Fabrication of Pre-Bended Layered Semiconductor Biosensors on Flexible Substrates

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Ultrasensitive flexible nanoelectronic biosensors are needed to enable point-of-care (POC) biomedical applications, such as saliva-based *in vivo* sensors that can be conformally attached to nonflat surfaces in mouths, implantable blood monitoring sensors in patients' bodies, and real-time sweat sensors on the skin surfaces.[1-3] The superior electronic and mechanical properties of emerging layered semiconductors (*e.g.*, MoS_2, WSe_2, and WS_2) could be potentially leveraged to fabricate flexible resist/transistor-based biosensors capable of detecting low-abundant biomarker molecules at femtomolar levels.[4, 5] To enable the fabrication of such flexible electronic devices with a high reliability and durability under different strain/stress/substrate conditions, we need nanofabrication methods that can product suspended or pre-bended layered semiconductor structures on flexible substrates.

Here, we present a nanofabrication method capable of producing precisely pre-bended biosensor structures based on layered materials, such as MoS_2 and WSe_2, on flexible substrates. The biosensing characteristics of such pre-bended sensor structures are insensitive to the strain conditions of the substrates. Using this method, we have demonstrated the fabrication of MoS_2 and WSe_2 biosensors capable of detecting low-abundant biomarkers at femtomolar levels.

Fig. 1 schematically illustrates the fabrication steps for making a pre-bended layered semiconductor biosensor on a flexible substrate, which include (a) fabrication of a topographic sacrificial structure on the substrate, (b) mechanical alignment and printing of a MoS_2 film (typically few-layer and multilayer structures) on top of the sacrificial structure, (c) fabrication of a pair of electrodes that can also serve as the fixtures of the pre-bended MoS_2 film, (d) removal of the sacrificial structure, and (e) biofunctionalization. **Fig. 2** displays the optical micrographs (OMs) of (a) a pre-bended MoS_2 film printed on top of a sacrificial structure on a Kapton™ substrate, (b) the pre-bended MoS_2 film fixed by a pair of electrode contacts, (c) the MoS_2 film after sacrificial structure removal, as well as (d) a zoomed SEM image of the pre-bended MoS_2 film, which can serve as a suspended biosensing area. **Fig. 3** shows the preliminary biosensing results obtained by MoS_2 sensors. Specifically, **Fig. 3a** shows the I-V characteristics of a sensor in response to IL-1β molecules with various analyte concentrations. **Fig. 3b** displays time-dependent sensor signals measured at a fixed IL-1β concentration of 100 fM, which exhibits the kinetic property of the IL1β-antibody binding reaction.

This work advanced the nanofabrication techniques for leveraging the superior electronic and mechanical properties of emerging layered semiconductors for practical biosensing applications.

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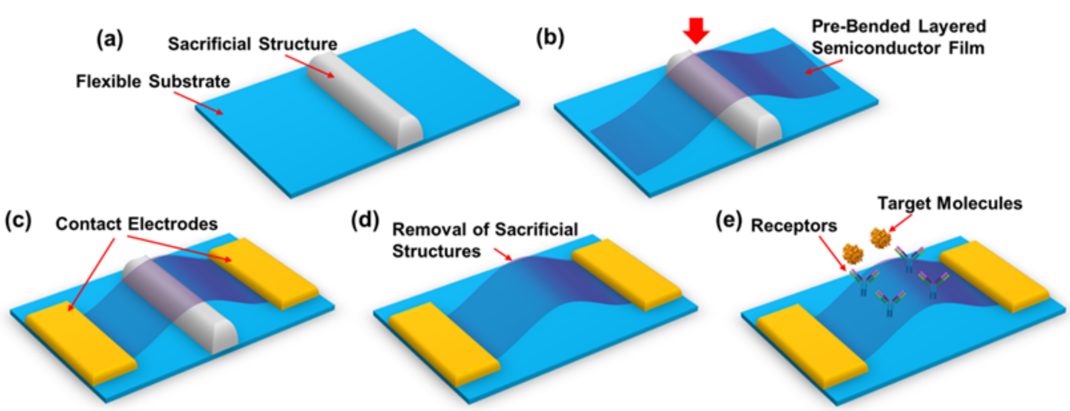

Fig. 1 Schematic steps for making pre-bended layered semiconductor biosensors on flexible substrates.

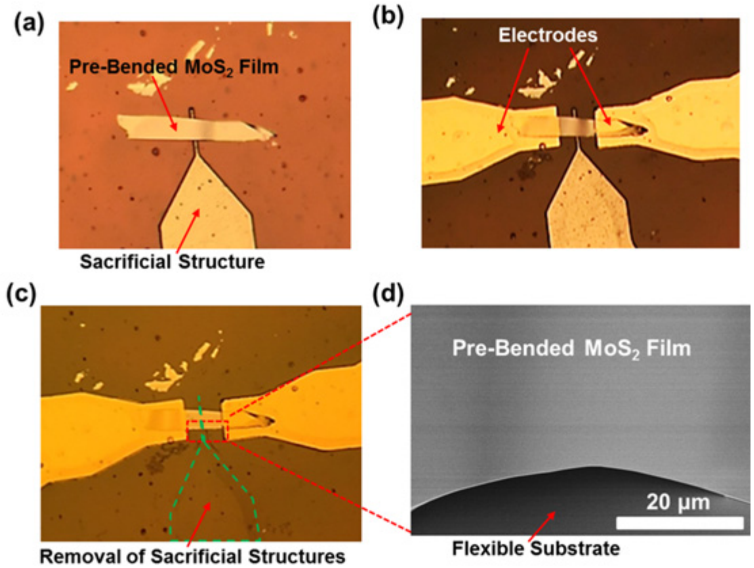

Fig. 2 Optical micrographs of (a) a pre-bended MoS_2 film printed on top of a sacrificial structure, (b) the pre-bended MoS_2 film fixed by a pair of electrode contacts, (c) the MoS_2 film after sacrificial structure removal; (d) zoomed SEM image of the pre-bended MoS_2 film, which serves as a suspended biosensing area.

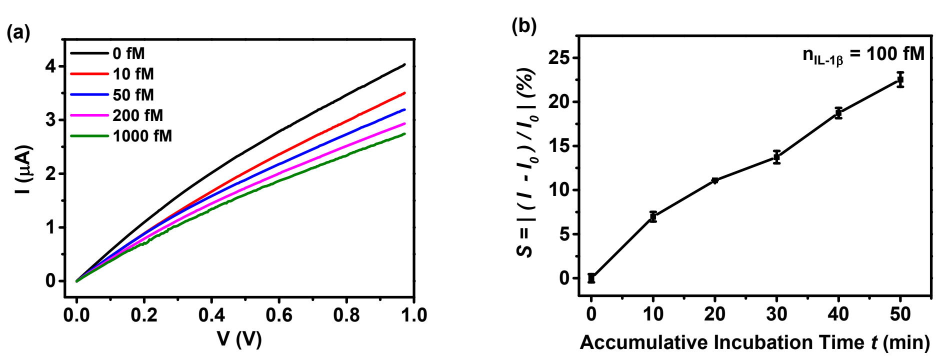

Fig. 3 Results of IL-1β detection and quantification: (a) I-V characteristics of a MoS_2 biosensor measured at various IL-1β concentrations (n = 0, 10, 50, 200, 1000 fM) (for all concentrations, incubation time = 20 min); (b) time– dependent sensor responses to n = 100 fM, which provides the information about the kinetic property of the IL1β-antibody binding reaction and enabling rapid low-abundant biomarker quantification.

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