Transition-metal dichalcogenide $NiTe_2$: an ambient-stable material for catalysis and nanoelectronics

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INTRODUCTION

Following the advent of graphene, the scientific community has widely investigated a large number of layered materials, which have been demonstrated to be effective for a myriad of applications in nanoelectronics, energy storage and sensing [1]. Transition-metal dichalcogenides (TMDs) can also host topologically protected electronic states. For example $NiTe_2$, has also been predicted to be a type-II Dirac semimetal [2]. Other recent studies have highlighted the capabilities of this material as an electrochemical sensor for glucose detection[3] and for urea conversion [4]. By means of experiments and theory, we assess the surface chemical reactivity and stability of nickel ditelluride $NiTe_2$. The Te surface termination forms a TeO_2 skin in an oxygen environment [5]. In ambient atmosphere, passivation is achieved in less than 30 minutes with the TeO_2 skin having a thickness of about 8 Å [5]. Consistently, $NiTe_2$-based field effect transistors exhibit superb stability over a timescale as long as one month. Specifically, $NiTe_2$ has been implemented in a device acting as a millimeter-wave receiver working at 40 GHz, which exhibits both superior performance and environmental stability with respect to graphene and black phosphorus [5].

RESULTS

Surface chemical reactivity

XPS core-level Ni-3p and Te-4d spectra collected from as-cleaved $NiTe_2$ and from the same surface modified by the exposure to $2\cdot10^4$ L of CO, H_2O and O_2. Strong changes appeare only after O_2 exposure. Ni-O component appear in Ni-3p and for the Te-4d oxidation exhibit new components at higher BEs and a further reduction of the intensity of the surface component [6,7].

