

Supplementary Materials

Carbon Dioxide Valorization into Methane Using Samarium Oxide-Supported Monometallic and Bimetallic Catalysts

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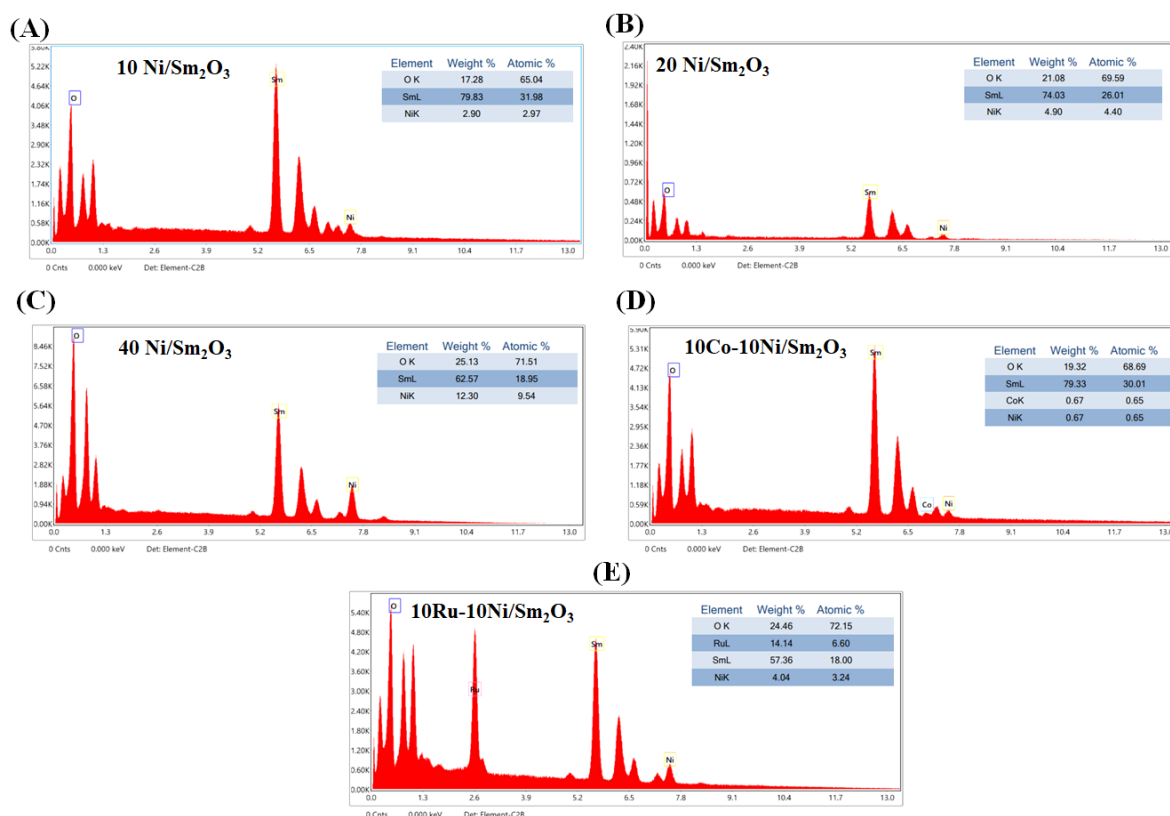


Figure S1. EDX elemental analysis of (A) 10Ni/Sm₂O₃ (B) 20Ni/Sm₂O₃ (C) 40Ni/Sm₂O₃ (D) 10Co-10Ni/Sm₂O₃ (E) 10Ru-10Ni/Sm₂O₃ catalysts

