



In situ growth of NiTe nanosheet film on nickel foam as electrocatalyst for oxygen evolution reaction

Zhichao Wang, Lixue Zhang*

College of Chemistry and Chemical Engineering, Qingdao University, Qingdao, 266071, Shandong, PR China

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ABSTRACT

Developing effective and low-cost oxygen evolution reaction (OER) electrocatalysts based on earth-abundant elements is vital for future clean and regenerated energy systems. In this work, one-step growth of NiTe nanosheet film on nickel foam (NiTe/NF) via a facile tellurization treatment of NF has been demonstrated. This NiTe/NF electrode exhibits remarkable OER activity with overpotential requirement as low as 262 mV to deliver an anodic current density of 10 mA cm^{-2} , as well as superior durability in alkaline solution. This work provides an attractive earth-abundant 3D catalyst electrode for OER in overall water splitting.

1. Introduction

The continued depletion of fossil fuels and the associated environmental issues have triggered considerable interests in exploring alternative energy carriers with high-performance, cost-effective and environmental benignity [1,2]. Hydrogen is regarded as an ideal substitute [3,4]. Electrochemical water splitting affords a promising approach to produce hydrogen at high purity [5,6]. However, the intrinsic sluggish kinetics of oxygen evolution reaction (OER) greatly hinder the efficiency of hydrogen production [7,8]. Consequently, efficient OER electrocatalysts must be utilized for reducing the overpotential of water splitting [9–11]. As the most effective OER catalysts, however, RuO_2 and IrO_2 suffer from unsustainable supply and high cost, impeding their practical applications [12]. Therefore, the development of alternative electrocatalysts with high-performance and cost-effective for OER is drawing great enthusiasms.

Transition metal chalcogenides (TMCs) have attracted extensive interest in electrochemically catalyzing OER [13–17]. Zhang and co-workers reported a Ni_3S_2 nanorods/Ni foam with excellent OER performance [13]. NiSe nanowires supported on nickel foam also showed excellent catalytic activity for OER according to the effort by Sun and co-workers [15]. Compared with S and Se chalcogenides, the smaller electronegativity of Te endows tellurides with more metallic character, which would bring benefits to their application as OER electrocatalysts [18–20]. Recently, Yu and co-workers reported a hierarchical CoTe_2 nanofleeces, which catalyzed OER efficiently with an overpotential of 367 mV to achieve 10 mA cm^{-2} [18]. However, it was synthesized by multi-step processes with high-temperature requirement. Besides, the majority synthetic procedures of metal tellurides yielded the final

products as bulk powder or film form [18,21–23], which, however, limit their potential electrocatalytic applications. Previous reports demonstrated that nanoarray structure can facilitate the penetration of electrolyte and diffusion of ionic species [24,25]. Accordingly, it is greatly needed to develop transition metal tellurides nanoarray electrocatalysts for catalyzing OER via a facile, efficient, and economical synthesis route [14].

In this work, we demonstrate an in situ growth of NiTe nanosheet array supported on nickel foam (NiTe/NF) via a facile tellurization treatment. The as-prepared NiTe/NF presents superior OER activity, as evidenced by achieving 10 mA cm^{-2} at an overpotential of only 262 mV and remarkable durability in 1.0 M KOH. This study offers a highly efficient and cost-effective 3D OER electrocatalyst in alkaline conditions.

2. Experimental

NF was provided by Shenzhen Green and Creative Environmental Science and Technology Co., Ltd. Te powder, NaBH_4 , $\text{RuCl}_3 \cdot 3\text{H}_2\text{O}$ and Nafion (5 wt%) were provided by Aladdin Ltd.

