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Irregularly Shaped NiO Nanostructures for Catalytic Lean Methane Combustion

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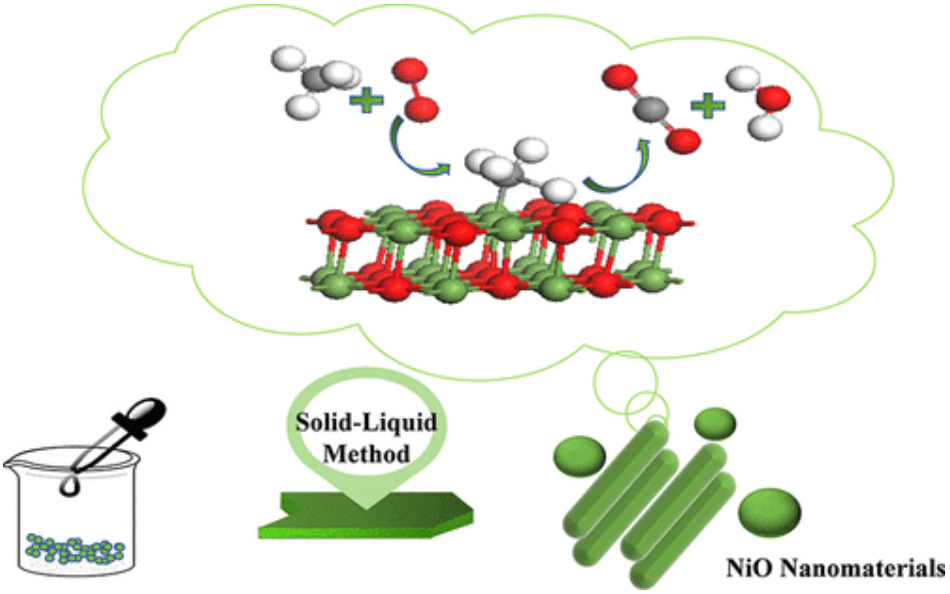
Supporting Info (1)»Supporting Information

SUBJECTS:

- Catalysts,
- Hydrocarbons,
- Oxides,
- Precipitation,
- Redox reactions

Abstract



NiO nanomaterials prepared using a solid–liquid $NH_3 \cdot H_2O$ precipitation method (NiO-NSL) were tested in the catalytic combustion of methane. The NiO-NSL presented a characteristic rod-like nanostructure with a length of about a few hundred nanometers except for a part of the nanoparticles. For comparison, the NiO nanomaterials prepared by the traditional liquid-phase $NH_3 \cdot H_2O$ precipitation method (NiO-NLL) were tested in the same reaction conditions. NiO-NSL exhibited significantly higher methane combustion activity than NiO-NLL and achieved the complete combustion of methane at 390 °C, which was outstanding in non-noble metal-based catalyst. X-ray photoelectron spectroscopy (XPS) and hydrogen-temperature-programmed reduction (H_2-TPR) results indicate that the surface Ni^{2+} content of NiO-NSL was higher than that of NiO-NLL, and the presence of more Ni^{2+} might be responsible for the enhanced activity. DFT calculations prove that the energy barrier for C–H bond activation on Ni^{2+} was lower than that on Ni^{3+}, which was consistent with the higher methane catalytic combustion activity of NiO-NSL. In addition, when the precipitating agent was replaced with NaOH and $(NH_4)_2CO_3$, the generalization of the solid–liquid precipitation method in the preparation of the NiO catalysts was also tested. The results show that the solid–liquid precipitation method proposed in this work was still applicable when NaOH was used as a precipitant. However, with the use of $(NH_4)_2CO_3$ as a precipitant, the methane catalytic activity of the NiO nanoparticles prepared by the solid–liquid precipitation method was reduced to a certain extent compared with the traditional liquid-phase precipitation method. This research can open up a highly efficient and environmentally friendly method for the synthesis of methane combustion catalysts.