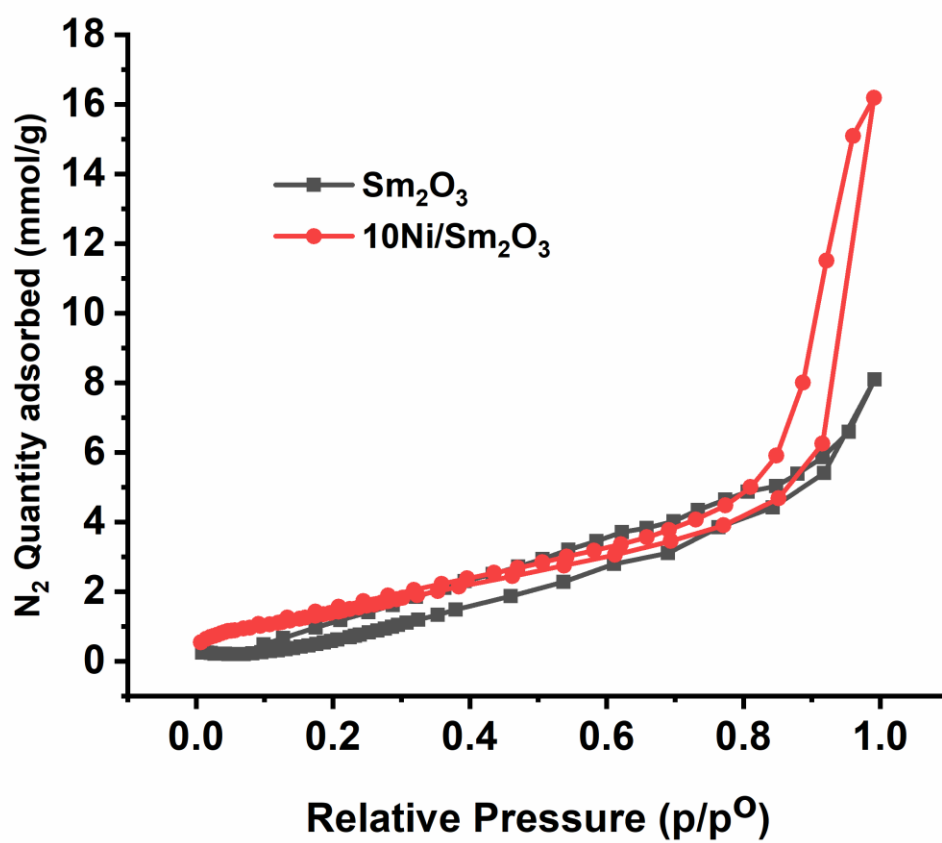


Figure S2. N₂ adsorption isotherm of Sm₂O₃ and 10Ni/Sm₂O₃ catalyst

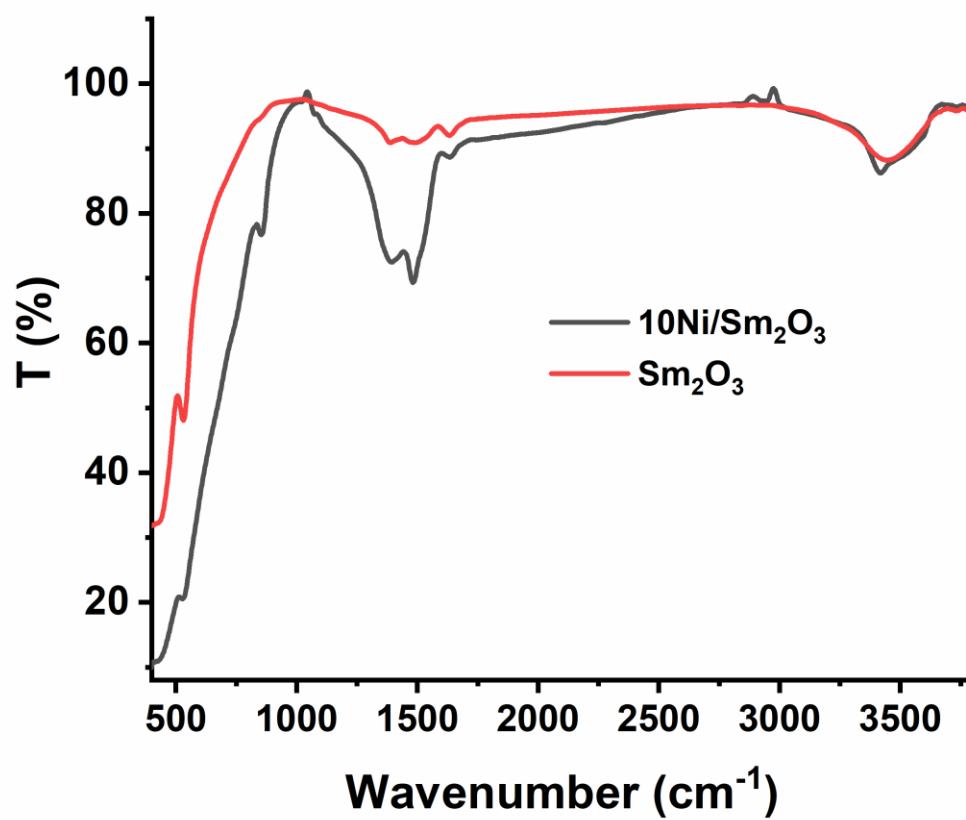


Figure S3. Infra-red transmittance spectra