The Light-Emitting Field Effect Transistor: A Novel Optoelectronic Device Concept

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We report a semiconducting polymer light emitting field-effect transistor (LEFET) fabricated by employing a new "angled" evaporation technique to deposit the two electrodes (Ag for hole injection and Ca for electron injection). Under ambipolar conditions, recombination of electrons and holes resulted in the observation of a narrow zone of light emission within the channel. The emission zone moved across the channel as the gate bias was swept during collection of the transfer data.

To fabricate the devices, a heavily doped n-type silicon wafer was used as the gate electrode. The gate electrode was coated with 400 nm of silicon nitride (SiN_x) deposited by plasma enhanced chemical vapor deposition (PECVD). PPcP was obtained from Aldrich and used to passivate the SiN_x as the gate dielectric. "SuperYellow" (SY), a PPV derivative obtained from Covion, was spin cast onto the substrate at 3000 rpm. The calculated capacitance of the completed device was 9 nF/cm^2.The devices reported on in this work had a 16 µm channel length and a 1000 µm channel width. Channel lengths less than 5 µm have been achieved with this technique.

Fig. 1 shows transfer data (I_{ds} vs. V_g scan) for the LEFET, together with the gate dependence of the light emission. The transfer scan was run with a constant drain voltage (V_d) of 200 V. The low work function source electrode (Ca) was grounded and the gate voltage (V_g) was swept from 0 to 200 V. When $V_g = 0$, there is no voltage drop between the source and gate. There is, however, a 200 V drop between the drain and gate which polarizes the gate dielectric and induces a hole channel in the vicinity of the high work function drain electrode (Ag). The current in this region (at lower V_g values) of the transfer scan is hole dominated.

As V_g increases, the voltage drop between the drain and gate decreases, causing the magnitude of the hole current to decrease. Simultaneously, the voltage drop between the source and the gate increases, but is oppositely charged, causing the gradual buildup of an electron channel near the low work function source electrode (Ca). At about V_g= 90 V, I_d reaches a minimum and then begins to increase again. This is the crossover point from hole dominated current to electron dominated current. Crossover is expected to occur at V_g= ½ V_d, in good agreement with the data in Fig. 1.

Using standard FET analysis, the field effect mobility (µ) can be calculated from the saturation regime of the transfer characteristics from the equation for the drain current, $I_d = \mu C_i{*}2W/L{*}(V_g-V_{th})^2$, where C_i is the capacitance of the gate dielectric, and V_{th} is the threshold voltage, W is the channel width and L is the channel length. The resulting hole and electron mobilities are $\mu_h = 3 \times 10^{-4}$ cm^2/V/sec and $\mu_e = 6 \times 10^{-5}$ cm^2/V/sec.

The light intensity data corresponding to the transfer scan is also shown in Fig. 1. The light intensity data begins increasing around 80V while hole current still dominates, reaching a maximum around 120 V, well into the electron dominated current regime. By employing the two-color electrode geometry, light emission should be observed when both electron and hole currents are simultaneously present during device operation, consistent the light intensity vs. V_g data in Fig. 2. At the crossover point the hole and electron currents are nearly equal each other, and the quantum efficiency for light emission is maximum. Note, however, that the light intensity peaks at V_g~120 V, i.e. when the electron current is greater than the hole current. The maximum emission intensity is expected when hole and electron densities are balanced (n_h=n_e), i.e. when each injected electron (hole) can recombine radiatively with a counter hole (electron).

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Due to the difference in hole and electron mobility (${}_h > {}_e$), this requires electron currents (I_e n_e ${}_e$) greater than hole currents (I_h N_h ${}_h$), which in our experiments correspond to V_g~120 V.
Images taken of the channel region during operation show the location and width of the emission zone. The emission was found to be in a very narrow region (< 2 μm) within the channel. The emission zone is not stationary within the channel, but in fact moves from the source to the drain as the gate voltage is swept from 88 V (a) to 93 V (b) to 98 V (c) in Fig. 1.
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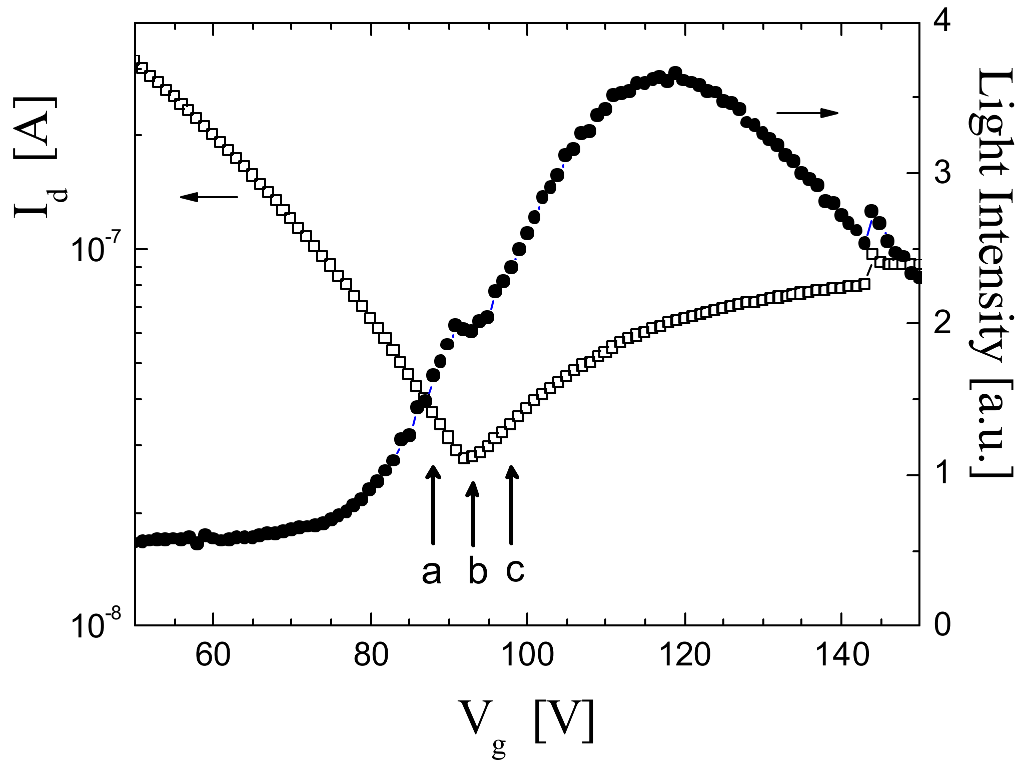

Fig. 1. Transfer scan (I_d vs. V_g) for the SY LEFET along with the corresponding emitted light intensity vs. V_g. The emission zone is located in the channel: a) near the Ca source electrode, b) near the center of the channel, and c) near the Ag drain electrode.