Spin-crossover Nanoparticles/MoS_2-based Hybrid Field-effect Transistor for Electronics

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ABSTRACT

This contribution presents molybdenum disulfide (MoS_2)-based field-effect transistor (FET) functionalized with spin-crossover (SCO) nanoparticles (NPs). Effect of SCO NPs on MoS_2 electronic properties by switching between two distinct states using an external stimulus is investigated.

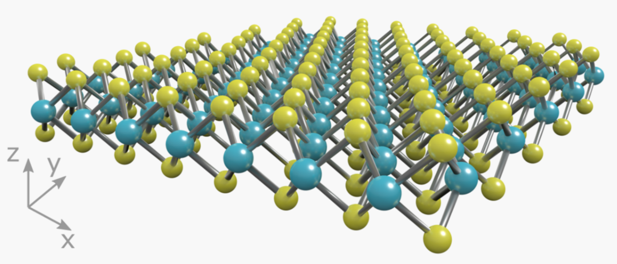
INTRODUCTION

Classical devices employing silicon are almost reaching their physical limits and alternatives, based on entirely new materials and principles, are being investigated. Examples of such new materials, which appear promising to be once used in the semiconducting industry, are two-dimensional materials (2DMs) and functional molecules due to their small dimensionality, low price, and unique functionalities. In both cases, materials display a full range of electrical, optical and magnetic properties, and therefore could find many applications in a new generation of devices. Moreover, it appears advantageous to combine them, both, different 2DMs together [1], and 2DMs with functional molecules, in heterostructures, which gives rise to unusual physical phenomena. The fabrication of hybrid organic/inorganic devices is of great potential thanks to the possibility to synthesize desirable molecules with predictable functionalities, giving additional degrees of freedom to devices [2].

In this scenario, we integrate 2DM into FET and introduce functional molecules in a form of thin layer of NPs to investigate their effect on electrical properties of the 2DM.

THEORY

MoS_2 has become a prototypical 2DM thanks to its intriguing properties, such as mechanical flexibility, its ease of exfoliation, air stability, and semiconducting behaviour with tunable bandgap which have been greatly appreciated for the fabrication of FETs. Moreover, it has been theoretically predicted that by applying an elastic strain to MoS_2 it is possible to change its band structure from semiconducting to semimetallic. Thus, if we find a way how to reversibly apply strain to MoS_2, we could switch between these two electrical modes and use it in a new generation of devices.



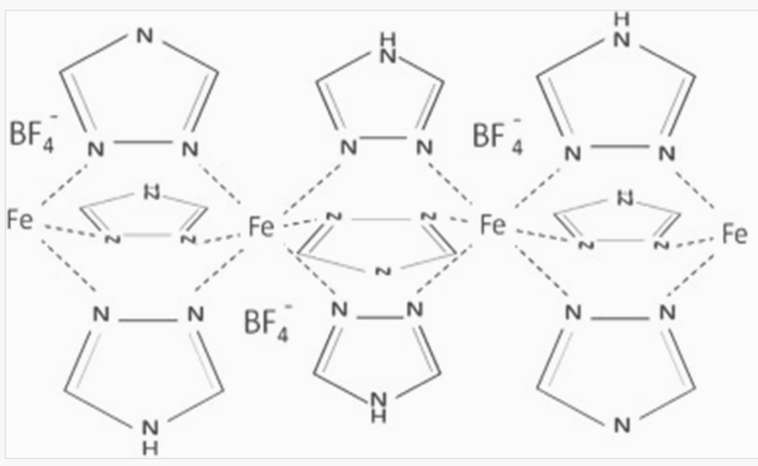


Figure 1. MoS_2 and polymer chain of spin-crossover molecules forming nanoparticles.

