Electrically controllable magnetoresistance switching in multifunctional organic based Spin-Valves devices

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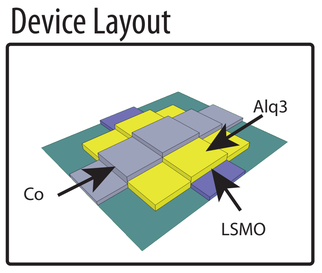
Spintronics is one of the most fertile approaches to meet current demands from the information and communication technology, such as lower power consumption, further miniaturization and multifunctionality required for the development of new device concepts and new materials . Nowadays, spintronics is facing the challenge of evolving from the first generation of devices, which lead to a revolution in the information storage (GMR readheads), to devices that feature multi-operation capabilities (logic, communication and storage) within the same materials technology.
The electrical control of the magnetoresistance can provide such capabilities. In this poster we will show that by meaning of Organic based Spin-Valves it is possible to easily achieve this capability.

Experimentals

The bottom electrode of the devices was a 1×5 mm2 strip of LSMO 20 nm thick. This film is grown on a matching SrTiO3 5×10 mm2 substrate in a pulsed plasma deposition (PPD) machine in a 4×10-2 mbar oxygen atmosphere, with the substrate kept at 880 °C. The sample was then exposed to air and moved to the organic semiconductor (OS) deposition chamber (base pressure 2×10-8 mBar). Prior to OS deposition, the LSMO sample was heated to 250 °C for 20 min to recover its surface properties. Alq3 layer was evaporated on top of it at a rate of 0.05 Å/s at room temperature with thicknesses ranging from 120 to 250 nm. Subsequently the sample was exposed to air and brought back to the CSA machine were a 2 nm thick AlOx tunnel barrier was deposited at a 2.5x10-2 Oxygen pressure. Finally the sample was exposed to air and moved to the metals deposition chamber, were a 40 nm thick Co film was evaporated with an electron gun at a 5×10-8 mBar base pressure.

Device Layout



Spin Valve

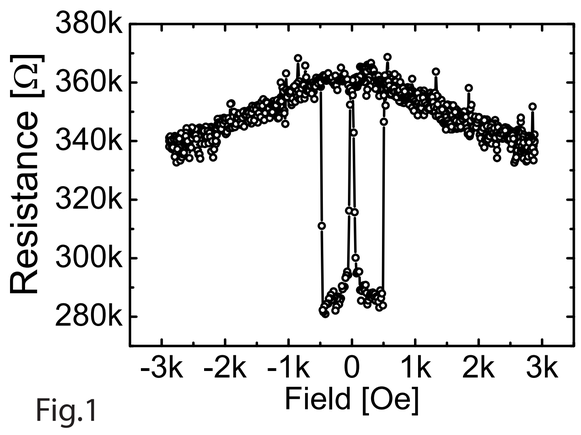


Fig.1

22% of MR measured at 100K Bias -100mV

A strong spin valve effect of about 22%, with very sharp and well defined resistance switches was detected at 100K. The organic layer thickness of the sample was 250nm. To the best of our knowledge this is the highest MR reported so far in organic spintronic devices at this temperature: together with the sharp vertical switches, it indicates the high quality of the devices reported here and of their interfaces

Electrical Bistability&Non-volatile States

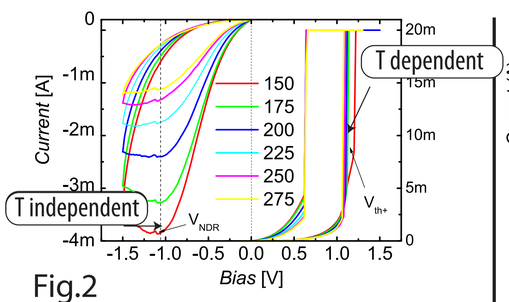


Fig.2

The samples showed and electrical bistability, as clearly visible in the graphs. I-V curves show an Hysteretic behaviour. Starting from zero and increasing the bias it is possible to reach a threshold voltage (Vth+) at which the current suddenly increase and the device switches to a lower resistance state. Going back to zero and applying a negative bias, we can bring back the device to a higher resistance state by reaching the negative voltage threshold.

