Magnetic Fringe Fields Control of Electronic Transport in Organic Thin Films: Organic Semi-Spin-Valves

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Abstract:

The electrical conductivity of organic thin film devices are very sensitive to small applied magnetic fields, producing phenomena such as organic magnetoresistance (OMAR) and magnetoelectroluminescence [1,2]. We have studied the effect of the inhomogeneous magnetic fields from a thin ferromagnetic electrode on OMAR by fabricating a device we denote a semi-spin-valve. Our device provides a means to control the electrical conductivity of an organic film at room temperature, using the spatially-varying magnetic fringe fields from a magnetically-unsaturated ferromagnet.

Project Summary:

We have fabricated an organic semiconductor device consisting of a ferromagnetic layer, a hole-injecting layer (a PEDOT polymer), an organic semiconductor (Alq3), and a capping electrode (CaAl) (see Figure 1). The ferromagnetic electrode (fringe fields source) is a Co|Pt multilayer deposited using electron-beam evaporation in ultra high vacuum on oxidized Si wafers for device studies and Si supported Si3N4 windows for magnetic domain imaging studies using an x-ray transmission microscope. Optical lithography is used to define the bottom electrode geometry. A hole-injecting layer followed, either by sputtered indium tin oxide (ITO) or the conducting polymer poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) deposited by spin-coating from an aqueous suspension (suspension purchased from H. C. Starck, CLEVIO P VP AI 4083). A 30 nm thick film of organic semiconductor Alq3 (sublimed grade, purchased from HWSands Corp.) was deposited by thermal evaporation in high vacuum and at room temperature. A Ca (10 nm) layer was used to take advantage of the favorable work function of Ca, and was covered by a capping layer of Al (40 nm).

The properties of the ferromagnetic electrodes were characterized in detail using a variety of complementary techniques. We have used vibrating sample magnetometry (VSM) to determine the electrodes’ magnetization versus field (hysteresis loops) and correlate it with magnetotransport properties of organic semi-spin-valve devices (see Figure 2). The experiments in Figure 2 were performed in a perpendicular applied magnetic field. The electrode was also
that demonstrates that the observed magnetoresistance occurs in the organic semiconducting (Alq₃) layer independently of the nature of the bottom electrode. We claim that our magnetoconductivity effect is caused by the fringe field distribution inside the organic semiconducting layer, not by spin-polarized injection from the ferromagnetic layer into the organic semiconductor. We have built a control device that was electrically isolated from the ferromagnetic film to prove that our semi-spin-valve effect was not caused by spin injection. A thin dielectric has been deposited on the ferromagnetic film and capped with a 12 nm Pt layer. The current path is therefore entirely outside the ferromagnetic thin film (i.e., in the Pt layer), and spin-injection cannot occur, yet the same magnetoconductivity response was observed.

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studied with ferromagnetic resonance spectroscopy (FMR), which provided a direct measurement of the electrode’s perpendicular magnetic anisotropy. Finally, transmission x-ray microscopy (TXM) based on the x-ray magnetic circular dichroism (XMCD) effect was used to determine the electrodes’ microscopic magnetic domain structure as a function of the applied perpendicular field (see Figure 3).

A typical magnetoconductivity trace for an organic device fabricated without a ferromagnetic layer (using a bottom electrode of ITO) is caused by random hyperfine fields. The hyperfine-induced magnetoconductivity response has a magnitude of several percent in our Alq₃ devices, saturates for fields in excess of 0.1 T, is non-hysteretic, and has a full-width-at-half-maximum of approximately 20 mT. Figure 2 shows a magnetoconductivity curve of a semi-spin-valve and their correlation with magnetic hysteresis loops of the ferromagnetic electrode. Magnetoconductivity (upper panel) changes are largest at the coercive field and the conductivity is suppressed between the nucleation field and saturation field of the ferromagnetic electrode.

A control device where the synthetic metal (PEDOT) bottom electrode was replaced with an inorganic metal (ITO) was measured. ITO is a commonly employed electrode material for OLEDs. We achieved a similar magnetoconductance effect comparable to the device with PEDOT-electrode — that demonstrates that the observed magnetoresistance occurs in the organic semiconducting (Alq₃) layer independently of the nature of the bottom electrode.

We claim that our magnetoconductivity effect is caused by the fringe field distribution inside the organic semiconducting layer, not by spin-polarized injection from the ferromagnetic layer into the organic semiconductor. We have built a control device that was electrically isolated from the ferromagnetic film to prove that our semi-spin-valve effect was not caused by spin injection. A thin dielectric has been deposited on the ferromagnetic film and capped with a 12 nm Pt layer. The current path is therefore entirely outside the ferromagnetic thin film (i.e., in the Pt layer), and spin-injection cannot occur, yet the same magnetoconductivity response was observed.

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