Microwave Synthesis of Ag-CdWO₄/Zeolite Composites Assisted by A Solid-State Metathetic Route

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Ag-CdWO₄/zeolite-A porous composites were synthesized using a solid-state metathetic (SSM) method with microwave irradiation. The characteristics of the solid-state metathetic reaction and the formation of the high lattice energy by-product NaCl were found to drive the reaction for Wolframite-type CdWO₄ toward completion. The Ag-CdWO₄/zeolite-A porous composites were formed completely at 600 °C. Monoclinic-like crystals of CdWO₄ were primarily co-mixed with porous zeolite-A. Small spherical silver particles were immobilized in the porous CdWO₄/zeolite-A matrix.

Key Words: Microwave synthesis, Solid-state metathetic, Ag-CdWO₄/zeolite.

INTRODUCTION

Cadmium tungstate (CdWO₄) is considered to be an attractive materials because of its optical, chemical and structural properties. It is well known that CdWO₄ crystals with Wolframite structures have high thermal stability, high average refractive index, low radiation damage, low intrinsic background, low after growing and high X-ray absorption. They can be used in spectrometry and radiometry of radio-nuclide in extra-low activities¹. CdWO₄ has a Wolframite-type crystal structure with lattice parameters of $a = 5.03 \text{ \AA}$ and $b = 5.86 \text{ \AA}$ and $c = 5.07 \text{ \AA}$ and $\beta = 91.47^\circ$ ². The CdWO₄ easily forms relatively thin structures due to its intrinsic (010) cleave plane because of the chain structure of the [WO₆]⁶⁻ octahedra in the Wolframite-type structure. The self-assembled rod-like and various short rod-like morphology of CdWO₄ are constructed with several submicron-rods attaching for their arrangements. Cadmium tungstate has attracted extensive attention because of their particular importance in investigating the sizes and shape-dependent properties as well as their immobilization in porous materials for potential applications. For tungstate materials to be used for practical applications, versatile characteristics are required for the particle size distribution and morphology of the particles. The well-defined particle features of the Ag-CdWO₄/zeolite-A porous composites are required for the immobilization features for potential applications³⁻⁷.

In recent years, the processes of CdWO₄ are prepared by a range of processes, such as a solid-state reaction^{8,9}, co-precipitation¹⁰⁻¹², a molten salt method^{13,14}, a hydrothermal

reaction^{15,16}, a combustion method¹⁷, a microwave synthesis¹⁷⁻²². Solid-state metathetic reactions involve the exchange of atomic/ionic species, where the driving force is the exothermic reaction accompanying the formation of NaCl with high lattice energy. Solid-state metathetic reactions occur so rapidly that the exothermic reaction is essentially used to heat the solid products. Solid-state synthesis of materials by the metathetic route is a simple method of synthesis, cost-effective, high yield and easy scale up and is emerging as a viable alternative approach for synthesizing high-quality novel inorganic materials in a short time^{23,24}. The solid-state metathetic approach assisted by microwave irradiation has been applied successfully to the synthesis of metal tungstates of Wolframite-type²⁵⁻²⁹. Ag-incorporated CdWO₄/zeolite-A porous composites are expected to have excellent adsorption and synergy effects in an immobilization mechanism of metallic catalysts for a wide range of applications, such as sensors, photocatalysts, luminescence, antibacterial matrices and optical effects in the UV and visible region.

In present study, Ag-CdWO₄/zeolite-A porous composites were synthesized using a solid-state metathetic method with microwave irradiation. The characteristics of the solid-state metathetic reaction and the formation of a high lattice energy by-product NaCl were discussed. The Ag-MnWO₄/zeolite-A porous composites were immobilized from mixed metathetic precursors at moderate temperatures. The crystallization process, thermal decomposition and morphology of the synthesized Ag-CdWO₄/zeolite-A porous composite powders were evaluated.