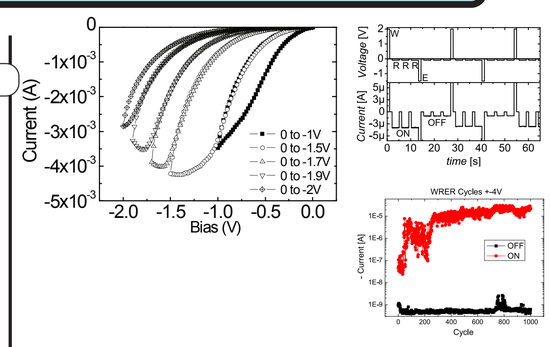


Fig.3

Consecutive I-V curves starting from zero and reaching a progressively lower negative voltage. The non-volatility comes from the fact that every curve starts from the last reached resistive state, perfectly following the previous curve. Bistability survived more than 10^4 WRER cycles, and the non-volatility has been probed up to 24hr @100K.
Ron/Roff ratio up to 4 order of magnitude has been found.

Electrical control of Spin-Valve Effect

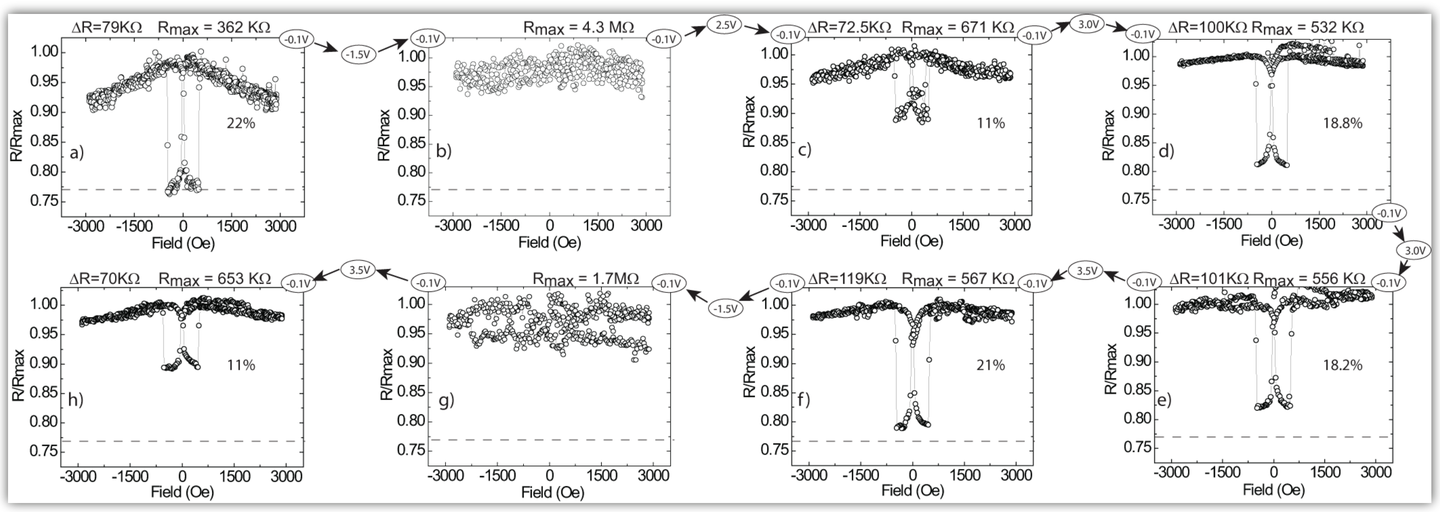


Fig.4

The Fig.4a shows the spin valve presented previously in Fig.1 before any higher voltage was applied - this corresponds to the lowest resistance state and a SVMR of 22%. Next, we apply a voltage bias of -1.5 V and the device resistance increases from 362 kOhms to 4.3 MOhms. The voltage is subsequently reduced back to the measuring value of -0.1 V and the magnetoresistance is measured. A dramatic modification of the magnetic switching is clearly visible in the Fig. 4b - no identifiable SV effect can be now detected. This remarkable effect is clearly reversible: the spin valve effect is recovered by moving back to the low resistance mode. Thus applying a positive bias of +2.5 V the device moves to 671 kOhms resistance value. In this state we recover a part of the full SVMR, namely 11% (Fig.4c). By further increasing the programming voltage to +3 V a 18.8% SVMR is detected at a standard -0.1 V measuring voltage (Fig.4d). We recover the full magnetoresistance intensity after the application of +3.5V programming voltage (Fig.4f). It is worth noting that applying the same voltage a second time results in no modification of either SVMR or device resistance (compare Fig.4d and Fig.4e for +3V). The complete reversibility of the process is finally confirmed by disappearance of the spin valve effect upon of the application of the programming voltage -1.5V (Fig.4g)

Phenomenological Model

A general and purely phenomenological model proposed recently by Rozenberg et al. provides a good starting point and helps to explain both the resistive switching and its interplay with the spin-valve effect. This model did not actually consider the spin degree of freedom. The nonvolatile switching from the low to the high resistive state is explained in terms of charging (charge trapping) of the so called top, bottom or middle domains (see Fig. 5a), and assuming that the interdomain tunneling amplitudes are by far exceeding the electrode-domain ones, i.e. the device resistance is dominated by the top and bottom domains.
