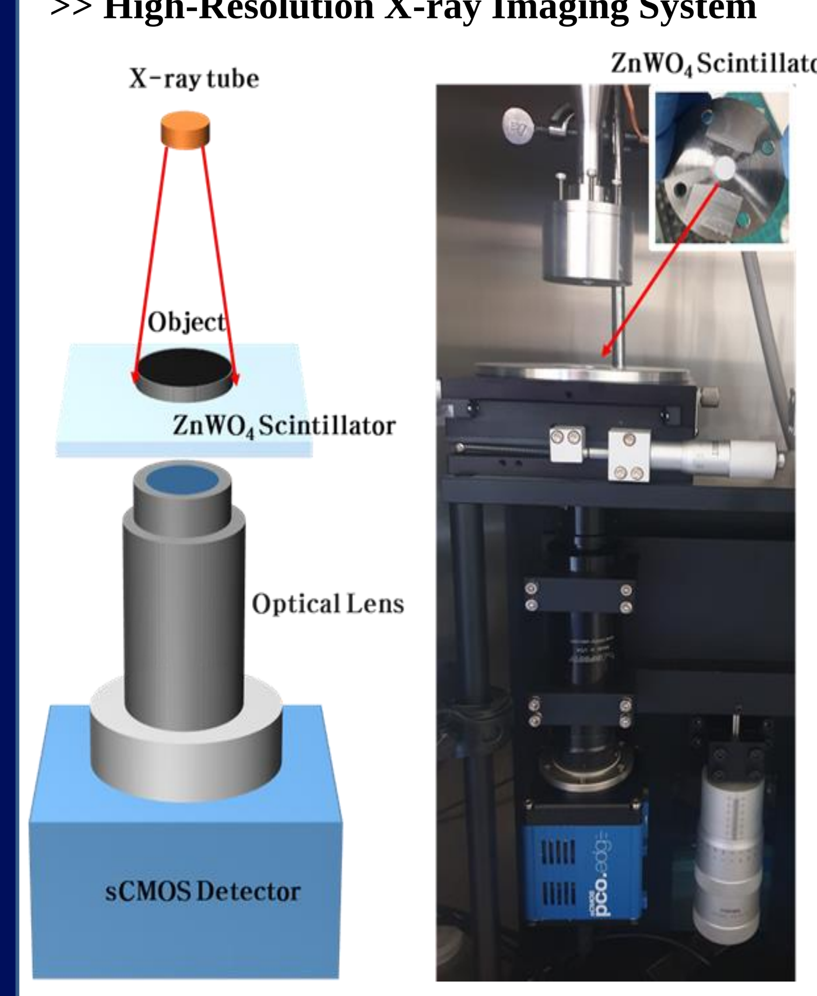


\>> XRD

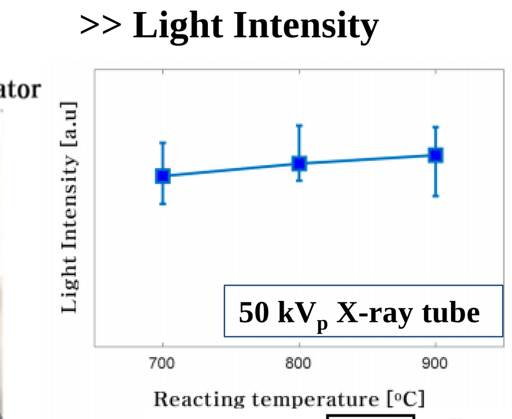


- **Characterization of $ZnWO_4$ Thin Film scintillator**

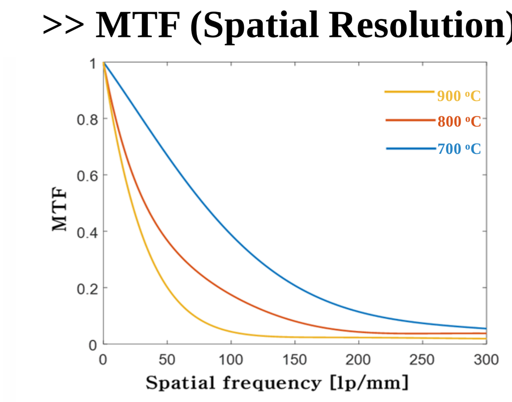
\>> High-Resolution X-ray Imaging System

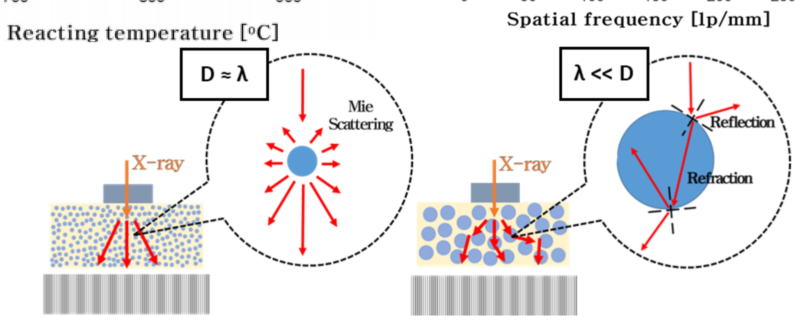


\>> Light Intensity

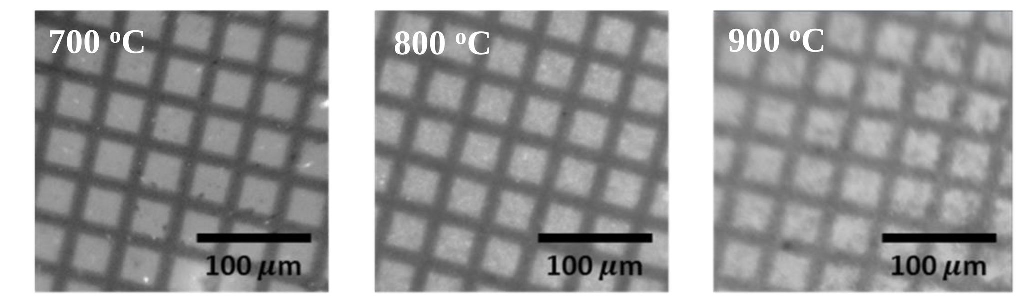


\>> MTF (Spatial Resolution)





\>> X-ray Image (TEM grid)



Smaller Scintillator Powder → Higher Spatial Resolution X-ray Image

Conclusion

The ZnWO4 scintillator particles were fabricated through anodization and a solid-state reaction. The fabricated particles were then applied to high-resolution X-ray imaging to evaluate the spatial resolutions of the produced X-ray images. The experimental results showed that the optimal spatial resolution is achieved when the average particle size is less than the emission wavelength. Since commercialized powder scintillators are currently micrometers in particle size [4], the ZnWO4 nanoparticles (100-250 nm), developed in our study, can be expected to reduce optical diffusion and provide superior spatial resolution in comparison. Furthermore, the significance of our results is not limited to ZnWO4 particles; it can also be applied to other scintillator particles.

Reference

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