Room-temperature magnetoresistance effect in magnetite/C$_{60}$/Co organic spin valves

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The manipulation and utilization of the spin polarization of electrons in organic semiconductors (OSs) has attracted considerable research interest for fundamental material science and potential applications. OSs are expected to possess a large spin-dependent transport (SDT) length due to their weak spin-orbit coupling [1,2]. However, a large SDT length in OSs has only been observed at low temperatures because the magnetoresistance (MR) effect disappears at room temperature. Thus, whether a large SDT length can be realized in OSs at room temperature remains unclear.

Recently, we fabricated a novel organic spin valve device with an MgO-substrate/Fe$_3$O$_4$/Al-O/C$_{60}$/Co/Al stacking structure. The Fe$_3$O$_4$ electrode was deposited via ultrahigh-vacuum magnetron sputtering with a shadow mask to form a strip on an MgO (001) substrate. Al (2 nm) was deposited on the MgO-substrate/Fe$_3$O$_4$ layer in the same chamber, and this was followed by immediate oxidation with exposure to oxygen plasma to obtain an Al-O layer. Then, MgO-substrate/Fe$_3$O$_4$/Al-O film was taken out and removed the mask in air. After that, the film was installed into the thermal evaporation chamber (base pressure $<10^{-6}$ Torr) for molecular deposition. A new shadow mask was used to form rotundity for C$_{60}$ layer. Then, the MgO-substrate/Fe$_3$O$_4$/Al-O/C$_{60}$ layers were transferred to a different chamber without breaking the vacuum conditions to deposit the Co layer (10 nm) via magnetron sputtering. The third shadow mask was inserted to form Co strip for patterning a cross configuration. Finally, Al (5 nm) was deposited to prevent oxidation of the Co layer. The top Co/Al layer was deposited at a very low electric power (10 W) to reduce their kinetic energy. The fabricated device area was 1.5 $\times$ 1.5 mm$^2$.

We studied the spin injection, transport, and detection in the devices, an MR ratio greater than 5% was observed at 300 K, which is one of the highest MR ratios reported to date. Most importantly, a large SDT length of over 100 nm was experimentally observed in the C$_{60}$ layer at room temperature. Moreover, an unusual and interesting dependence of MR ratio on C$_{60}$ layer thickness has been observed, as shown in Figure 1, which differs to the reports so far. It is found that the MR ratios sharply increase with the increase of C$_{60}$ layer thickness from 10 nm to 40 nm, and then slowly increase for the C$_{60}$ layer increasing till 80 nm. Beyond this range, further increase C$_{60}$ layer thickness leads to a drastic reduction of MR ratio. Our investigation indicates this is due to the competing effects of activation energy and electric field magnitude on the spin diffusion length and carrier mobility in the C$_{60}$ layer [3]. The newly obtained MR ratio at 300 K can be 7.5% in the C$_{60}$ based organic spin valve. Such an investigation furthers our understanding of spin transport in OSs and could be pivotal in the development of spin-based molecular electronics for future applications.

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