# Synchrotron X-ray Studies on Structure and Electronic States of $WO_3$ Thin Films for Electrochromic Application

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Tungsten oxide ($WO_3$) has gained greater attention for its electrochromic properties in both amorphous and crystalline states, enabling rapid coloration and bleaching times with high coloration efficiency [1]. It is an n-type semiconductor having a wide band gap (2.6-3.0 eV). It exhibits different phases, but it shows exceptional stability in monoclinic and hexagonal phases at room temperature [2]. In this work, $WO_3$ thin films were prepared using the pulsed laser deposition (PLD) technique with different laser shots, such as 2000 (W_2), 4000 (W_4) and 6000 (W_6), and then were studied for electrochromic applications. It is found that the W_2 film exhibits the highest coloration efficiency of 10.4 $cm^2/C$.

To study the structural, chemical, and electronic properties of the material at atomic and molecular levels, synchrotron-based grazing-incidence X-ray diffraction (GIXRD) and X-ray photoelectron spectroscopy (XPS) were performed on the PLD-deposited $WO_3$ thin films at NSSRC, Taiwan. The GIXRD results reveal that these thin films retain the monoclinic phase before and after testing the electrochromic characteristics. The monoclinic phase of $WO_3$ has a deformed structure and high coloration efficiency. The XPS data were critically analyzed to find the chemical composition and valence band edge of $WO_3$. W 4f core-level spectra indicate the presence of multiple valence states and oxygen vacancies [3]. Deconvoluted O 1s spectra show the presence of lattice and chemisorbed oxygen in the $WO_3$ thin films, which again confirms the presence of Oxygen vacancies in the films. The valence band spectra of these oxide thin films show the Fermi level ($E_f$) at ~3 eV, which indicates the n-type conductivity of the films. In addition, a small broad feature is observed from 0 to 2 eV, which is associated with the presence of oxygen vacancies [4]. W_2 sample shows a highly intense peak from 0 to 2 eV, which is evidence for the presence of oxygen vacancies in the respective film. More oxygen vacancies enhance the electrochromic properties due to the existence of more defects and electronic states.

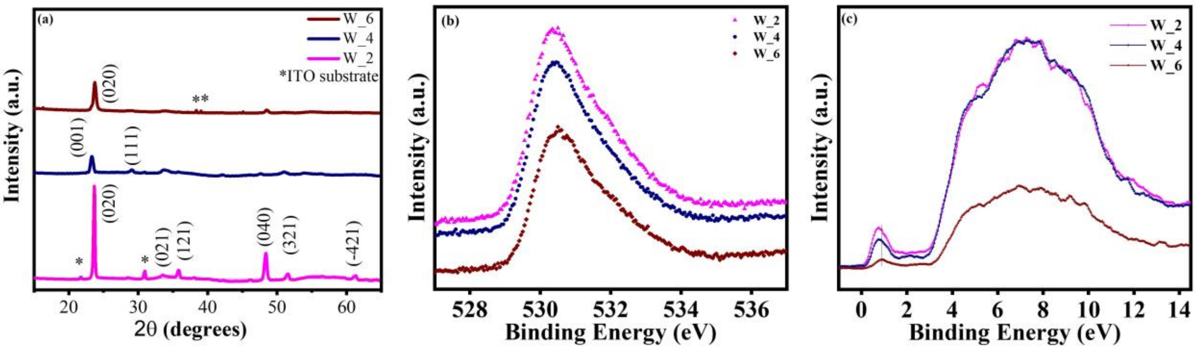

**FIGURE. (a)** Synchrotron GIXRD spectra, **(b)** O 1s core-level spectra, and **(c)** Valence band spectra of PLD-grown W_2, W_4, and W_6 thin films.

# REFERENCES

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