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# Organic magneto-resistance at small magnetic fields; compass effect

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ABSTRACT

Utilizing the magneto-resistance response of organic light emitting diodes (OLEDs) at ultra-small magnetic field we show that both the value and direction of the local earth magnetic field ($\mathbf{B}_E$) can be accurately obtained. We further demonstrate a 'compass response' in the magneto-conductance and magneto-electro-luminescence of OLEDs based on three isotopes of a π-conjugated polymer. We found that both responses are dependent on the direction of a small, fixed magnetic field $\mathbf{B}_0$ (≈50 μT) with respect to $\mathbf{B}_E$, and this effect is used to determine $\mathbf{B}_E$ direction. We conjecture that living creatures may use the same principle for magneto-reception and navigation.



## 1. Introduction

The magnetic field effect in organic light emitting diodes (OLEDs) such as magneto-conductance (MC) and magneto-electroluminescence (MEL) have been intensely studied in the past decade. A relatively large MC of ~10% at $B \sim 10$ mT has been routinely observed [1–8]. Recently, both MC and MEL responses of OLED based on many organic semiconductors were found to contain a non-monotonic magnetic field response at small fields $B_m \sim 0.2$ mT [9–11]. Similar non-monotonic field response was also found in the singlet yield of biochemical reactions [12–14]. The proximity in the value of $B_m$ to that of the earth magnetic field, $B_E$ (~0.05 mT), points towards the possibility that $B_E$ might influence the MC and MEL responses of OLEDs, as well as the outcome of bio-chemical reactions in living creatures.

In this work we show that $B_E$ indeed influences the low field response of both MC and MEL in OLEDs, and use this effect to determine the magnitude of the local $B_E$. Subsequently, we introduce a method to determine the direction of a small, fixed magnetic field, $B_0$, by measuring MC($B$) and MEL($B$) responses in the presence of $B_E$. We demonstrate this room-temperature 'compass behavior' in OLEDs based on various isotopes of poly[2,5-dioctyloxy, *p*-phenylene-vinylene] (DOOPPV, structure shown in Fig. 1a inset).

## 2. Experimental

The OLEDs used in this work were fabricated using home-made isotope enriched [DOO-PPV] [9,10]. They include H-DOOPPV (fully protonated-hydrogen), D-DOOPPV (deuterated-hydrogen rich), and C13-DOOPPV ($^{13}$C rich). The three isotope-rich DOOPPV polymers are characterized by different hyperfine coupling constants, $a_{HFI}$. In H-DOO-PPV the hyperfine interaction (HFI) is caused by the protons (nuclear spin $I = ½$, nuclear $g$-factor $g_H = 5.585$) having $a_H/g\mu_B \sim 3$ mT [9], where $g \approx 2$ and $\mu_B$ is the Bohr magneton. In D-DOOPPV the skeletal protons were replaced by deuterium ($I = 1$, $g_D = 0.8$) with $a_D/a_H \approx 0.15$ [9] (see Fig. 1 inset for chemical backbone of D-DOOPPV). In C13-DOOPPV ~15% of the $^{12}$C nuclei ($I = 0$, no HFI) were replaced by $^{13}$C nuclei ($I = ½$ $g_{13} = 1.5$) [10], thus increasing

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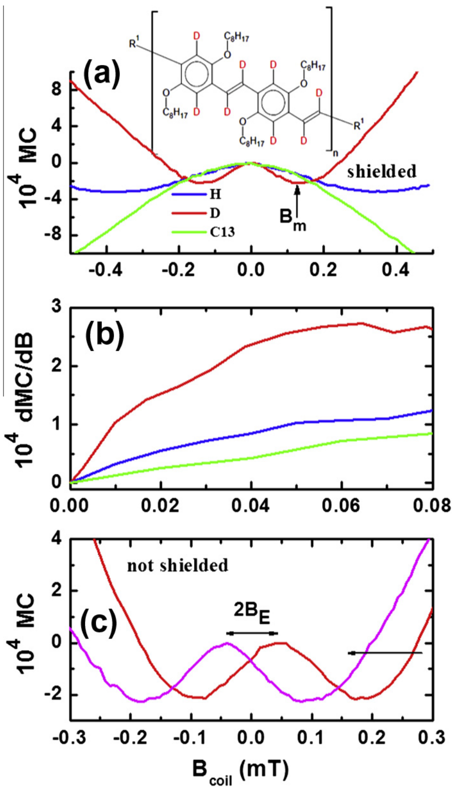


