Energy Deposition of a $ZnWO_4$ Thin-Film Scintillator for High-Resolution X-ray Imaging

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Introduction

- **$ZnWO_4$ Inorganic Scintillator**
  - ✓ High density and effective atomic number
  - ✓ Excellent mechanical and chemical properties[1,2]
  - ✓ Relatively high light yield (~10,000 photons/MeV)[3]
  - → Can generate a significant number of photons
- **Characteristics Depending on Scintillator Thickness**
  - ✓ Scintillator thickness ➔ Image resolution[4]

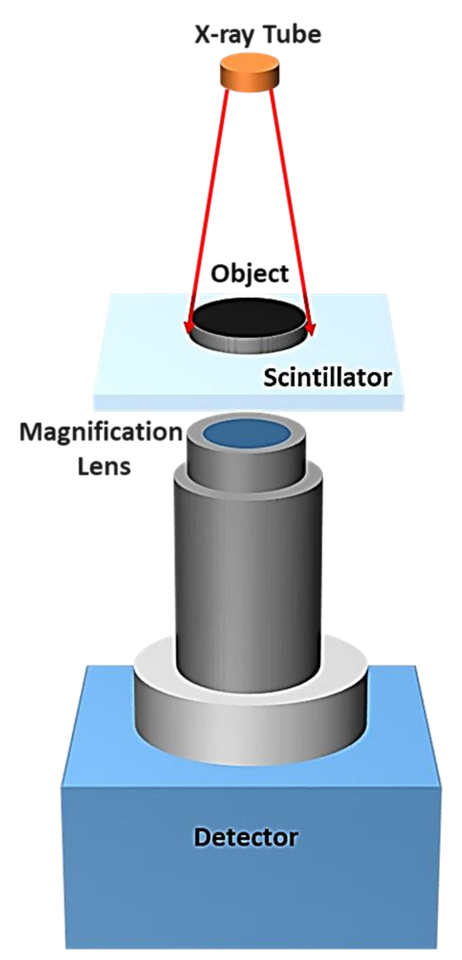
▼ Comparison of thick scintillator and thin scintillator

	Thick scintillator	Thin scintillator	
Structure	Mesh-grid	Powder- type	Glass-type
Advantage	High sensitivity	Higher sensitivity Easy fabrication Flexibility	Higher sensitivity High spatial resolution High stability
Disadvantage	Grid size limitation Low reproducibility	Optical scattering[5]	Complex fabrication

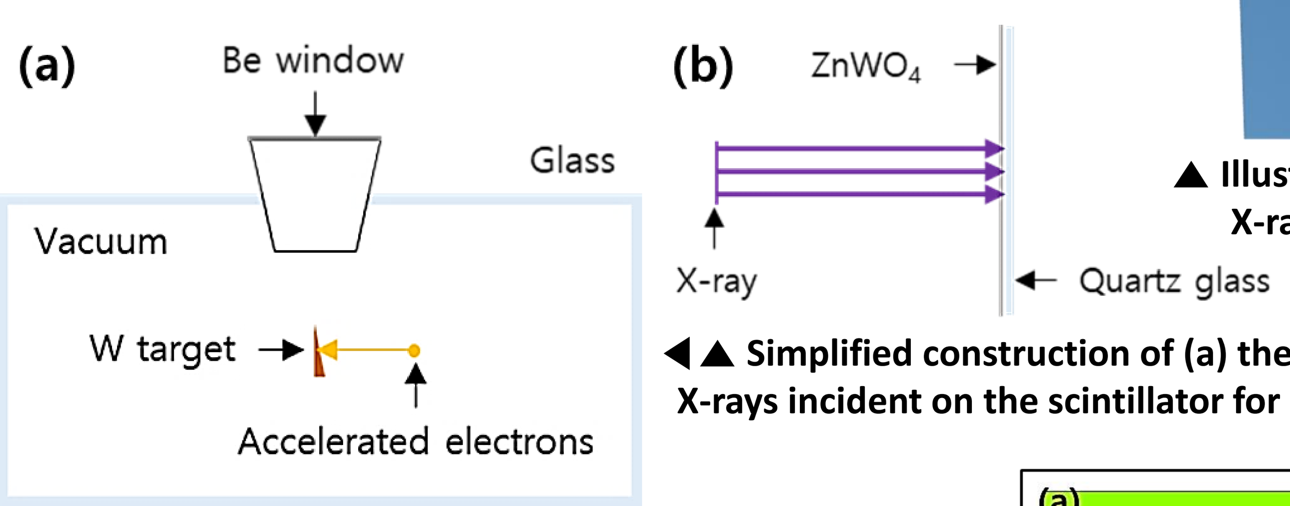
  - ✓ Glass-type thin-film scintillator
  - → High-resolution X-ray Imaging
- **Research Focus**
  - ✓ Investigate the energy deposition of a glass-type $ZnWO_4$ thin-film scintillator using the Monte Carlo N-Particle (MCNP) transport code
  - → X-ray tube with constant tube power for high-resolution X-ray imaging
  - → Various X-ray energy spectrum depending on tube current and tube voltage
  - → Energy absorption distribution

