Atomic-scale observation of epitaxial growth through two-dimensional materials

Sungkyu Kim (Sejong University)

Based on the conventional epitaxy mechanism, various single-crystalline materials can be directly grown on single-crystalline substrates with acceptable lattice mismatched system. The conventional heteroepitaxy with the relatively huge lattice mismatch generates dislocations to release the accumulated strain energy. These epitaxial growths are theoretically based on atomic interaction and repetitive stacking and can be easily confirmed through experimental results. The recently reported new concept of remote epitaxy method allows the growth of single-crystalline materials onto two-dimensional materials due to strong ionic bond from substrates. Although remote epitaxy materials such as GaN[1], GaAs[2], and various oxide[3] have been successfully demonstrated, atomic arrangement based on ionic interaction across two-dimensional graphene is still not fully understood.

Herein, we demonstrate the role of a graphene layer that allows the formation of ionic bonding between substrate and epitaxy film. In order to directly observe atomic arrangement, the remotely grown single-crystalline film was characterized by cross-sectional STEM analysis. The physically transferred monolayer graphene on Ga-terminated (100) GaAs substrate is effective not only to protect the atoms supplied from the outside during growth process, but also to observe the growth mechanism by ionic fields. Although some areas under the graphene were damaged, it was clearly confirmed that arsenic atoms are located above gallium-terminated substrate through the graphene with the physical distance of 0.60 nm. In addition, heteroepitaxy system between GaAs substrate and GaP film represents the origin of remote epitaxy including the spontaneous relaxation of dislocations through graphene. These findings provide crucial evidence to explain remote epitaxy phenomena, which could eventually broaden epitaxy technologies.

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[2] Bae, S.-H. et al. Graphene-assisted spontaneous relaxation towards dislocation-free heteroepitaxy. Nature Nanotechnology 15, 272-276 (2020)

[3] Kum, H. S. et al. Heterogeneous integration of single-crystalline complex-oxide membranes. Nature 578, 75-81 (2020)