of Sm₂O₃ and 10Ni/Sm₂O₃ catalyst

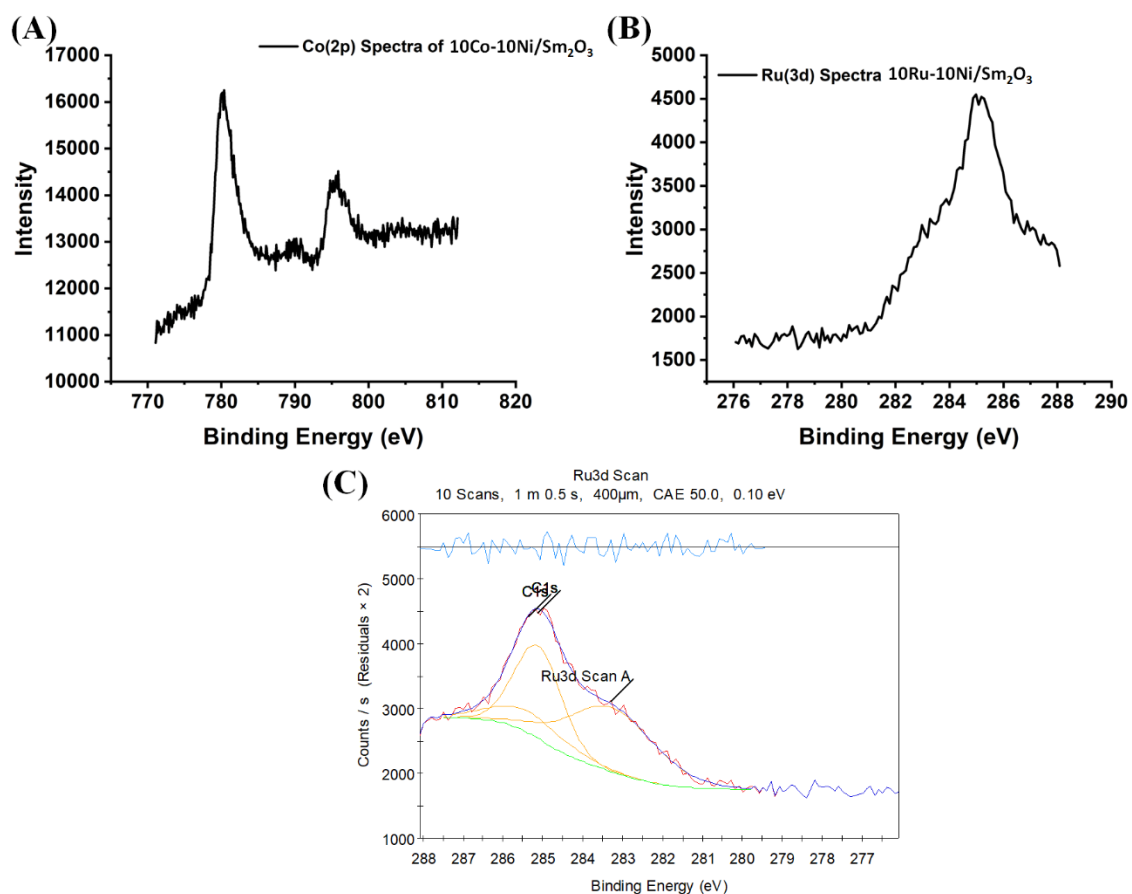


Figure S4. (A) Co(2p) core level XPS spectrum of Co-Ni/Sm₂O₃ (B-C) Ru (3d) XPS spectra of Ru-Ni/Sm₂O₃ catalyst.