KEYWORDS:

- solid–liquid precipitation method

- rod-like nanostructure
- methane catalyticShow More

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Supporting Information

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- Stability test results of NiO-NSL (Figure S1); wide-angle XRD patterns of the as-precipitated samples using $(NH_4)_2CO_3$ as the precipitant and a standard $xNiCO_3 \cdot yNi(OH)_2$ sample (Figure S2); representative TEM images of the precursors and as-calcined catalysts of the other four samples (Figures S3 and S4); specific performance data of samples in previous research (Table S1); XPS analysis of the other samples (Table S2, Figures S5 and S6); H_2-TPR profiles of the other samples (Table S3, Figures S7 and S8); detailed DFT calculation results (Table S4); the surface model used in the calculations (Figure S9) (PDF)

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Figure S2.

Wide-angle XRD patterns of the as-precipitated samples using

(NH

4

)

2

CO

3

as precipitant and standard xNiCO

3

·yNi(OH)

2

sample.

They

both showed typical crystal structure of monoclinic nullaginite (JCPDS

PDF#35-0501). The crystallinity of xNiCO

3

·yNi(OH)

2

-NCSL was slightly

better than that of xNiCO

3

·yNi(OH)

2

-NCLL since the diffraction peaks of

xNiCO

3

·yNi(OH)

2

-NCSL were slightly sharper than those of the latter.

Figure S3.

Representative TEM images of (a) Ni(OH)

2

-NaLL, (b)

Ni(OH)

2

-NaSL,

(c)

xNiCO3·yNi(OH)2-NCLL

and

(d)

xNiCO3·yNi(OH)2-NCSL.

Figure S4.

Representative TEM images of (a) NiO-NaLL, (b) NiO-NaSL,

(c) NiO -NCLL and (d) NiO -NCSL.

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Figure S5.

X-ray photoelectron spectroscopy (XPS) results of (a) Ni 2p

and (b) O 1s spectra of NiO-NaSL and NiO-NaLL.

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Figure S6.

X-ray photoelectron spectroscopy (XPS) results of (a) Ni 2p

and (b) O 1s spectra of NiO-NaSL and NiO-NaLL.

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1. Ehsan Akbari, Seyed Mehdi Alavi, Mehran Rezaei, Zahra Montazeri. AOx−MnOx (A = Ni, Cu, Fe, or Co) Nanocatalysts Fabricated by the Mechanochemical Preparation Method for Lean Methane Catalytic Combustion Assisted by a DBD Plasma Reactor. ***ACS Applied Nano Materials*** **2023**, *6* (18) , 16189-16200. https://doi.org/10.1021/acsanm.3c02129
2. Yan Fu, Cunshuo Li, Shengxin An, Wenzhi Li, Liang Yuan. Cu and Zn Bimetallic Co-Modified H-MOR Catalyst for Direct Oxidation of Low-Concentration Methane to Methanol. ***ACS Omega*** **2023**, *8* (30) , 27179-27189. https://doi.org/10.1021/acsomega.3c02388
3. Kun Chen, Wenzhi Li, Chen Zhu, Liang Yuan. Construction of Hollow Cobalt Tetroxide Nanocages through the Metal Salt Bifunctional Etching Strategy for Catalytic Oxidation of Propane at Ultrahigh Space Velocity. ***ACS Applied Nano***

