Fracturing of polycrystalline MoS_2 nanofilms

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Recent years have seen a rapid increase in demand for personal flexible and wearable devices. With the development of 2D materials, the pursuit of high-performance flexible devices would seem even closer to realisation [1]. However, one of the key requirements for flexible and stretchable devices is the ability to handle a reasonably high strain. Of the myriad 2D materials, graphene is considered the strongest material ever measured. It possesses a Young's modulus of 1.0 TPa and an intrinsic strength of 130 GPa, and has been shown to handle deformations beyond the linear regime [2]. In the case of transition metal dichalcogenides, a single-crystal, single-layer MoS2 film was shown to possess a Young's modulus of about 270 GPa [3], and breaking of the film was reported to occur at an effective strain between 6 and 11% for MoS2 single and bi-layers, respectively. However, in the polycrystalline MoS2 large concentration of defects and grain boundaries significantly degrades its mechanical properties. For example, for polycrystalline MoS2 we observed inverse pseudo Hall–Petch weakening behaviour and reduction of Young modulus to 16-20 GPa [4].
In this work the fracture in polycrystalline MoS2 films with an average grain size below 10 nm is studied at the micro- and nanoscale using electron microscopy [5]. Two samples with different thicknesses and grain orientations: horizontal and vertical to (100) crystallographic plane are measured. The critical uniaxial strain is determined to be approximately 5% and independent of the sample morphology. However, electron beam irradiation is found to enhance the interaction between the MoS2 and the PDMS substrates, leading to an increased critical strain that can exceed 10%. This enhancement of strain resistance was used to fabricate a mechanically robust array of lines 1 mm in length. Finally, nanoscale crack propagation studied by transmission electron microscopy showed that cracks propagate along the grain boundaries as well as through the grains, preferentially along van der Waals bonding. These results provide insight regarding the fracture of polycrystalline 2D materials and a new method to tailor the critical strain and nanofabrication of ultra-thin MoS2 devices using well-developed tools, which will be of great interest to the flexible electronics industry.

References

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