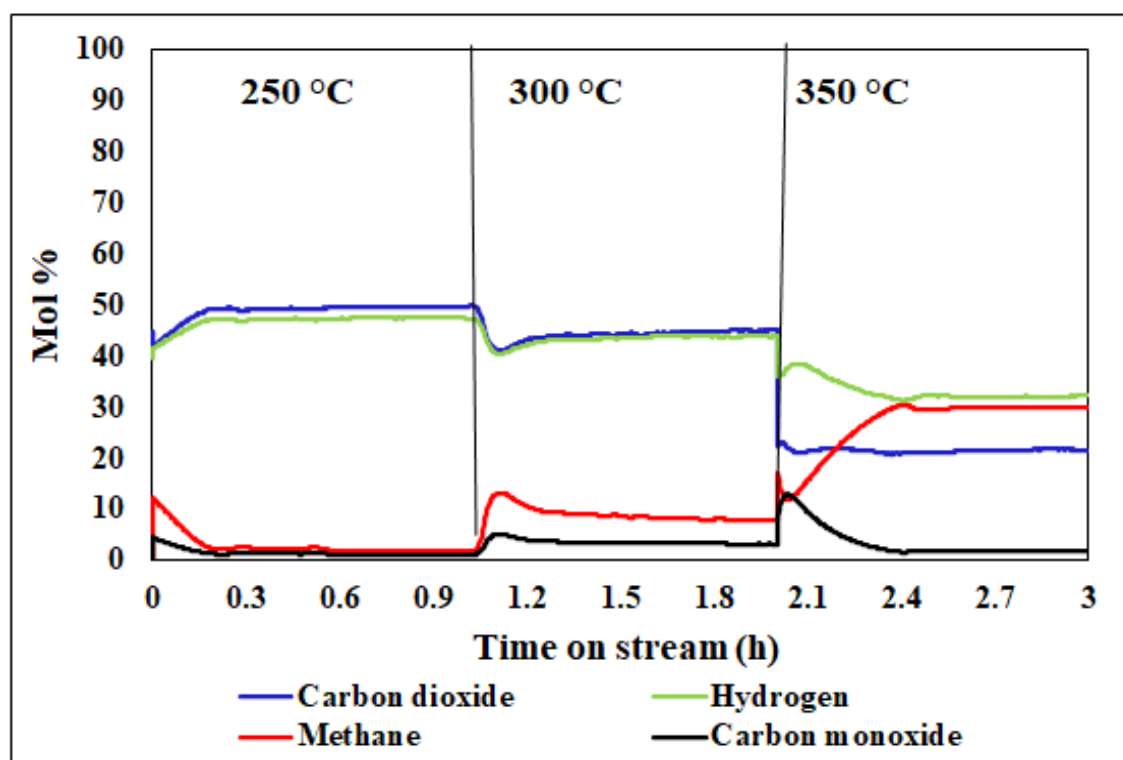


Figure S5. The methanation reaction over 10Ni/Sm₂O₃ at 3-different temperature for 1h at each 250°C, 300°C and 350°C.

Supporting Information S6. The detail description of instrument and characterization procedure:

(A) N₂ adsorption–desorption isotherms are carried out at –196 °C, using (NOVA 3200 apparatus, Quantachrome Corporation, Boynton Beach, Florida, USA). The samples were previously outgassed under vacuum at 300 °C overnight. The surface areas (SBET) were calculated from multipoint at relative pressure (p/p^0) ranging from 0.05 to 0.30. The particle size distribution was calculated by the Barrett, Joyner, and Halenda (BJH) method using the desorption branch of the isotherms.

(B) The X-ray diffraction experiment for the prepared catalyst was carried out by Shimadzu XD-1 diffractometer. The patterns were recorded using Bragg’s configuration 2θ range

of 10 –70 using CuK α radiation ($\lambda = 0.15418$ nm) at a rate of 0.05 s. The equipment has a Ni filter and worked at 40 kV and 30 mA. Phase identification was found out by X'PertPRO PANalytical software.

(C) Fourier-transform infrared (FTIR) was performed using Nicolet Is-10 model (USA) Infrared spectrophotometer adopting KBr technique. The samples were measured as KBr discs by mixing the sample with KBr (spectroscopic grade) where the solid samples were transferred into the cell after melting using an infrared lamp. The spectra of all the studied samples were measured in the range of 400–4000 cm⁻¹ with a suitable scan resolution of 4 cm⁻¹ and a scan rate of 16 cm/min.

(D) Temperature programmed reduction (TPR) measurements were carried out to investigate the redox properties (the ease of reducibility of the metal oxide) over the resultant materials. The experiments were performed in automatic equipment (ELCAT-II chemisorption equipment (BEL Inc., Japan). Typically, 100 mg of a pre-calcined sample was loaded into a quartz reactor and pretreated by heating under an inert atmosphere (20 ml min⁻¹ nitrogen) at 200 °C for 3 h prior to running the TPR experiment, and then it was cooled to room temperature in N₂. Then, the sample was subjected to a constant rate of heat treatment (10 °C min⁻¹ to 1000 °C) in a gas flow (80 ml min⁻¹) of a hydrogen/nitrogen (5/95 vol%) mixture as the reducing gas. A thermal conductivity detector (TCD) was employed to monitor the amount of hydrogen consumption.

(E) The XPS results were collected using K-ALPHA (Thermo Fisher Scientific, USA) instrument with monochromatic X-ray Al K α radiation from 10 to 1350 eV. The used spot size was 400 μ m at pressure 10⁻⁹ mbar. The power for the full spectrum pass energy was 200 eV and at narrow spectrum 50 eV

(F) The elemental mapping of catalyst samples was carried out by Energy Dispersive X-ray Spectroscopy instrument (Zeiss Smart EDX) equipped with a field-emission scanning electron microscope (FE-SEM; FEI Quanta FEG 250).