NaHTe was prepared according to previous report [26]. The pink uniform NaHTe solution was added into EtOH (80 mL) under Ar protection. Subsequently, the mixture and acid-treated NF were put into 100 mL Teflon-lined stainless steel autoclave and kept at 180°C for 15 h. After cooling down naturally, the product was washed with ultrapure water and EtOH before dried in vacuum for 2 h. RuO_2 was prepared according to previous literature [27]. 10 mg RuO_2 was dispersed in 490 μL water with 10 μL 5 wt% Nafion to obtain a homogenous ink. Then, 35.0 μL of the RuO_2 ink was drop-dried onto a 0.25 cm^{-2} NF.

* Corresponding author.

E-mail address: zhanglx@qdu.edu.cn (L. Zhang).

XRD patterns were acquired on a LabX XRD-6100 X-ray diffractometer. SEM and TEM measurements were collected with a XL30 ESEM FEG scanning electron microscope and a FEI Tecnai G2 F20 electron microscopy (FEI, Hillsboro, America), respectively. XPS data were recorded on an ESCALABMK II X-ray photoelectron spectrometer. Inductively coupled plasma optical emission spectroscopy (ICP-OES) experiments were performed on a Thermo Scientific iCAP-7600 spectrometer. Electrochemical measurements were carried out with a CHI 660E electrochemical workstation in a three-electrode system using NiTe/NF (RuO₂/NF or NF), Hg/HgO and graphite plate as the working, reference and auxiliary electrodes, respectively.

3. Results and discussion

XRD patterns of NiTe/NF clearly show the diffraction peaks located at 31.0°, 42.8°, 45.8°, 56.1°, 58.1°, 64.5°, and 75.3° (Fig. 1a), corresponding to the (101), (102), (110), (201), (103), (202), and (211) planes of NiTe phase (JCPDS No. 38-1393), respectively. The peaks located at 44.5°, 51.9°, and 76.4° arise from NF substrate [15]. SEM images (Fig. 1b) reveal the fully covered dense NiTe film on NF with a cross-linked 3D nanosheet array. TEM image (Fig. 1c) demonstrates that such nanosheet has a rough surface with high crystallinity. The HRTEM image (Fig. 1d) shows well-resolved lattice fringes of 2.89, 2.18, and 1.97 Å, which are consistent with the (101), (102), and (110) planes of NiTe, respectively. XPS spectra are presented in Fig. 1e and f. In Ni 2p region (Fig. 1e), the peaks at 857.3 and 855.6 eV with two satellites (abbreviated as Sat.) are attributed to Ni²⁺ in NiTe [28]. The peaks at 852.5 and 869.7 eV are assigned to metallic Ni 2p from the NF

substrate [23]. Whereas, the peaks shown in Fig. 1f centered at 583.5 and 573.2 eV are ascribed to Te 3d_{3/2} and Te 3d_{5/2}, respectively, confirming the Te²⁺ reduction state of tellurium in the NiTe nanosheet film [29]. Furthermore, two peaks located at 576.2 and 586.5 eV suggest the surface oxidation of tellurium species owing to superficial oxidation [26].

The electrocatalytic performance of NiTe/NF towards OER (NiTe loading: 2.8 mg cm⁻²) was assessed in 1.0 M KOH. NF and RuO₂ loaded on NF (RuO₂/NF) with identical loading amounts were also evaluated for comparison. The linear sweep voltammetry (LSV) data in this study have been calibrated with RHE scale and iR-correction unless special statement [30,31]. In the LSV curves (Fig. 2a), the peak at around 1.35 V is referred to the Ni oxidation [19,32]. RuO₂/NF shows excellent catalytic activity towards OER, while bare NF shows poor activity. However, NiTe/NF shows remarkable activity and demands an overpotential of only 262 mV to achieve the current density of 10 mA cm⁻², which is superior to that of most recently reported performance of Ni-based OER electrocatalysts like NiSe/NF (ca. 270 mV) [15], NiCo₂S₄ nanowires/graphdiyne (ca. 308 mV) [33], and Ni₃N/NC (310 mV at 10 mA cm⁻²) [34]. The Tafel slope of NiTe/NF catalyst is 74 mV dec⁻¹, much lower than that of NF (216 mV dec⁻¹) and RuO₂/NF (84 mV dec⁻¹) (Fig. 2b), and some other reported OER electrocatalysts like Ni₃N-NiMoN (118 mV dec⁻¹) [35], Co_{0.13}Ni_{0.87}Se₂/Ti (94 mV dec⁻¹) [36] and CoTe₂@N-GC (90 mV dec⁻¹) [37], indicating the favorable catalytic kinetics of NiTe/NF electrode towards OER. Besides, electrochemical durability is also a critical parameter for the evaluation of electrocatalysts. The polarization curve of NiTe/NF presents no clear decay after 1000 cyclic voltammetry scanning (Fig. 2c).