One possible way to do that could be a functionalization of MoS_2 with SCO NPs. These NPs are synthesized from polymerizable SCO molecules, that can crossover from low to high spin state and vice versa as a result of an external stimulus (e.g. temperature, light). The SCO phenomenon is accompanied by a change of volume of the molecules and, as a result, NPs made of them expand and shrink their size about 10 % [3]. If present in a compact layer over MoS_2 surface, we could use them to reversibly apply strain to the 2DM and effectively switch the electrical mode of the device.

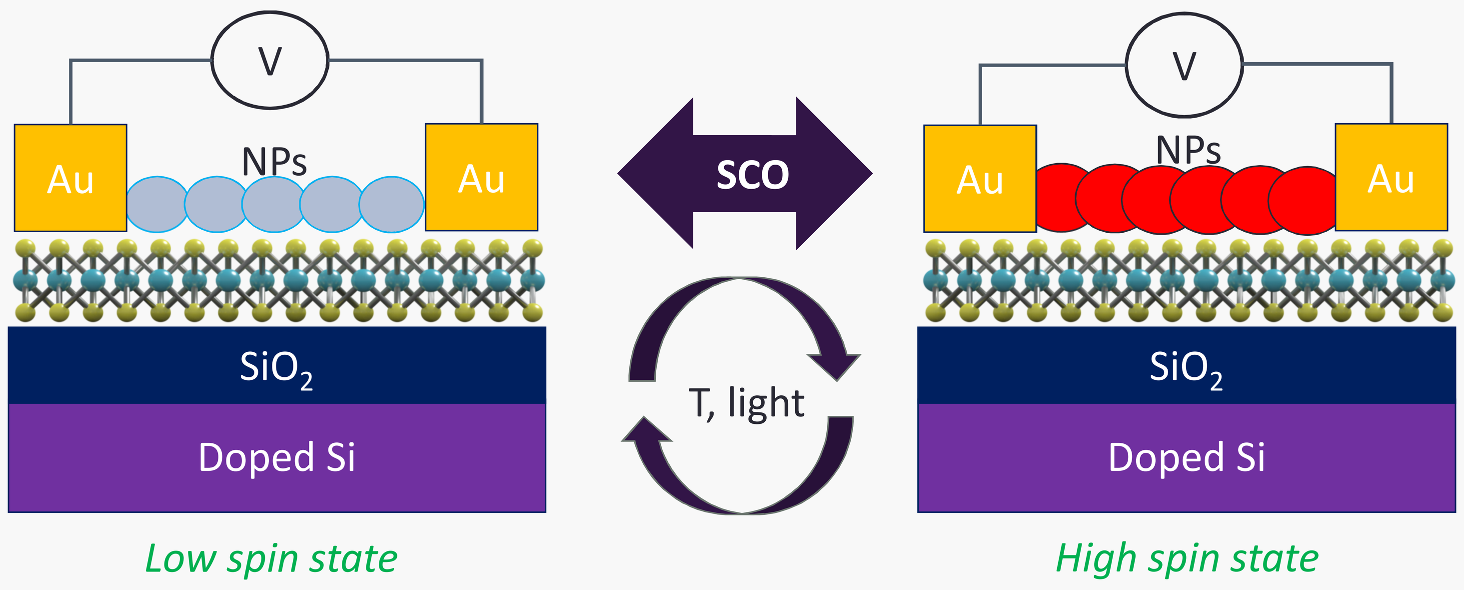


Figure 2. Hybrid switchable device. Spin state of nanoparticles is switched by external stimulus, they change volume and are expected to apply strain to MoS_2.

RESULTS AND DISCUSSION

To prepare SCO NPs/MoS_2 hybrid FETs, first, thin layers of MoS_2 are exfoliated from MoS_2 crystal and deposited onto SiO_2/Si wafer. Then, the most suitable flakes for the device fabrication are found with an optical microscope and characterized with an atomic force microscope (AFM). We are looking for MoS_2 mono- and bi-layers with unbroken and clean surface with sufficient area to contact the flakes with electrodes. Only the thinnest flakes are selected since the strain effect of NPs is expected to influence mostly superficial layers of MoS_2, thus, if present, underneath layers could decrease signal of the investigated effect. The electrodes contacting selected flakes are prepared by an e-beam lithography process and subsequent evaporation of Au in the ultra-high vacuum chamber. FET channel length (the gap between Au electrodes) is approximately 1.5 µm. After that, functionalization of MoS_2 surface with SCO NPs is performed and devices are contacted to the chip to be measured at cryostat.