Indeed the charge transport in amorphous organic materials is governed by a thermally activated hopping between strongly localized states. Assuming that every hopping event requires the same time, we can consider the mobility to be directly proportional to the mean number of hops needed to cross the device from one electrode to the other.
One can clearly see that by lowering the electrons mobility, their transit time is increased and the SVMR is consequently lowered. At the same time, a lower electron mobility corresponds to a higher electrical resistance, and the concurrency of this two changes is exactly what we found in our devices.
We infer that the mechanism trough which the mobility decreases is charge trapping inside selected domains described above. We tentatively place these domains near the bottom interface (see Fig.5a), although both the top domains and a combination of top and bottom ones could be as well a possible solution. We tend to exclude the middle domain due to the observed bipolar switching which requires in principle a trapping potential asymmetry. While such an asymmetry is hardly expectable in the isotropic bulk of the amorphous organic layer, it can be easily achieved near the interfaces. For example, UPS measurements have shown a strong modification of Alq3 energetics up to 7 nm distance from the LSMO surface. This was ascribed to a order-disorder dipole transition. These dipoles can break the potential symmetry of a trapping domain close to the interface, giving rise to the required different behavior with the bias polarity.

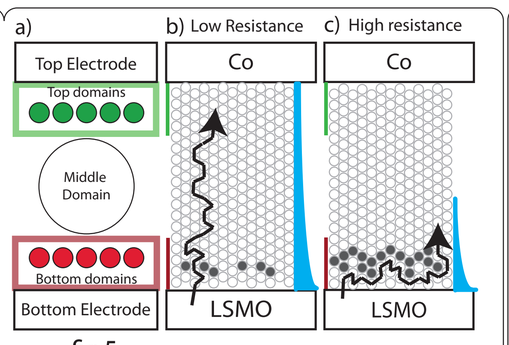


fig.5

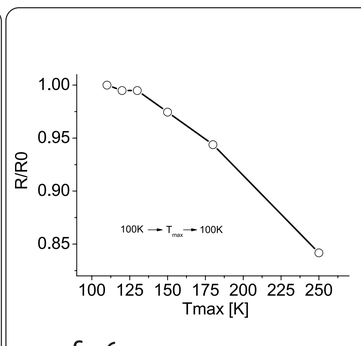


fig.6

A procedure similar to Thermally Stimulated Current measurements was followed on a device switched to the high resistance mode. Starting from 100 K the device is warmed to various selected temperatures Tmax and cooled back to 100 K for a resistance measurement. Fig. 6 shows these resistances normalized to the pristine value R0 at 100K. We can see that the resistance decreases by about 20% by only increasing Tmax, indicating that we are gradually removing the cause of resistance by a thermically assisted process, as it is the carrier emission from a trapping site.