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Layer-thinning of MoS_2 using electron beam and atomic force microscope

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Possessing a large band gap (BG) of 1.8 eV makes single layer MoS_2 a promising material as the basis of nanoelectronics [1]. Not only single layer but also few layer MoS_2 is of interest since the direct BG changes into indirect BG of 1.2 eV. Therefore controlling the number of layers is necessary in fabrication of MoS_2 devices. To obtain thin layer devices, micromechanical and liquid-based exfoliation methods [1,2] are highly used for layered materials such as graphene and MoS_2. However it is difficult to control the thickness and the shape of the nanosheets. In this work we present a new method to thin the nanosheets of MoS_2 with controlling the number of removed layers.

We first expose a surface of a MoS_2 nanosheet by electron beam at acceleration voltage of 50 kV and beam current of 500 pA for 10 minutes. Subsequently, using atomic force microscope (AFM) in contact mode, we rubbe the surface at a minimum force of 20 nN for several times. Figure 1 shows AFM tapping mode images of MoS_2 nanosheet before (a) and after (b) the rubbing procedure. Obviously, several layers are removed in the right area [Fig.1 (b)] by AFM rubbing. The profiles taken along the marked lines [Fig.1 (c)] demonstrate that thickness of nanosheet reduces by about 2.4 nm which corresponds to 4 layers. Further AFM rubbing removed the same number of layer in the entire area of the nanosheet (not shown). We confirmed the EB exposure is required for the rub-induces layer removal. We examined effects of the beam current I_b and the acceleration voltage V_a on the layer removal process. We found that the number of the removed layers increase with I_b, while V_a in the studied range does not highly affect the number of removed layers. The EB-assisted AFM thinning method can possibly applied on other layered materials and can be used for thinning desired size nanosheets into required number of layers.

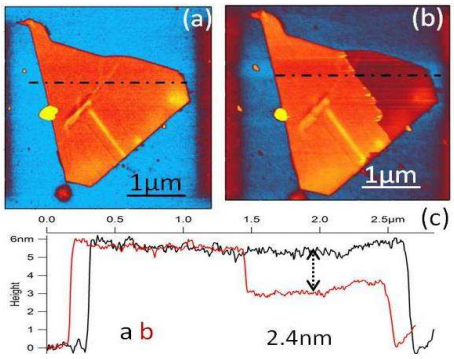

Fig.1 (a)- (b) show the layer removal during AFM rubring .(c) profiles show height reduction of 2.4 nm.

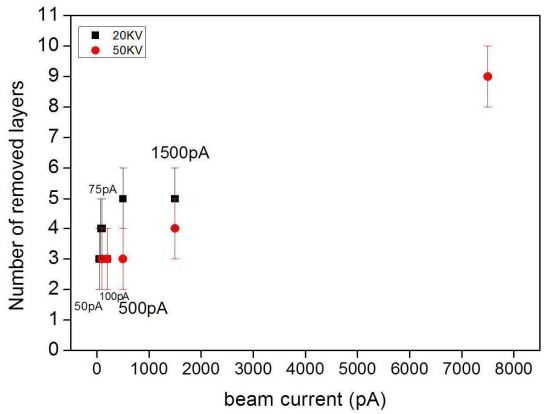

Fig.2 Beam current dependency of the removed layers at acceleration voltage of 20kV and 50kV.

[1] B.Radisavljevic *et. al*., Nature nanotechnology, **6**, 147 (2011)

[2] K. S. Novoselov *et. al.* Nature **438**, 197 (2005)