Methods

- **Geometry Construction**
  - ✓ X-ray tube (P030.24.12F100W, Petrick GmbH)
  - → Sealed with glass
  - → Filled with vacuum
  - → Tungsten target and beryllium window
  - ✓ Scintillator (Φ15 mm, 3 μm)
  - → Thickness $t = \frac{sl}{M^2 D} = 3\ \mu m$,
    where *s*: detector pixel size (6.5 μm)
    l: distance between lens and detector (21 cm)
    M: magnification (8)
    D: diameter of the lens (0.75 cm)
  - → Deposited on 1 mm quartz glass
  - ✓ Disk X-ray source

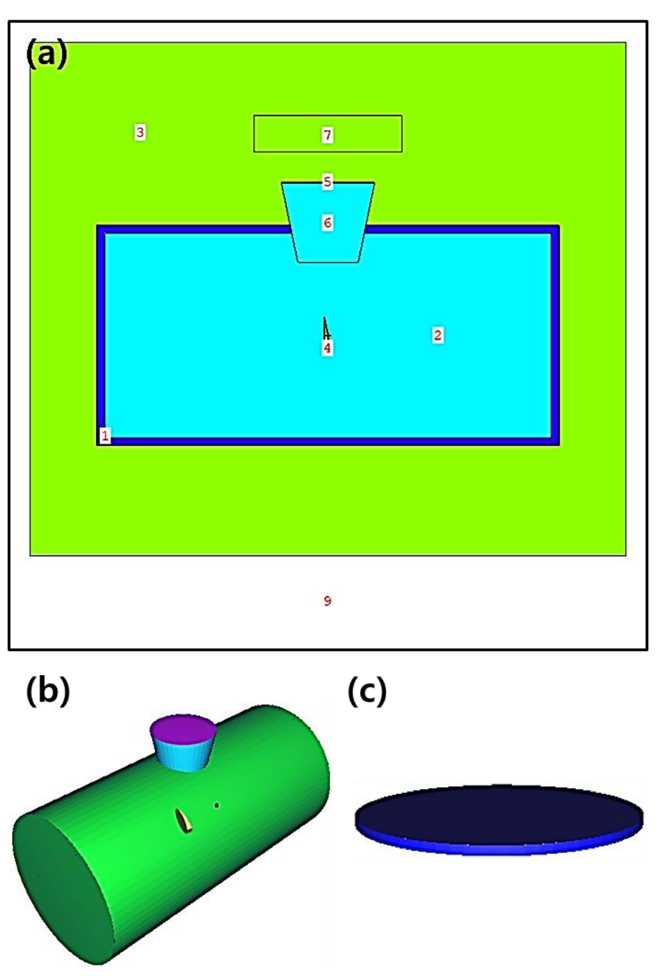


▲ Illustration of the general X-ray imaging system



◀▲ Simplified construction of (a) the X-ray tube and (b) X-rays incident on the scintillator for MCNP simulation