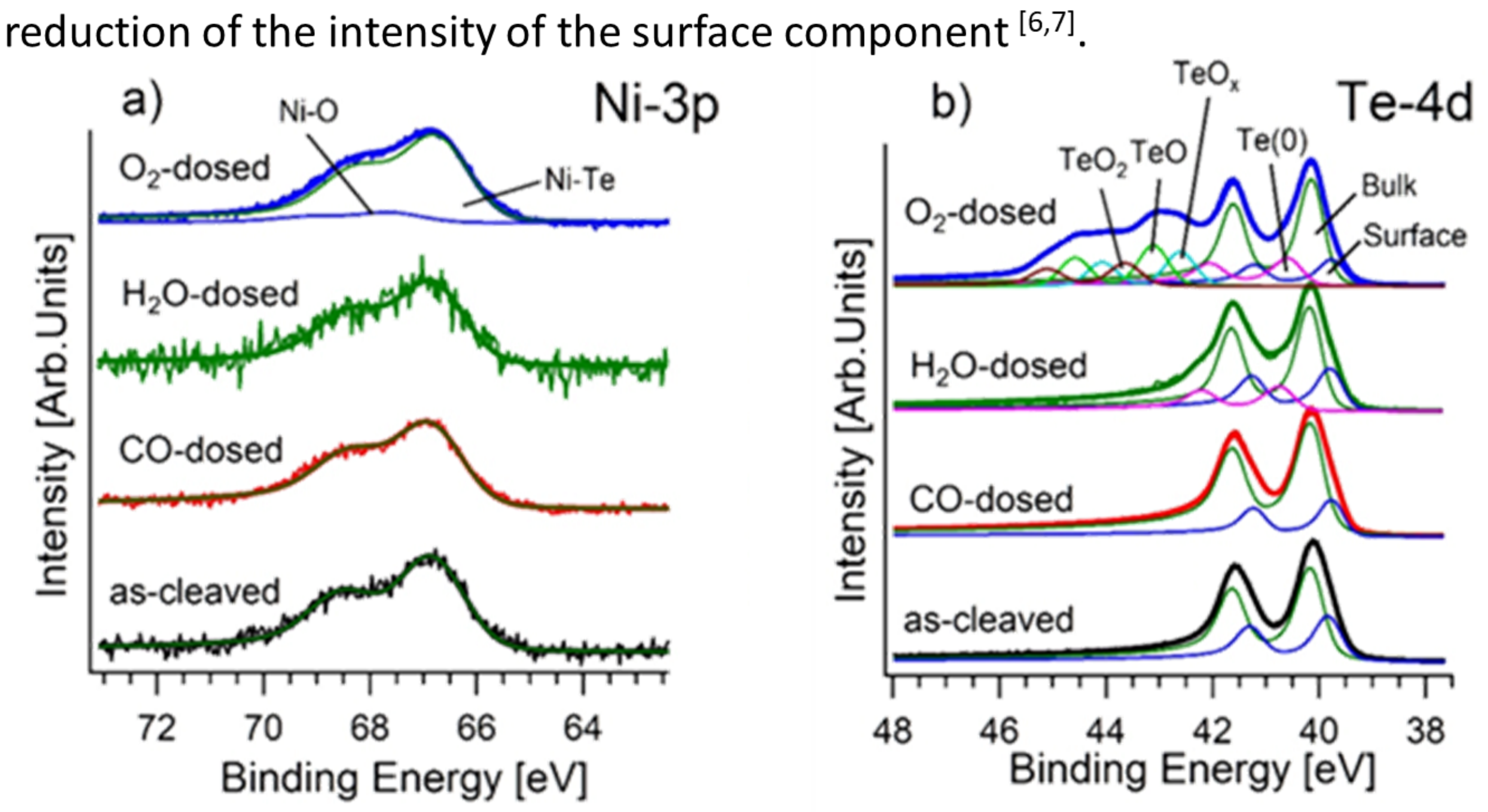

Fig 1. Core-level Ni-3p (a) and Te-4d (b) spectra collected from as-cleaved $NiTe_2$ and from the same surface exposed to CO, H_2O and O_2. Photon energy is 596 eV and the spectra are normalized to the maximum.

AFM enviromental stability

AFM analyses demonstrate that prolonged exposure to ambient atmosphere does not change the morphology of the flakes (Fig. 2a-d), as confirmed by the height profile along a specific direction remaining constant with time (Fig. 2e).