EXPERIMENTAL

Fig. 1 shows a flow chart for the synthesis of Ag-CdWO₄/zeolite-A porous composites from the solid-state metathetic method using microwave irradiation. CdCl₂·2.5H₂O and Na₂WO₄·2H₂O were used to prepare the cadmium tungstate compound. The preparation of cadmium tungstates was carried out by reacting well-ground mixtures of CdCl₂·2.5H₂O and Na₂WO₄·2H₂O for CdWO₄ at a molar ratio of 1:1. The sample mixtures were dried at 100 °C for 12 h and 5 wt % AgNO₃ and 25 wt % synthetic zeolite-A were then added. The samples were placed into crucibles and exposed to domestic microwave (Samsung Electronics Corp. Korea) operating at a frequency of 2.45 GHz and a maximum out-put power of 1250 W for 10 min. The samples were treated with ultrasonic radiation and washed many times with distilled water and ethanol to remove the sodium chloride reaction by-product. The samples were dried at 100 °C in an oven. Heat-treatment of the samples was performed at 600 °C for 3 h.

Fig. 1. Flow chart for the synthesis of Ag-CdWO₄/zeolite-A porous composites from the solid-state metathetic method using microwave irradiation

The phase existings in the particles after the solid-state metathetic reactions and heat-treatment were identified by XRD (D/MAX 2200, Rigaku, Japan). FTIR (Nicolet IR200, Thermo Electron corporation, USA) was used to examine the thermal-decomposition behaviour of the solid-state metathetic reaction and the obtained particles over the frequency range, 4000 to 400 cm⁻¹. The microstructure and surface morphology of the Ag-CdWO₄/zeolite-A porous composite powders were observed by scanning electron microscopy (JSM-5600, JEOL, Japan) and energy-dispersive X-ray spectroscopy (EDS).

RESULTS AND DISCUSSION

Fig. 2 shows FT-IR spectra of the Ag-CdWO₄/zeolite-A porous composites after (a) solid-state metathetic reaction (Ag-CdWO₄-Z-m) and (b) heat-treated at 600 °C for 3 h (Ag-CdWO₄-Z-m600). The absorption bands at 473 and 532 cm⁻¹ can be assigned to symmetric and asymmetric deformation mode of Cd-O in CdO₆ octahedra. The absorption bands with their maxima at 633 and 710 cm⁻¹ can be due to the stretching modes of W-O in WO₆ octahedra. The bands at 834 and 877 cm⁻¹ were due to symmetrical vibrations of bridge oxygen atoms of the Cd-O-W groups. The small band at 1450, 1630, 3400 cm⁻¹ can in Fig. 2(a) Ag-CdWO₄-Z-m are assigned to the HOH bending vibrations. It is assumed that the samples prepared contain a significant amount of surface-adsorbed water and alcohol.

Fig. 2. FT-IR spectra of the Ag-CdWO₄/zeolite-A porous composites after (a) solid-state metathetic reaction and (b) heat-treatment at 600 °C for 3 h

Fig. 3 shows SEM images of the Ag-CdWO₄/zeolite-A porous composites after (a)/(b) solid-state metathetic reaction and (c)/(d) heat-treated at 600 °C for 3 h. Fig. 3(a) and (b) shows SEM images of the Ag-CdWO₄/zeolite-A porous composites synthesized by solid-state metathetic reaction after removing the NaCl. CdWO₄ crystallizes in Wolframite crystal structures. Presence of sodium chloride confirms the reaction has proceeded in solid-state metathesis way. Parhi *et al.*²⁵ reported the microwave metathetic synthesis of various metal tungstates and showed that microwave radiation provided the energy required to overcome the energy barrier that precludes a spontaneous reaction and helped heat the bulk of the material uniformly, resulting in fine particles with a controlled morphology and the formation of the product in a green manner without the generation of solvent waste.

