Phase-transition induced magnetism modulation and logic implementation in NiFe/VO_2 heterostructure

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With more degree of freedom to manipulate information, multi-field control of magnetic and electronic properties may trigger various potential applications in spintronics and microelectronics. [1, 2] However, facile and efficient modulation strategies which can simultaneously response to different stimuli are still highly desired. Here, the strongly correlated electron system VO_2 is introduced to realize appreciable control of the magnetism in NiFe by phase-transition. Utilizing the multi-field modulation feature, programmable Boolean logic gates are implemented based on the heterostructure. As a demonstration of phase-transition spintronics, this work may pave the way for next-generation electronics in the post-Moore era.

I. Heterostructure preparation and property modulation

The NiFe/VO_2 bilayer is prepared by pulsed laser deposition (PLD) and magnetron sputtering. VO_2 is chosen as a representation of strongly correlated electron system, which exhibits fascinating property change as it transforms from a monoclinic insulator into a rutile metal at a critical temperature around 340K (**Figure 1a**). [3] Triggered by the phase-transition, the heterostructure features appreciable modulations in the coercivity (60%), saturation magnetic strength (7%) and magnetic anisotropy (33.5%) as shown in **Figure 1b**. Further characterization of the magnetization temperature dependence in this film, which exhibits abrupt variation with the happening of phase-transition (**Figure 1c**), verifies that the magnetism modulation is mainly attributed to the interfacial strain coupling of the system.

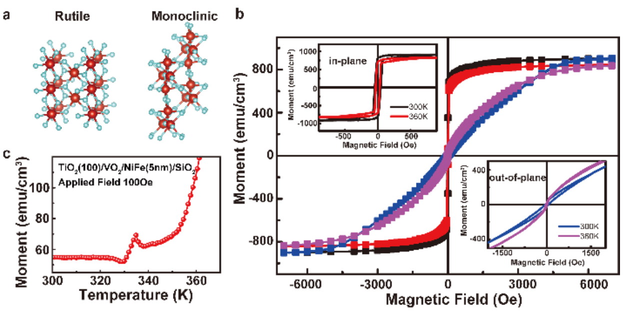

Figure 1 | Phase-transition of VO_2 and characterizations of the NiFe/VO_2 heterostructure. (**a**) The reversible phase-transition of VO_2 between monoclinic (M1) and rutile lattice structures. (**b**) Temperature dependence of out-of-plane magnetization at magnetic field 100 Oe. (**c**) *M*–*H* hysteresis loops of NiFe (5 nm)/VO_2 (40 nm)/TiO_2 (100) sample measured at 300 and 360 K. The insets give the scanning results of the small fields.

II. Device fabrication and multi-field control applications

These appreciable effects in the heterostructure may further enable emerging device applications with a capability of multi-field modulation. As a demo, a phase-transition anisotropic magnetoresistance device (PTAMR device) is fabricated. The magnetoresistance curves measured with H_x field applied are shown in **Figure 2b & 2c**. The coercivity change from about 50Oe to less than 10Oe and resistance drops more than 10% with illumination applied. Utilizing this feature, the PTAMR device provides an opportunity to achieve multi-resistance states, under multiple controls of the magnetic field and light illumination. **Figure 3c** demonstrates an example of six different resistance states, realized via synergistic control of light illumination and magnetic field. Furthermore, this phase-transition spintronic device also shows a potential to construct programmable logic gates with multi-field inputs by setting different threshold resistance windows (**Figure 2d & 2e**).

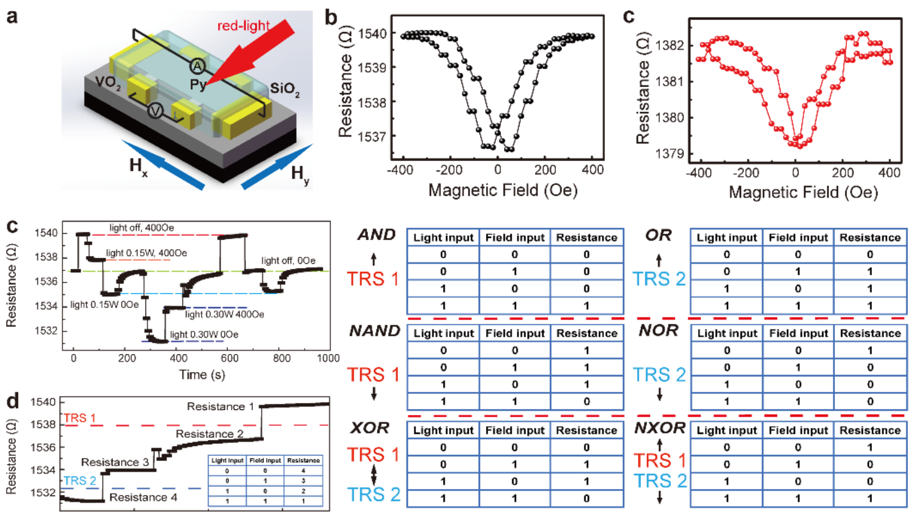

Figure 2 | PTAMR devices and magnetoresistance measurements. (**a**) Schematic drawing of the PTAMR devices. (**b & c**) Comparison of the H_x magnetoresistances of the device without (c) and under (d) the illumination of 0.5W/cm^2 red-light. (**c**) Six different resistance states are realized using two kinds of illumination power, and 400Oe H_x magnetic field. (**d**) Four resistance states are picked out from (**c**) to illustrate the logic operation. Light and magnetic field are designed as two kinds of input signals. (**e**) The truth table of six basic logic operations with different threshold resistance settings (TRSs).

This work would benefit the research on the magnetic logic devices and will also be of great importance to the development of novel materials, devices and technologies for magnetic data storage and advanced applications.

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