Applied Surface Science 528 (2020) 146951

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Multi-wafer-scale growth of WSe_2 films using a traveling flow-type reactor with a remote thermal Se cracker

Hang Kang[a,b,1], Sun Jin Yun[a,b,*,1], Kwang Hoon Jung[a], Jung Wook Lim[a,b]

[a] ICT Materials Research Group, Materials & Components Basic Research Division, Electronics and Telecommunications Research Institute (ETRI), 218 Gajeong-ro, Yuseong-gu, Daejeon 305-700, South Korea

[b] Department of Advanced Device Engineering, University of Science and Technology, 217 Gajeong-ro, Yuseong-gu, Daejeon 305-350, South Korea

ARTICLE INFO

Keywords:
WSe_2
Transition metal dichalcogenide
Selenization
Traveling flow-type reactor
Thermal Se cracker

ABSTRACT

Two-dimensional (2D) transition metal dichalcogenides (TMDCs) have demonstrated superior electrical and optical characteristics and are expected to replace silicon in semiconductor materials. However, in practice the use of TMDCs remains a challenge due to the lack of a suitable method for the large-scale synthesis of TMDCs. Herein we demonstrated a multi-wafer-scale growth method to obtain very uniform and continuous 2D WSe_2 films by combining the selenization of the W metal using thermally cracked Se molecules, a metal-agglomeration-suppressed growth technique, and a traveling flow-type reactor. The usefulness of the traveling flow reactor must be attributed to the self-saturated selenization of a very thin W metal precursor film on a large-area substrate. The number of 2D WSe_2 layers was easily controlled by varying the thickness of the W precursor. Raman scattering and thickness measurements showed that WSe_2 films grew uniformly on three 4-inch Si wafers at once, at both 530 and 600 °C. The average Hall mobility and carrier concentration of 6-nm-thick p-type WSe_2 films on the three wafers were 22.8 $cm^2\ V^{-1}\ s^{-1}$ and 3.69 × $10^{16}\ cm^{-3}$, respectively. The field effect (FE) transistor with the 6-nm WSe_2 channel and SiO_2 back gate insulator also showed p-type transfer characteristics. The formation of a $WSe_2/MoSe_2$ vertical heterostructure also demonstrated the usefulness of the method proposed herein.

1. Introduction

Two-dimensional (2D) transition metal dichalcogenides (TMDCs) have been studied as next-generation semiconductor materials that are expected to replace Si and its compounds because a few nm-thick TMDC films show superior electrical and photoelectronic characteristics such as high mobility, high photosensitivity, and high gas sensitivity [1,2]. TMDC layers are bonded by weak van der Waals forces, which allows the crystal planes to be easily cleaved layer by layer. In addition, strong covalent bonds between the transition metal and chalcogen atom intralayer allow carriers to be easily transported along the layer. Thus, the superiority of 2D TMDC nanosheets strongly depends on the crystallinity. In earlier studies on TMDCs, a mechanical exfoliation method was mostly utilized to obtain mono- or multi-layered single-crystalline TMDC nanosheets, and it is still frequently used in the fabrication of various new functional devices and the characterization of their unique properties [3–5]. However, TMDC nanosheets obtained by mechanical exfoliations suffer from the serious limitation that they cannot be used in the large-scale fabrication of practical devices that require reproducibility and uniformity over a large area.

To overcome these limitations, chemical vapor deposition (CVD) was performed at a temperature greater than or equal to 700 °C in order to form 2D TMDC nanosheets or continuous films in quartz tubes in laboratory-scale experiments [6–9]. This high growth temperature causes the migration of synthesized molecules and induces island-like growth, diffusion of chalcogen atoms into the under-layer, and degradation of the underlying films; the latter sometimes requiring a transfer to other substrates for the fabrication of electronic devices [10]. Furthermore, wafer-scale uniform growth and control over the thickness remain unfavorable aspects of the technique. Although TMDC films grown by metal–organic CVD have shown relatively improved wafer-scale uniformity and electrical properties, the technique suffers from the limitation that it cannot ensure the growth of various high quality TMDC compounds at an appreciable growth rate with low impurity incorporation from precursors such as carbon, oxygen, or halogens, especially at a relatively low deposition temperature [11,12].

* Corresponding author.
E-mail address: sjyun@etri.re.kr (S.J. Yun).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.apsusc.2020.146951
Received 2 April 2020; Received in revised form 25 May 2020; Accepted 9 June 2020
Available online 13 June 2020