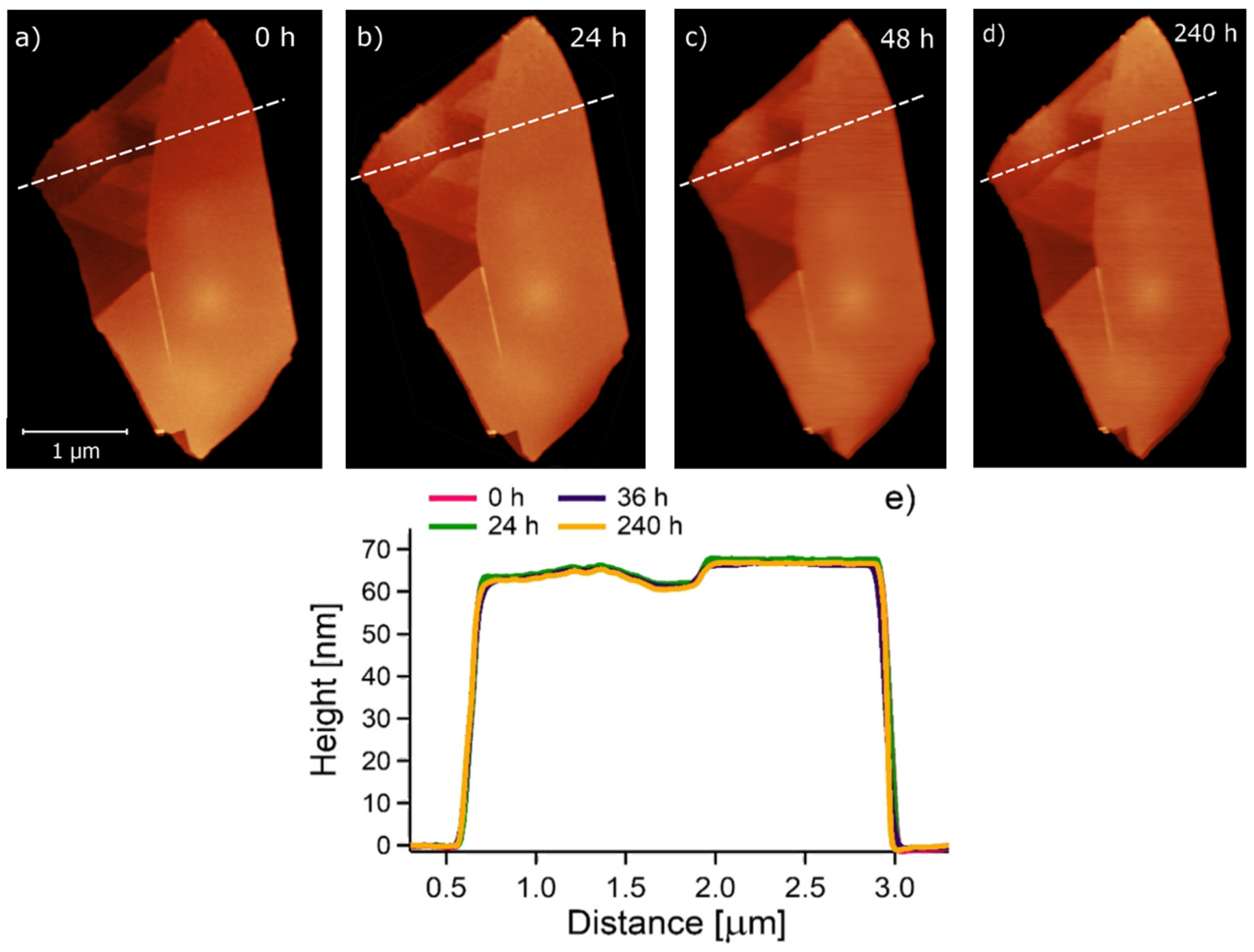

Fig.1 Time evolution of AFM images of a ~60 nm thick flake of $NiTe_2$.
Panel (a) shows the flake immediately after exfoliation, while panels (b)-(d) show the same flake after 24, 48 and 240 hours in air, respectively.
The dotted white lines indicate the path of the height profile shown in panel (e).

Aging study in ambient atmosphere

In ambient atmosphere, passivation is achieved in less than 30 minutes with the TeO_2 skin having a thickness of about 8 Å. A prolonged exposure time (up to 41 hours) does not induce further oxidation of the $NiTe_2$ surface, while TeO and TeOx are both converted to TeO_2. The NiO component reaches a maximum of 58% of the Ni-3p total spectral area after 30 minutes, and no further increase after a longer storage time in ambient air was observed.

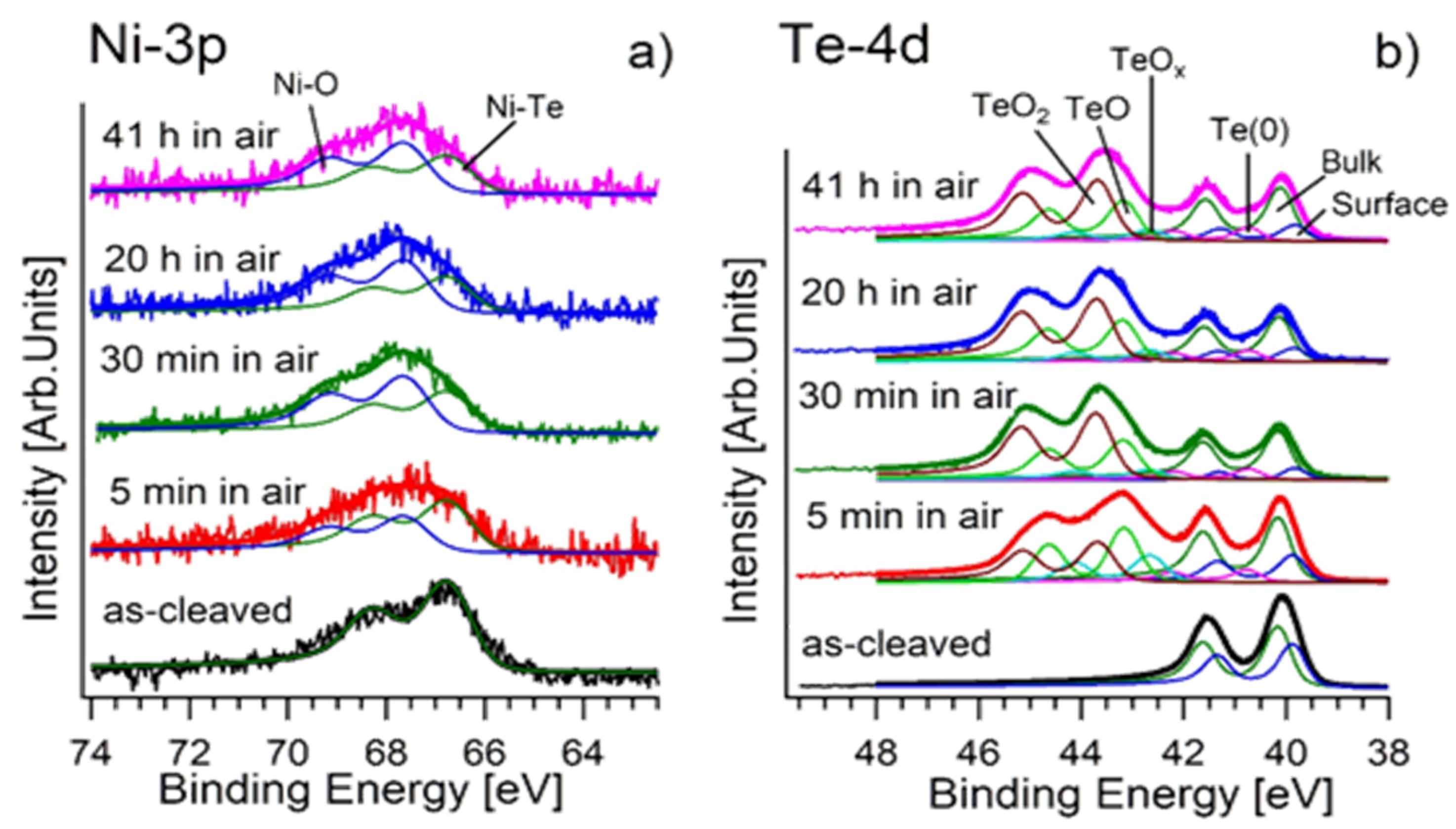

Figure 3. Core-level Ni-3p (a) and (b) Te-4d spectra collected from $NiTe_2$ exposed to air for 5 min, 30 min, 20 h and 41 h. Photon energy is 596 eV and the spectra are normalized to the maximum.