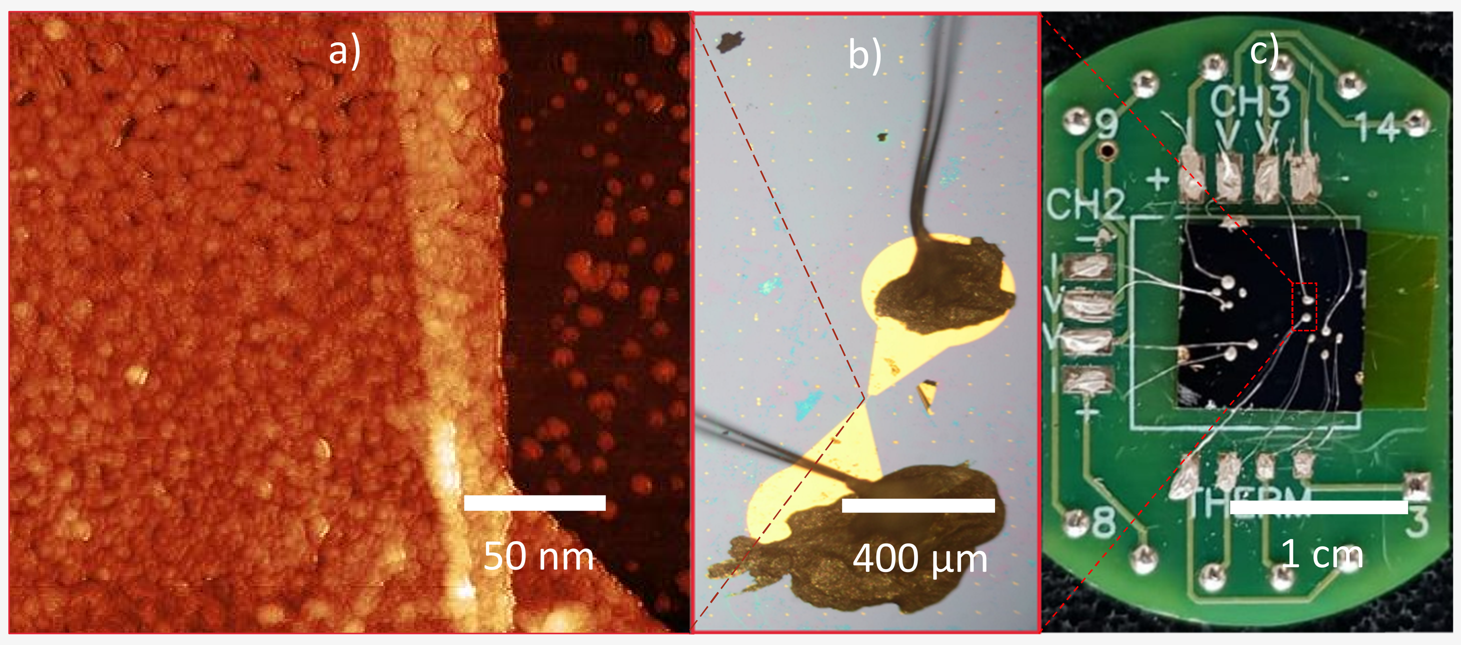


Figure 3. a) AFM image of MoS_2 flake after functionalization with spin-crossover nanoparticles, b) Optical microscopy image of Au electrodes contacting MoS_2 flake, c) electrodes wired to the chip.

