Resistless Nanopatterning of 2D Materials by Field Electron Emission Scanning Probe Lithography

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Experimental nanoelectronic devices based on two-dimensional materials are commonly fabricated by means of electron beam lithography (EBL). However, the exposure with high energy electrons combined with the resist related chemistry often creates defects as well as surface contaminations, eventually resulting in degraded device performance [1-3].
Moreover, to identify the exact numbers of atomic layers present in the observed sample, atomic force microscopy (AFM) is frequently used to determine the actual material thickness. Here, we present and discuss an unconventional combination of AFM and EBL that is based on an AFM cantilever with a nanoscale tip emitting a Fowler-Nordheim tunnelling current of low energetic electrons (<70eV) (Fig. 1). The emission current is kept on a constant writing setpoint via a feedback loop which controls the utilized AFM's z-piezo position, leading to a defined electron exposure dose [4].
Through this, we are able to exploit the non-invasive character of AFM and the related ultra-high spatial alignment capability together with the lithographic resolution of an electron beam emitted from a sharp cantilever tip. As a result, we show that sub-20nm resolution nanolithography can be performed on a variety of van der Waals materials, ranging from graphene to semiconductors (InSe & MoS_2), to semimetals (1T'-$MoTe_2$) and topological insulators (Bi_2Se_3). The only chemical involved during the patterning process is condensed water on the sample surface, originating from the relative humidity of the surrounding ambient environment. In combination with the applied sample bias voltage and the field emission current an electrochemical surface oxidation is induced. For instance, in case of MoS_2 samples, MoO_3 is created. MoO_3 can be used to either functionalize the MoS_2 surface for sensing applications or to pattern it by dissolving it in deionized water (Fig. 1c).

References

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Figures

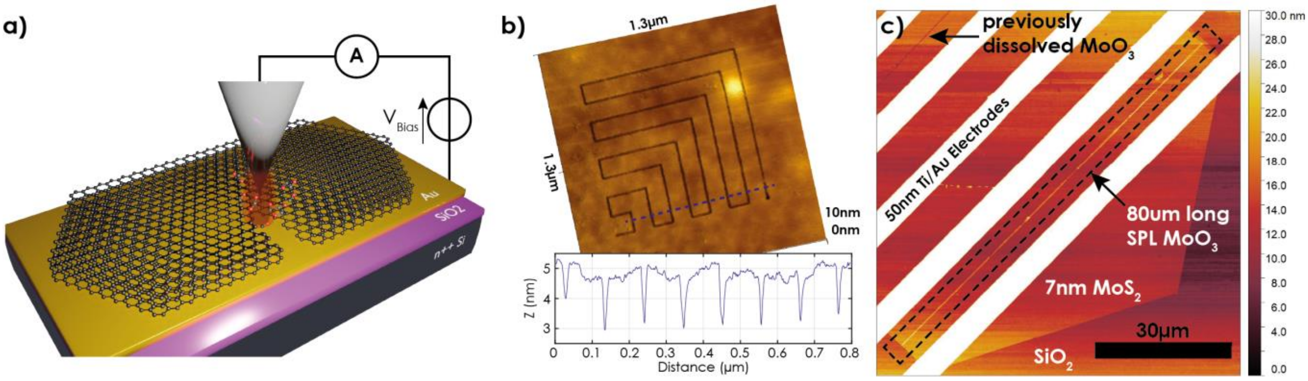

Figure 1: a) Schematic representation of the used experimental setup. b) Test pattern directly etched into a 15nm thick graphene nanosheet transferred onto a 40nm thick gold thin film. The average FWHM of the features is 10nm. c) Large range nanoscale modification of a MoS_2 FET structure. After immersion in deionized water the MoO_3 was dissolved, resulting in a thinning of the MoS_2 nanosheet from about 11 atomic layers to ca. 5 layers.