Device implementation

NiTe2-based field effect transistors exhibit superb stability over a timescale as long as one month.

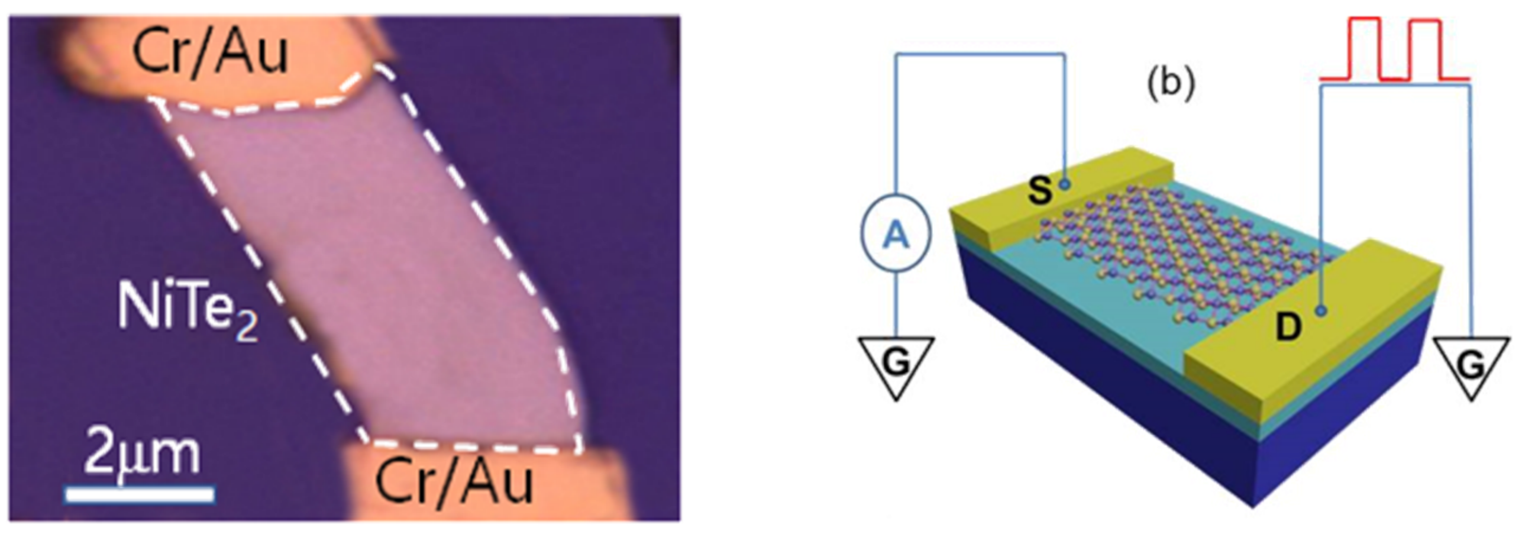

Fig.4 (a) Optical microscopy of $NiTe_2$-based FET obtained from mechanically exfoliated bulk single crystal. (b) Schematic diagram of the nanodevice with a $NiTe_2$-based active channel.

Tab 1. Comparison of the performance of receivers based on graphene, black phosphorus and $NiTe_2$ at 40 GHz carrier frequency.

	graphene	black phosphorus	$NiTe_2$
Responsivity (A/W)	1.50±0.01	0.74±0.01	5.18±0.01

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CONCLUSIONS

Bulk $NiTe_2$ is an ambient-stable material with diverse applications, ranging from catalysis to nanoelectronics. A passivating TeO_2 overlayer is formed after exposure to ambient atmosphere for less than 30 minutes. The passivated surface is stable in air over a timescale of several weeks. The $NiTe_2$ surface does not show any reactivity toward H_2O and CO, enabling the possibility to fabricate CO-tolerant electrodes. Furthermore, devices with active $NiTe_2$ channels exhibit high stability in air even without encapsulation. Finally, we tested the suitability of $NiTe_2$ for high-frequency electronics. The signal exhibits especially good repeatability without decay even after a one-month exposure to the ambient environment.