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The JMR effects in the Co/Alq3/Fe thin films

Dong Gyun You[1]*, Il Jin Park[1], Chul Sung Kim[1], Chang Oh Kim[2], In Seong Jeong[2], Kwang Ho Jeong[2]
[1]Department of Physics, Kookmin university
[2]Department of Physics, Yonsei university

1. Introduction

Organic π-conjugated materials have been used to manufacture devices such as organic light-emitting diodes,[1] photovoltaic cells, [2] and field-effect transistors.[3] While these materials are exploited for their tunability of charge-carrier transport properties, their *spin* transport properties is a least explored area, especially for organic semiconductors (OSCs), which are pertinent for future spin-based electronics. Because OSCs are composed of mostly light elements (i.e., C, H, N, or O) and thus have a weaker spin-orbit interaction compared to inorganic semiconductors, spin coherence lengths can be long in these materials. Recent observations of magnetoresistance(MR) effects in OSCs has opened up the potential of these materials for spin-conserved transport. In an organic spin valve study using Alq3 as the spacer layer between ferromagnetic $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) and Co electrodes, Xiong *et al.*[4] measured a giant inverse magnetoresistance (GMR) of 40 % at 11 K, which reduced to zero by T >200 K. The thickness range of Alq3 used in that study was from 130 to 260 nm, and a spin diffusion length of 45 nm was estimated at liquid helium temperatures. They also concluded that there was an ill-defined layer of ~100 nm of Alq3 containing Co inclusions. Mermer *et al.*[5] showed room-temperature MR of polyfluorene films and Alq3 films several nanometers thick, sandwiched between *nonferromagnetic* electrodes.

Here we report the fabrication and magneto-transport studies of Cu/Co/Alg3/Fe organic multilayer thin films. We obtained JMR of about 65 % at 77 K in the 5000 G.

2. Experiment

The sample preparation was carried out in an ultra-high vacuum (UHV) chamber system equipped with molecular beam epitaxy (MBE). First, we fabricated device with Cu/Co/Alq3/Fe layer. SiO_2/P-type Si(001) is used by Substrate. Prior to film deposition, the substrates were cleaned and positioned in a UHV chamber, the base pressure of the MBE chamber was 6 x 10^{-9} Torr. The Fe film (bottom ferromagnetic layer) of thickness of 250 Å was deposited on SiO_2 (1000 Å)/Si (001). The surface RMS roughness, estimated from atomic force microscopy images (AFM), was about 0.87 nm. The Alq3 layer was subsequently deposited by thermal evaporation method at a room temperature and other chamber. The second magnetic 50 ~ 150 Å-thick Co layer was grown on the top of the Alq3 barrier by the MBE method. Finally, a 150-Å-thick Cu capping layer was grown to protect from oxidation of Co underlayers. The junction area is about 78.5 x 10^{-4} m^2, which is defined by the width of the top Cu/Co electrode and width of the Alq3 square between the bottom layer and the top layer.

To begin with, by using the AFM, we measured the each layer's roughness that is the most important in the device, the then by using the XRD, we checked out with each layer's structure. We measured the magnetic property by using the MOKE and Vibrating sample Magnetomater (VSM), and then measured the MR by applying the 2-point probe to 237 device made by Keithley Instruments, adding the magnetic field (±5000 G) on the film in the direction of in-plane, to measure the voltage and subsequently calculate the MR ratio with such acquire resistance value.

3. Results

First, we measured the RMS roughness of the Fe layer in which Fe growth was made on the SiO_2/Si substrate and of the Alq3/Fe layer film in which Alq3 was deposited, because the roughness was very important part for the JMR device film. From the image of Fe layer, the RMS roughness value resulted in 0.87 nm while its Max. height resulted in 8.82 nm. In the result of Alq3 layer, the RMS roughness and Max. height were analyzed as 0.37 nm and 3.45 nm, respectively. For the next step, XRD was measured in order to find out the structure of each film. Fe was grown with the amorphous by the influence of SiO_2 structure. Likewise, Alq3 was grown with the amorphous by the influence of Fe. In order to continuously find out about each layer's magnetic property, we measured VSM. as the RT results, no antiferromagnetism was checked even at the low temperature. As the differences in each layer's coercivity are small, the measurement was made without the low resolution due to the device type, because the low resolution makes one see the antiferromagnetism. We looked for the appropriate thickness of Alq3, by changing the thickness of Alq3 and measuring I - V. shows the I - V and JMR data measured at room temperature and 77 K, of (a) Cu(25 nm)/Co(5 nm)/Alq3(37 nm)/Fe(25 nm)/SiO_2(100 nm)/Si(100) film and (b) Cu(15 nm)/Co(15 nm)/Alq3(37 nm)/Fe(25 nm)/SiO_2(100 nm)/Si(100) film. Where each current is given as 0.1 μA, 10 nA, 1 nA and -10 nA, we acquired background MR value of (a) 0.61, 0.42, 0.018 and 0.38 and (b) MR value of 0.24 at 10 nA and 0.042 at 50 nA from the each sample.

4. Conculusion

We have fabricated and studied a novel organic spin-valve type device, namely Fe/Alq3/Co where the organic semiconductor is sandwiched between two d-band FM electrodes with high Curie temperature. This device shows a JMR ratio of about 65 % at 77 K in the 5000 G. But the JMR actually vanishes at room temperature. The JMR decrease with temperature is mainly caused by an increase in the carrier spin relaxation rate with temperature, but is also influenced by carrier injection at the Fe/Alq3 interface. An injected carrier will transmit and contribute to current if its spin does not flip within the spacer layer. In the presence of spin-orbit interaction, a magnetic field will increase the spin-flip rate by inducing spin mixing. Thus, the probability of spin flipping increases with increasing magnetic field. If the injected carrier's spin flips, then it will be blocked by the detecting contact and the current will decrease, resulting in an increase in resistance. Thus, the resistance should increase with increasing magnetic field, resulting in a positive background monotonic resistance.

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