Materials **2022**, *5* (5) , 6575-6584. https://doi.org/10.1021/acsanm.2c00650

4. Kun Chen, Wenzhi Li, Ge Guo, Chen Zhu, Wenjian Wu, Liang Yuan. Nickel Hydroxide Nanosheets Prepared by a Direct Manual Grinding Strategy for High-Efficiency Catalytic Combustion of Methane. *ACS Omega* **2022**, *7* (10) , 8536-8546. https://doi.org/10.1021/acsomega.1c06348
5. Zhixiong Wang, Jia Lin, Hong Xu, Yong Zheng, Yihong Xiao, Ying Zheng. Zr-Doped NiO Nanoparticles for Low-Temperature Methane Combustion. *ACS Applied Nano Materials* **2021**, *4* (11) , 11920-11930. https://doi.org/10.1021/acsanm.1c02487
6. Fen Wang, Yao Ouyang, Xiumiao Yang. Promoting effect of Pt on the activity and stability of Pd/MgFe2O4 for catalytic combustion of methane. *Journal of the Energy Institute* **2023**, *110* , 101341. https://doi.org/10.1016/j.joei.2023.101341
7. François Nkinahamira, Ruijie Yang, Rongshu Zhu, Jingwen Zhang, Zhaoyong Ren, Senlin Sun, Haifeng Xiong, Zhiyuan Zeng. Current Progress on Methods and Technologies for Catalytic Methane Activation at Low Temperatures. *Advanced Science* **2023**, *10* (5) https://doi.org/10.1002/advs.202204566
8. Lan Xie, Jiajia Hao, Shengtao Xing. Enhanced non-radical activation of persulfate with pompon-like NiO microspheres for removing sulfamethoxazole in water. *Environmental Science and Pollution Research* **2023**, *30* (6) , 14455-14463. https://doi.org/10.1007/s11356-022-23274-4
9. Andoni Choya, Beatriz de Rivas, Jose Ignacio Gutiérrez-Ortiz, Rubén López-Fonseca. Beneficial effects of nickel promoter on the efficiency of alumina-supported Co3O4 catalysts for lean methane oxidation. *Journal of Environmental Chemical Engineering* **2022**, *10* (6) , 108816. https://doi.org/10.1016/j.jece.2022.108816
10. Diptangshu Datta Mal, Debabrata Pradhan. Recent advances in non-noble metal-based oxide materials as heterogeneous catalysts for C–H activation. *Dalton Transactions* **2022**, *51* (46) , 17527-17542. https://doi.org/10.1039/D2DT02613A
11. Junaid Khan, Gohar Ali, Ayesha Samreen, Shahbaz Ahmad, Sarfraz Ahmad, Mehmet Egilmez, Sadiq Amin, Nadia Khan. Quantum-dot sensitized hierarchical NiO p–n heterojunction for effective photocatalytic performance. *RSC Advances* **2022**, *12* (50) , 32459-32470. https://doi.org/10.1039/D2RA05657G
12. Wenjie Liu, Dandi Wei, Xueying Zhao, Feng Xiao, Chao Yang. Enhanced xylene-sensing property of hierarchical NiO/montmorillonite hetero-structures via In doping. *Applied*

Surface Science **2022**, *602* , 154301. https://doi.org/10.1016/j.apsusc.2022.154301

13. Cunshuo Li, Songquan Tang, Bingyue Tang, Wenzhi Li, Liang Yuan. The effects of alkali metal ions on the physiochemical and catalytic properties of Pd/NiAlOx catalysts for lean methane oxidation. *Molecular Catalysis* **2022**, *530* , 112614. https://doi.org/10.1016/j.mcat.2022.112614

14. Yuan Gao, Mingxin Jiang, Liuqingqing Yang, Zhuo Li, Fei-Xiang Tian, Yulian He. Recent progress of catalytic methane combustion over transition metal oxide catalysts. *Frontiers in Chemistry* **2022**, *10* https://doi.org/10.3389/fchem.2022.959422

15. Chuan-Bin Du, Zhi Xuan Law, Ren-You Huang, De-Hao Tsai. Aerosol-phase synthesis of bimetallic NiCu oxide-decorated CeO2 nanoparticle cluster for catalytic methane combustion. *Advanced Powder Technology* **2022**, *33* (8) , 103649. https://doi.org/10.1016/j.apt.2022.103649

16. Rubén López-Fonseca, Andoni Choya, Beatriz de Rivas, Jose Ignacio Gutiérrez-Ortiz. Beneficial Effects of Nickel Promoter on the Efficiency of Alumina-Supported Co3o4 Catalysts for Lean Methane Oxidation. *SSRN Electronic Journal* **2022**, *53* https://doi.org/10.2139/ssrn.4197987

17. Yaxin Zhang, Chenhui Zhang, Shengtao Xing. Fabrication of NiO/Mg–Al layered double hydroxide with superior performance for peroxydisulfate activation. *Journal of Solid State Chemistry* **2021**, *304* , 122565. https://doi.org/10.1016/j.jssc.2021.122565

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