Increasing the scale of 2D materials synthesis

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Abstract (Century Gothic 11)

2D materials have shown the potential for future electronics due to their unique electronic, magnetic, and thermal properties and are considered replacements for traditional semiconductor materials in transistors, sensors, and light emitters. To compete with established materials, such as Silicon or Germanium, synthesis has to be conducted at sufficient scales.[1] Despite significant recent advances in the large scale synthesis 2D materials through CVD processes, their production throughput is several orders of magnitudes smaller than silicon single-crystal Czochralski growth. We here identify the fundamental limitations of 2D materials' growth and demonstrate routes towards increasing their production scale.
First, by investigating the effect of growth parameters on graphene synthesis, we establish a novel figure of merit, termed conversion efficiency between precursor and graphene, that depends on the interaction time of the catalyst with the precursor. Simulations indicate that this parameter is controlled by a transport limited reaction process over a wide range of fluid dynamical conditions. We therefore introduce three different approaches to establish a reaction-limited growth process by increasing the residence time of methane by several orders of magnitude. These approaches enhance the conversion efficiency to unprecedented levels and permit the growth of thousands of square centimeters of graphene layers within 10 minutes reaching levels of production throughput of mature semiconductor materials.
The gained understanding was applied to the scalable synthesis of novel transition-metal dichalcogenides, MoS2 and WS2. Control of the precursor diffusion pathway was found to yield high quality single-layer grains of these 2D materials and novel routes were introduced to extend their scalable production. Moreover, we demonstrate that atomic confinement of precursors can yield novel morphologies of WS2 with potential applications in optoelectronic devices.
Finally, we describe novel routes to extend the scale of 2D materials production beyond traditional abilities. Using interfacial reactions, we succeeded in growing silicene and Cu2S that had been previously considered thermodynamically unstable and which can be produced at conditions that would be unachievable by chemical vapor deposition.

References

[1] AJ. Alexander Liddle and Gregg M. Gallatinuthors, ACS Nano, 10 (2016), 2995–3014.

Figures

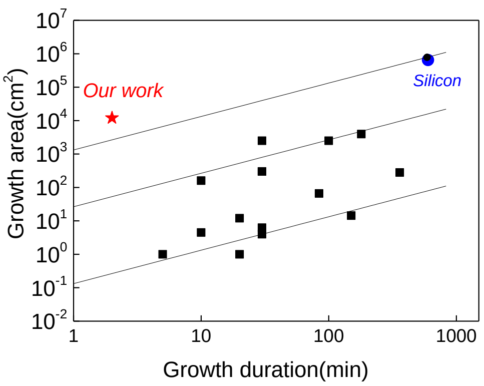

Figure 1: Our new method allows synthesizing graphene with highest yield.