Nonlinear mechanical response of ripple structure in MoS_2 nanosheet

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Investigating the mechanical behavior of the two-dimensional (2D) materials under strain is important for their applications. Here, we perform in situ transmission electron microscopy (TEM) observation to analyze the strain dependence of the ripple structure in the atomic-thin MoS_2 nanosheet. By applying geometric phase analysis (GPA) [1] to TEM images, the ripple structure, which formed due to the externally imposed strain [2], was estimated. By analyzing the geometric evolution of ripple structure, the Poisson's ratio of MoS_2 nanosheet with increasing tensile strain was revealed.

The mechanical response of MoS_2 nanosheets under strain conditions was investigated by in situ stretching TEM observation. The TEM image of a MoS2 nanosheet, which is suspended across the trench and stretched with tensile strain (x direction), shows a periodic contrast modulation that the areas with and without clearly visible lattice fringes, suggesting the formation of the rippled structure, as shown in Fig. 1(a). The corresponding apparent strain was obtained by the GPA method, as shown in Fig. 1(b). By analyzing the value and distribution of the apparent strain (ε_{yy}) in the strain map, the amplitude (A) and period (λ) of the observed ripple can be estimated [3]. With the tensile strain (ε) applied along with the x direction from 1.42% to 2.44%, the structural evolution of ripples was revealed, as shown in Fig. 1(c). It is found that the periods of ripples did not follow the 1/4-power scaling law, indicating that the continuum mechanics approximation is invalid. Also, our experimental results suggest that each MoS_2 layer does not have in-plane distortion by bending. Since the Poisson's ratio (v) could be obtained by: $v=\pi^2A^2/(2\varepsilon\lambda^2)$, the strain dependence of the Poisson's ratio was revealed, as shown in Fig.1(d). The estimated Poisson's ratio was found to increase with the strain, it increased to 0.7 at longitudinal strain of 2.44%. Such a phenomenon can be explained by the increase of bonding angle in MoS_2 layer under stretching based on our analytical model.

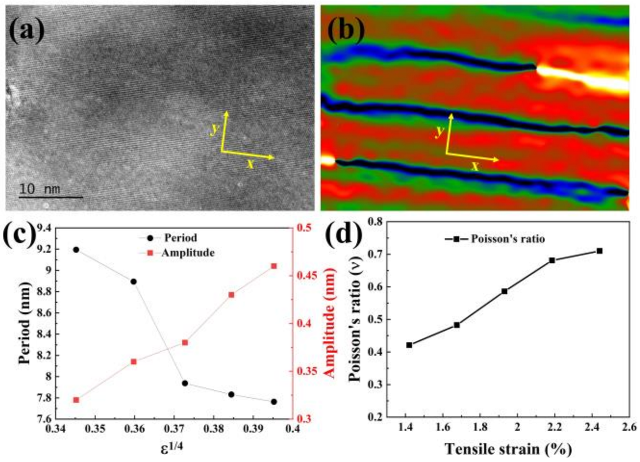

Fig. 1: (a) The TEM image of MoS_2 nanosheet with a tensile strain of 1.68%. (b)Corresponding strain map of (a). (c) The relationship between the strain (ε) and the ripple structure. (d) The relationship between the strain and estimated Poisson' ratio.

The strain dependence of Poisson's ratio in MoS_2 layers could be explained by the nonlinearly mechanical response. We conclude that the nonlinear mechanical response of the ripple structure of MoS_2 layers is intrinsic under tensile strain.

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