Investigations on the Plasma-Surface Interaction during Atomic Layer Etching of Thin Transition-Metal Dichalcogenide Films

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Abstract: Layered transition-metal dichalcogenides such as MoS\textsubscript{2} or WS\textsubscript{2} are interesting materials for the integration in future transistor channels, photodetectors, or sensors due to their intrinsic bandgap. The plasma-surface interaction of selected plasma effects on these materials was investigated to provide fundamental understanding of the interactions and to derive concepts for a targeted material modification.

Keywords: 2D materials, MX\textsubscript{2}, plasma damage, ALE

1. Introduction

The dimensional scaling in nanoelectronics lead to ultra-thin layers approaching the extreme of one atomic layer film. Graphene received lots of attention due to its high mobility and strength. However, graphene does not have an intrinsic bandgap and is difficult to integrate using traditional electronic device concepts. In contrast, transition-metal dichalcogenides (TMDC) such as MoS\textsubscript{2} or WS\textsubscript{2} are layered material with an intrinsic bandgap and are therefore considered as promising compounds for transistors, photodetectors, or sensors [1]. First devices have been reported on mechanically exfoliated flakes using traditional processes such as lift-off/e-beam lithography. However, these techniques are not compatible with industrial fabrication methods involving several plasma-based techniques.

2. Plasma damage

Plasmas are applied in dry etching processes, deposition of dielectric materials, and doping in transistors. This implies that sensitive and ultra-thin TMDCs are exposed to ions, neutrals, and high energetic light released by the plasma. This could lead to sputtering, amorphization, oxidation/reduction [2], or functionalization [3] of the layered TMDCs. Since the films are very thin, the undesired interactions have to be minimized or controlled. This require insight into the fundamental plasma-TMDC interaction mechanisms.

3. Concept of infinite selectivity

A major concern is the plasma etching of dielectrics on top of the TMDCs. When conventional dielectric plasma conditions are applied, the plasma interacts also with the TMDC as soon as it breaks through the dielectric and could degrade it severely as depicted in Fig. 1. Based on the conclusions of the fundamental study, selected plasma conditions will be applied to dielectrics and the etch rates compared, targeting an infinite selectivity of the dielectric towards the TMDC.

4. Experimental

MoS\textsubscript{2} layers (3-10 nm) were exposed to different plasma conditions. To separate the distinct plasma effects, samples were exposed to non-reactive Ar\textsuperscript{+} and reactive discharges in an inductively coupled plasma (ICP) chamber. In addition, samples were treated in downstream plasmas (DSP) for investigating the influence of reactive species only. By using DSP, the ion bombardment and the high energetic light can be avoided.

After the treatment, the films were characterized by spectroscopic ellipsometry to determine the remaining thickness. Furthermore, the composition was analysed by Rutherford Backscattering and the film quality evaluated from Raman spectroscopy. Water contact angle measurements provided information about the films’ hydrophobicity which is related to the near-surface chemical changes. Moreover, X-ray photoelectron spectroscopy was used to analyse the chemical state of the surface layers.

5. Results and Discussion

The effect of a non-reactive Ar-plasma has been investigated and was compared to a typical dielectric etch chemistry containing CF\textsubscript{4}. The sulfur/molybdenum ratio decreased with higher bias power in Ar-only plasma as
shown in Fig. 2. The higher the selected bias voltage, the higher was also the energy of the ions approaching the MoS$_2$ surface. This led to a preferential removal of sulfur atoms from the films.

This shows that the fluorocarbon containing chemistries have a high affinity towards molybdenum-containing compounds. Furthermore, it motivates the necessity to develop soft-landing and/or ALE processes.

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**References**