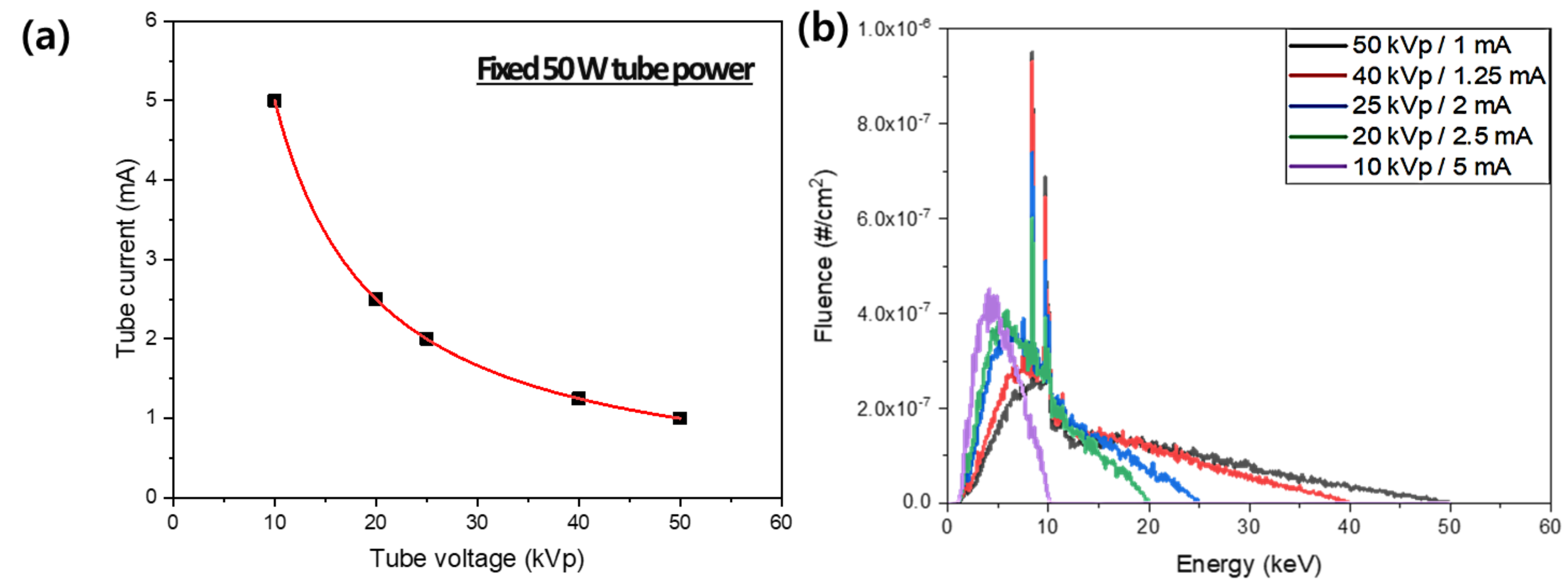
- **MCNP Simulation**
  - ✓ Electron source
  - → 1 cm away from target
  - → Mono-energy
  - ✓ X-ray distribution
  - → F4 tally with energy bins (Mode P, E and 10^9 nps)
  - → Importance: 1 (photons and electrons), 0 (void)
  - ✓ Energy deposition
  - → X-ray source: Histogram for continuous energy distribution using "SI" and "SP" Disk source and uni-direction
  - → *F8 tally (Mode P, E and 10^8 nps)
  - → Importance: 1 (photons and electrons), 0 (void)



▲ (a) Defined cells by MCNP, and a 3D image of simulated (b) X-ray tube and (c) $ZnWO_4$ thin-film scintillator

