AFM Fountain pen Nanolithography for strain engineering in atomic thickness membranes

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Strain engineering is the process of tuning a material's electronic properties by altering its structural or mechanical properties[1]. This technique is widely used throughout the semiconductor industry as a means of enhancing the mobility of electrons in silicon by depositing strained silicon nitride layers on top of transistor channels. The past few years have seen an explosion of interest in two-dimensional (2D) crystals derived from layered materials that possess strong in-plane bonding and weak van der Waals bonding between crystal planes. The most prominent member of this family is graphene; other 2D crystals include hexagonal boron nitride and a number of transition metal dichalcogenides such as MoS_2. These materials offer a wide variety of interesting optical and electronic properties. For example, graphene is a highly conductive semimetal and monolayer MoS_2 is a 1.8 eV direct-gap semiconductor[2]. In experiments, graphene has been seen to withstand elastic strains of up to 25% which represents the ultimate maximum strain of a perfect carbon lattice[3-4]. Moreover, the breaking strain of MoS_2 crystal was found to be at least 10% [5]. Owing to the large changes in electronic band structure that result under such strain, there is currently great interest in exploiting strain engineering in atomic thickness membranes for electronic applications.

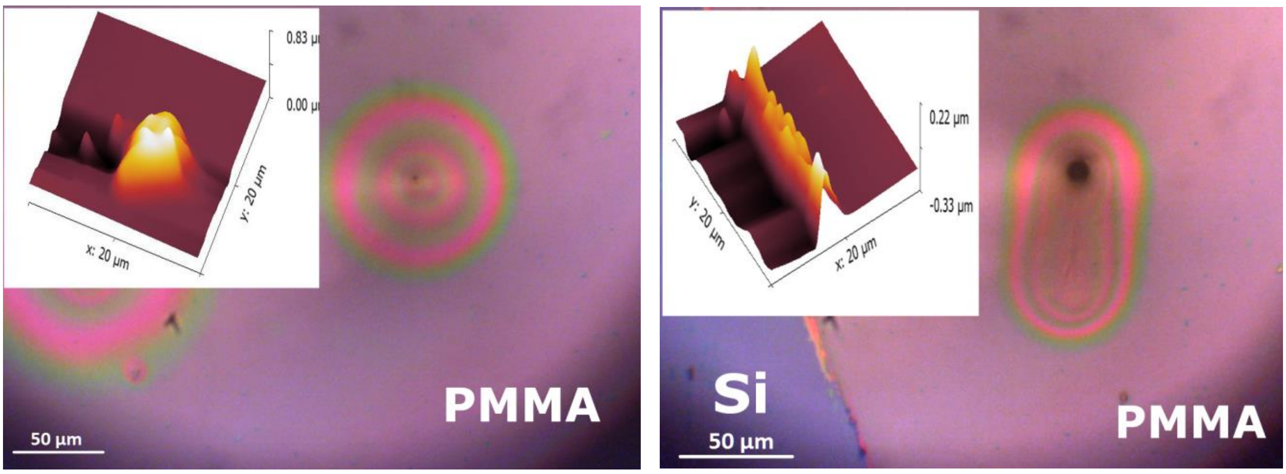

Fig. 1 Optical microphotographs of a patterned (a) dot and (b) linear mound. The colored interference fringes correspond to the starting phase of the spread of the micron size toluene droplet. The insets are the corresponding AFM images of the patterned features.

In this perspective, a new technique for efficient and controlled strain engineering of graphene and MoS_2 sheets of various thicknesses is described here. It is based on nanolithography using an Atomic Force Microscope (AFM), in which the AFM tip resembles to a fountain pen with an aperture of the order of few tens of nanometers. The tip is fed by a specific solvent and micron sized dots (fig. 1a) and linear mounds (fig. 1b) with height of a few hundreds of nm can be patterned onto a thin PMMA layer spin casted onto a SiO_2 wafer. The optimization of the proposed lithographic process is discussed in terms of adjusting critical parameters such as the writing pressure and velocity, tip aperture diameter and the type of solvent. Finally, AFM combined with Raman maps will be used for determining the engineered strain on graphene and MoS_2 sheets laid on a dot or a linear mound.

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