Electron spin transport facilitated by a low work function metal in Alq3

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Organic semiconductors are considered to be promising media for spin information technology by providing long spin life-times due to their low spin-orbit coupling and weak hyperfine interactions.[1] In addition, devices made of organic semiconductors can be light-weight (thin and truly portable) and mechanically flexible while mass produced at low cost.[2]

Since the first experimental observation on spin transport in tris-(8-hydroxyquinoline) aluminum (Alq3) was reported,[3] the focus has been on holes as the spin carrier because the work functions of ferromagnetic materials are close to the highest occupied molecular orbital (HOMO) of Alq3 even though electron transport is preferred in Alq3.[4,5] Therefore, the experimental observation of spin polarized electron transport in Alq3 requires the modification of band alignment between Alq3 and metal electrodes.[6] In this report, we present our experimental demonstration of spin polarized electron transport over a distance of 150 nm in Alq3 by using a thin layer of Ca insert and thus facilitating the injection of spin polarized electrons into and extraction from Alq3.

The Co/Ca/Alq3/Ca/NiFe spin-valve structures and the Co/Alq3/NiFe devices were fabricated in parallel so that the latter structures can provide hole spin injection in contrast to the former. Thermal evaporation in a vacuum deposition system and a mechanical shadow mask were used for the device fabrication and the mask was changed in a glove box under Ar gas without exposure to ambient air between deposition steps in order to avoid any oxidation and contamination.

We demonstrate that the introduction of a 1 nm thick Ca layer between the 150 nm thick Alq3 film and ferromagnetic transition metals (Co and NiFe) enables electron spin injection into Alq3 because the Fermi level of pristine alkali metal, Ca (2.9 eV) is closely aligned with the lowest unoccupied molecular orbital (LUMO) of Alq3 ($\approx$ 3.0 eV) as illustrated in Fig. 1. On the other hand, hole spin injection is dominant in the Co/Alq3/NiFe structure where the Fermi levels of Co ($\approx$ 5.0 eV) and NiFe (4.5 – 5.0 eV) are more closely aligned with the HOMO of Alq3 ($\approx$ 5.8 eV).

We observe that the devices with an intermediary electron injection layer, Ca show symmetric current-voltage (I-V) characteristics, which indicates that the charge injection properties are identical on either side of the Alq3 and also, they display positive magnetoresistance as large as 4% at 4.5K attributed to electron spin transport as shown in Fig. 2. On the contrary, we detect asymmetric I-V characteristics in the Co/Alq3/NiFe devices and no spin-valve effect. We conclude that the main reasons for the clear magnetoresistance signal in the devices with Ca are the improved band alignment and Alq3's higher electron mobility relative to hole transport. Our conclusions are further supported by the observation of positive magnetoresistance in the Co/Ca/Alq3/Ca/NiFe test structure.

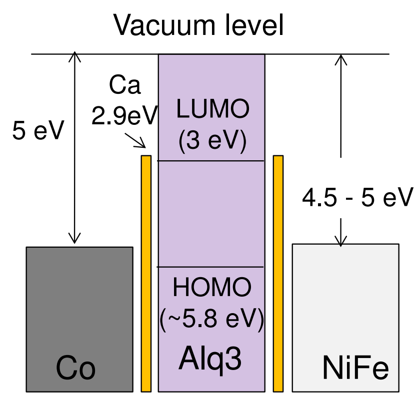

Fig. 1. Illustration of energy level alignment of Alq3 and metal contacts

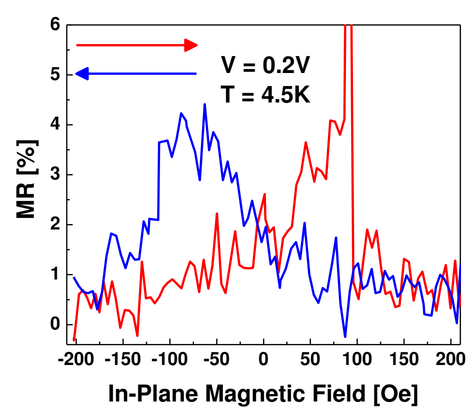

Fig. 2. Magnetoresistance (MR) curves measured at 4.5 K for Co/Ca/Alq3/Ca/NiFe spin-valve structure

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