Results & Discussion

- **X-ray Energy Spectrum**



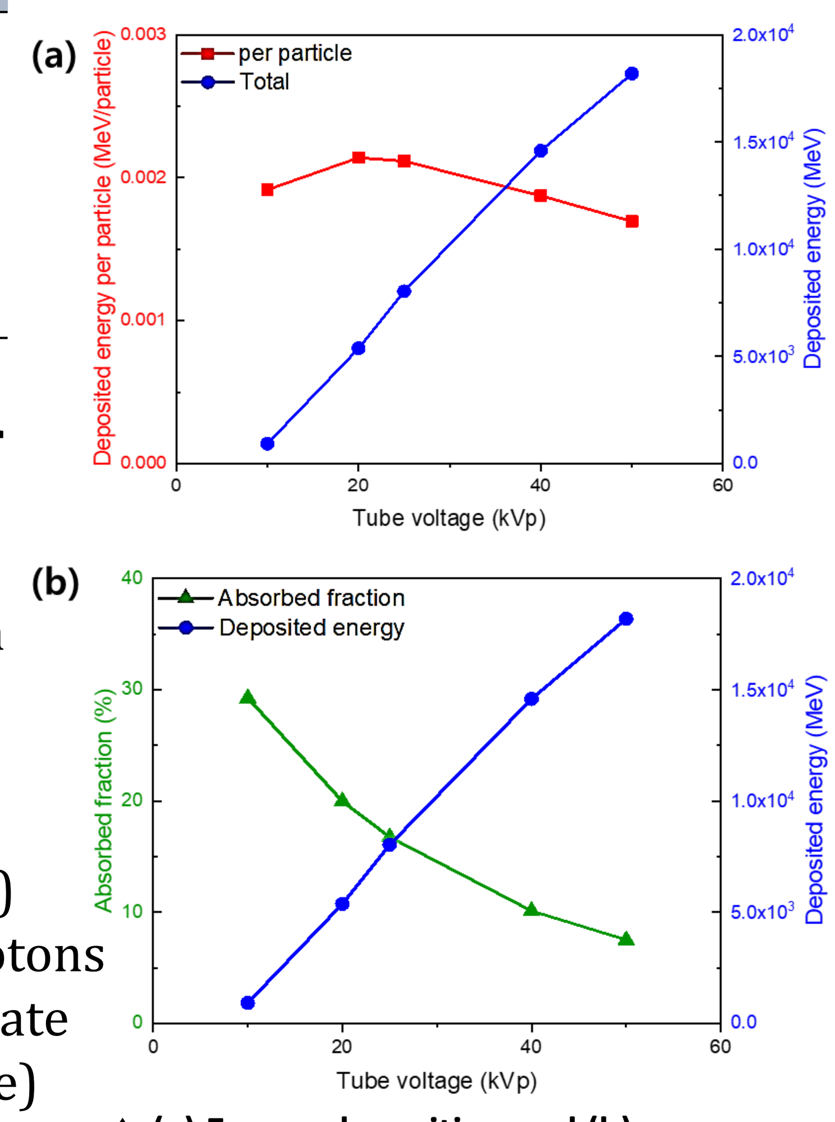
▲ (a) Relationship between tube current and tube voltage at a fixed 50 W tube power and (b) calculated X-ray energy spectra at various tube voltage/current conditions

  - ✓ Constant 50 W tube power: (Tube voltage) ∝ $(\text{Tube current})^{-1}$
  - → Changes in the number of electrons incident on the target
  - → (The number of electrons) ∝ (Tube current)
  - ✓ Two W characteristic X-rays near about 10 keV
  - → Not observed at the 10 kV_p/5 mA case
  - ✓ The higher the tube voltage, the more the number of X-ray photons
  - → Obtained by multiplying the number of electrons in each case

▼ The number of generated X-ray photons calculated from MCNP simulation

Tube voltage (kV_p)	Number of photons (s^{-1})
10	1.09×10^{11}
20	1.76×10^{11}
25	1.93×10^{11}
40	2.19×10^{11}
50	2.30×10^{11}

- **Deposited Energy in Scintillator**
  - ✓ Assumption: Absorbed energy ➔ Light production
  - ✓ The most energy absorption in the 20 kV_p case for the same number of particles (red line)
  - ✓ The highest total deposited energy at the 50 kV_p (blue line)
  - → Due to different amount of photons
  - ✓ The lower energy absorption rate as voltage increases (green line)
  - → Reasonably, 25 kV_p/2 mA case for high resolution



▲ (a) Energy deposition and (b) energy absorbed fraction of $ZnWO_4$ thin-film scintillator at various tube voltages

Conclusions

- **Energy deposition of the $ZnWO_4$ thin-film scintillator was analyzed using MCNP simulation for achieving high-resolution images**
- **The energy deposited in the scintillator increased as the tube voltage is higher, but energy absorption fraction was decreased**
- **It is necessary to obtain a reasonable tube voltage condition that can exhibit the best image resolution by reflecting both energy absorption and absorbed fraction**

Acknowledgement

This work was supported by the National Research Foundation (No. 2020M2D8A2069727).

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