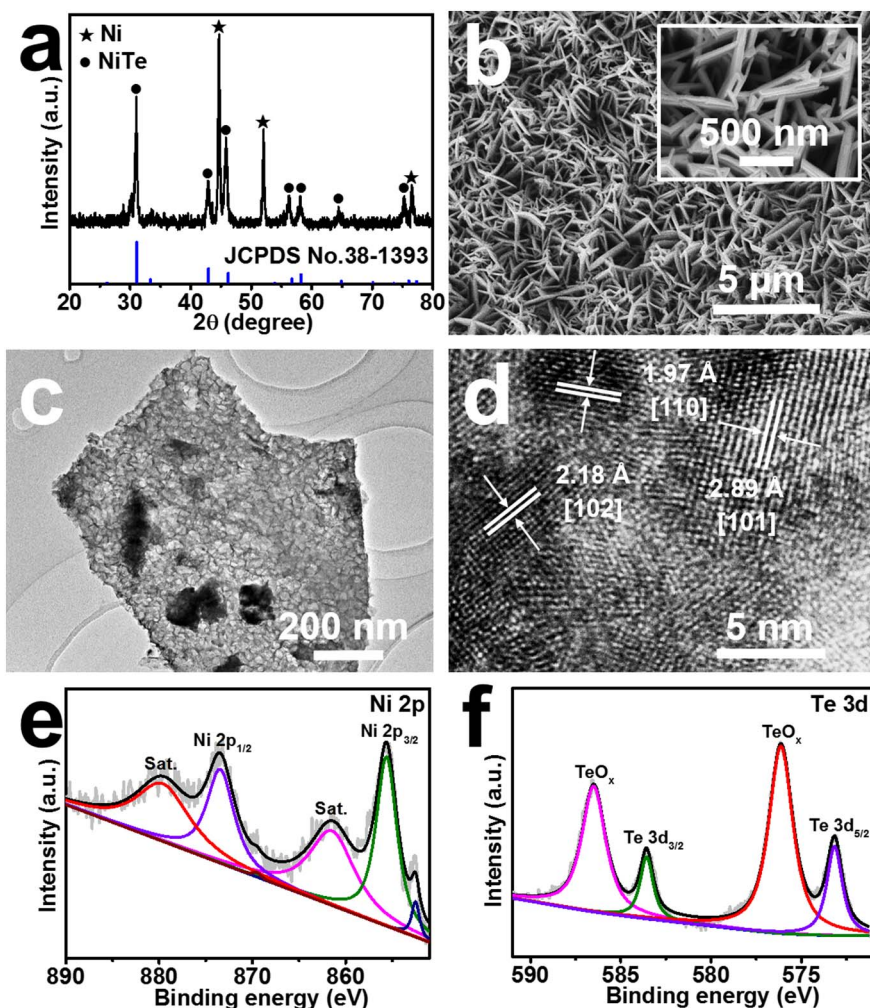


Fig. 1. (a) XRD pattern and (b) SEM images of NiTe/NF. (c) TEM and (d) HRTEM images of NiTe nanosheet. XPS spectra of NiTe in the (e) Ni 2p and (f) Te 3d regions.

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