**Fig. 1.** MC(B) response of OLEDs based on (D-, H- ,and C13-)-DOOPPV (red, blue, green, respectively). (a) Up to 0.5 mT, where the earth magnetic field, $B_E$, is shielded, showing maximum at $B_{coil} = 0$ and minima at $B_{coil} = \pm B_m$. The inset shows the chemical backbone of D-DOO-PPV. (b) The first derivative, $|d(MC)/dB|$ of the response shown in (a) up to 0.08 mT; $|d(MC)/dB|$ is largest for D-DOOPPV. (c) MC(B) in OLED based on D-DOOPPV when $B_E$ is not shielded, for $\mathbf{B}_{coil}$ parallel ($\alpha = 0$, magenta) and anti-parallel ($\alpha = 180°$, red) to $\mathbf{B}_E$. Note the respective shift of the response by $\pm B_E$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

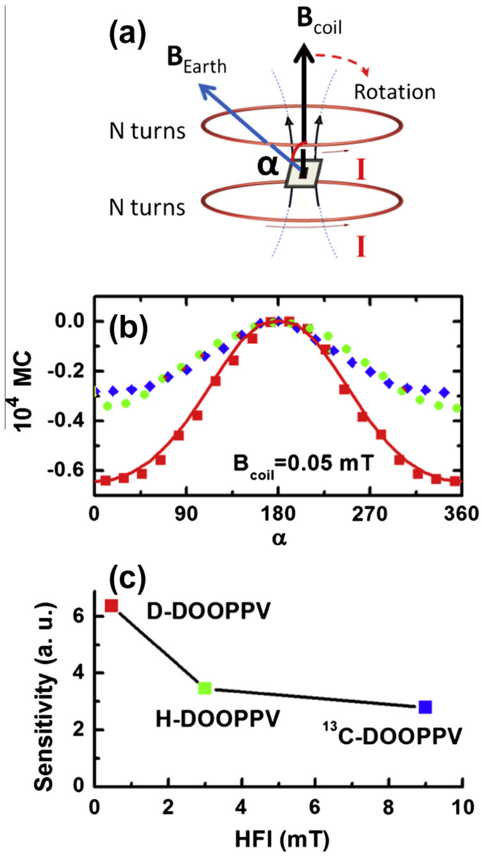


**Fig. 2.** (a) The experimental setup for the direction-sensitive MC and MEL measurements. (b) MC($\alpha$) response for the three isotopes using $B_{coil} = 0.05$ mT. The line through the data points is a fit using the data in Fig. 1a and a procedure described in the text. (c) The directional sensitivity $D_S = |MC(0)–MC(180°)|$ vs. the estimated HFI coupling constant of the polymer used.

the effect of the HFI relative to H-DOOPPV by an estimated factor of ~1.5. The detailed material synthesis and OLEDs fabrication can be found elsewhere [9]. The $0.5 \times 0.5\ mm^2$ OLEDs were subsequently encapsulated and placed at the center of a home-made Helmholtz pair (see Fig. 2a). The magnetic coils with $N = 50$ turns each and radii of 6 mm were wound around a cylindrical wood frame. We used a Keithley 238 apparatus having a pA resolution current source for the magnetic coils. The induced magnetic field at the device position as a function of current source was calibrated using a Lakeshore Gauss probe with 2 μT field resolution. The coil and power supply arrangement could produce magnetic field, $B_{coil}$, with 5 μT field resolution. For the directional sensitive studies, the Helmholtz coil pair with the device were placed on a non-magnetic rotation axis of a high precision motor enabling 360° tilt angle variation between $\mathbf{B}_{coil}$ and $\mathbf{B}_E$. The magnetic field from the motor was shielded using mu-metal shield foils. The direction of the Earth magnetic field, $\mathbf{B}_E$ was determined with an uncertainty of 2° using two magnetic compasses. One compass was used to determine the projection of $\mathbf{B}_E$ direction in the horizontal plane, whereas the other compass was used to obtain $\mathbf{B}_E$ inclination angle. A Keithley 238 apparatus was used as a constant bias voltage source for the OLED devices. The device current density was set to ~1 μA/mm$^2$ in all measurements for optimizing the MC and MEL magnitudes. The EL intensity was detected by a photovoltaic Si diode. The MC and MEL responses were measured at constant applied voltage while sweeping the field $B$. MC and MEL are defined as $\frac{\Delta I}{I} = [I(B) - I(B=0)]/I(B=0)$ and $\frac{\Delta EL}{EL} = [EL(B) - EL(B=0)]/EL(B=0)$, respectively. For the angle dependent MC and MEL the applied voltage and $\mathbf{B}_{coil}$ were kept constant while the conductivity and EL were recorded as a function of the tilt angle, $\alpha$, relative to $\mathbf{B}_E$.

## 3. Results and discussion

Fig. 1a shows MC($B$) response of the (H-, D-, and C13 rich)-DOOPPV OLEDs up to applied field $B_{coil} = 0.5$ mT, with a fixed angle $\alpha$ between $\mathbf{B}_{coil}$ and $\mathbf{B}_E$. In this experiment, the apparatus was shielded using mu-metal shield foils so that the influence of the earth magnetic field ($B_E \approx 53\ \mu T$ in