In Fig. 3(c) and (d), the SEM images of Ag-CdWO₄/zeolite-A porous composites after solid-state metathetic reaction and followed by heat-treatment at 600 °C for 3 h show the well crystallized CdWO₄ on the zeolite-A synthesized by a solid-state metathetic reaction. The monoclinic-like crystals of CdWO₄ were primarily co-mixed with Ag on the porous

Fig. 3. SEM images of the Ag-CdWO₄/zeolite-A porous composites after (a) and (b) solid-state metathetic reaction and (c) and (d) heat treatment at 600 °C for 3 h

zeolite-A surfaces. The spherical small particles of silver were well immobilized in the porous CdWO₄/zeolite-A composites matrix. Solid state metathesis reactions, such as $\text{AgCl}_2 + \text{Na}_2\text{WO}_4 \longrightarrow \text{Ag}_2\text{WO}_4 + 2\text{NaCl}$, involves the exchange of atomic/ionic species, where the driving force is the formation of thermodynamically stable alkali or alkaline earth halides with high lattice energy. The thermodynamic basis for such metathetic

reactions has been reported^{25,30-32}. Parhi *et al.*²⁵⁻²⁸ calculated the enthalpy (ΔH) and free energy change (ΔG) associated with the formation of tungstates and reported $\Delta H = -36.17$ KJ/mol for ZnWO₄ showing that both the enthalpy change favours the metathesis reaction and the enthalpy change is indeed the driving force for the metathesis involving the formation of NaCl. Solid-state metathetic reactions occur so rapidly that all the enthalpy released is essentially used to heat up the solid products, usually raising the alkali halide near or above its normal boiling point and have been recognized to be approximately adiabatic in nature³³.

Fig. 4 shows (a) EDS patterns, (b) quantitative compositions, (c) a SEM image and (d) quantitative results of the synthesized Ag-CdWO₄/zeolite-A porous composites at 600 °C for 3 h. The EDS patterns and quantitative compositions of the synthesized Ag-CdWO₄/zeolite-A porous composites were composed of Ag, CdWO₄ and zeolite-A.

For tungstate materials to be used for practical applications, versatile characteristics are required for the particle size distribution and morphology of the particles. The well-defined particle features of the Ag-CdWO₄/zeolite-A porous composites synthesized by solid-state metathetic reactions have control over the morphology of the final particles and can be used for such technological applications. Owing to the enthalpy change by the driving force for the metathetic formation of NaCl, the solid-state metathetic reactions affect not only the

Fig. 4. EDS patterns (a), quantitative compositions (b), a SEM image (c) and quantitative results (d) of the synthesized Ag-CdWO₄/zeolite-A porous composites

morphology of the CdWO_4 particles, but also the formation of functional zeolite and Ag immobilized in the porous composite matrix. Therefore, a variation of metathetic reactions of $\text{CdCl}_2 + \text{Na}_2\text{WO}_4 \longrightarrow \text{CdWO}_4 + 2\text{NaCl}$ is required to control the well-defined particle features of the Ag- CdWO_4 /zeolite-A porous composites.

Conclusion

Ag- CdWO_4 /zeolite-A porous composites were synthesized using solid-state metathetic method with microwave irradiation. The Ag- CdWO_4 /zeolite-A porous composites at 600 °C for 3 h were completed entirely at 600 °C. The well crystallized CdWO_4 on the zeolite-A synthesized by a solid-state metathetic reaction. The monoclinic-like crystals of CdWO_4 were primarily co-mixed with Ag on the porous zeolite-A surfaces. The spherical small particles of silver were well immobilized in the porous CdWO_4 /zeolite-A composites matrix. The enthalpy change favours the metathesis reaction and the enthalpy change is indeed the driving force for the metathesis involving the formation of NaCl. Solid-state metathetic reactions occur so rapidly that all the enthalpy released is essentially used to heat up the solid products of Ag- CdWO_4 /zeolite-A porous composites.

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