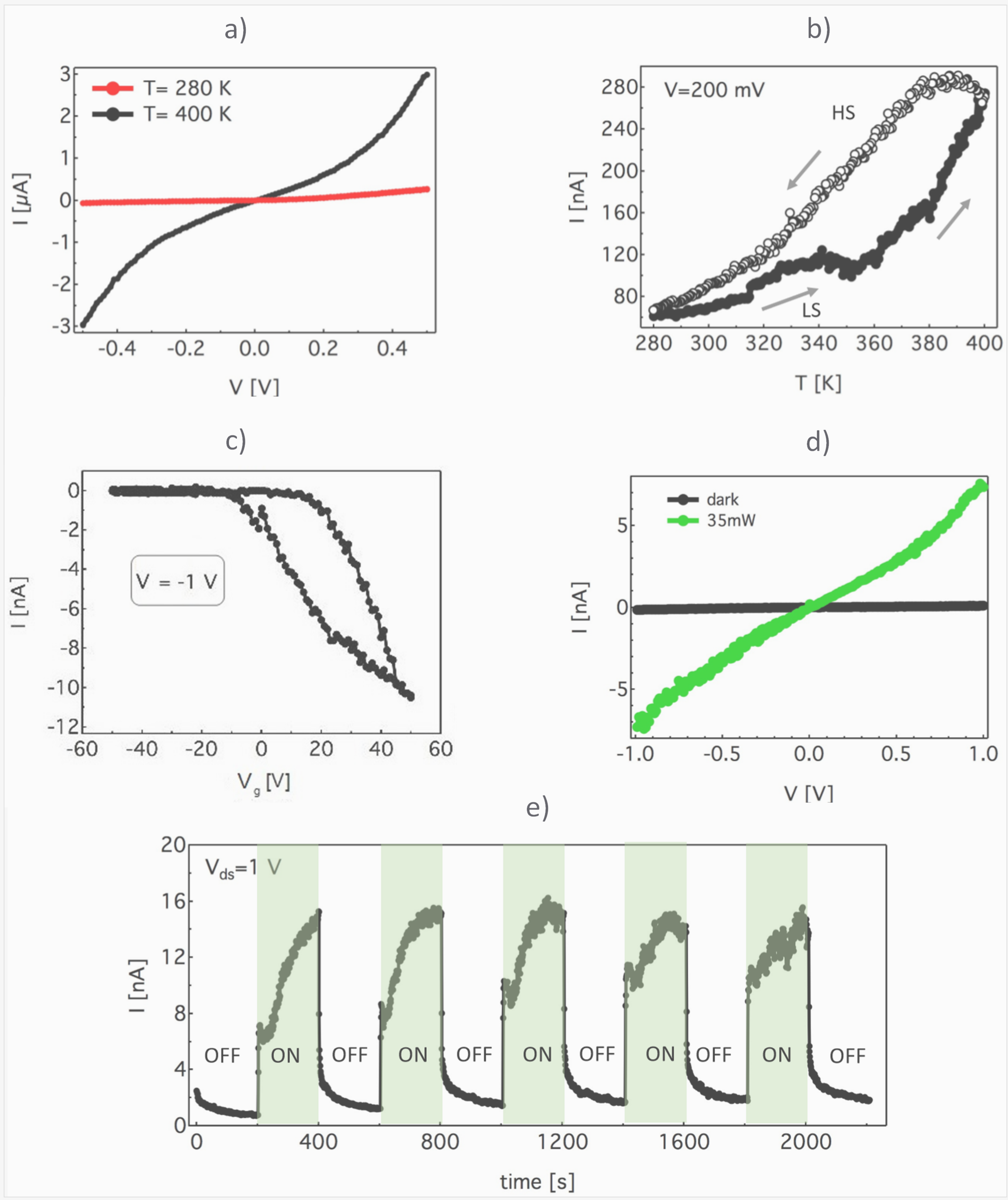


Figure 4. Electrical characterization of the hybrid device. a) IV curves measured at two distinct temperatures, b) current vs temperature measurement, c) back-gate characterization, d) IV curves in dark and in light, e) characterization with pulses of light.

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