Detection of a Space-Charge Region in an Organic Photoconductive Sensor

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ABSTRACT

In our contribution we will present a transparent photoconductive sensor based on organic materials. The performance of the photoconductive sensor will be demonstrated by electrical and spectral response measurements. The existence of a high-field space charge region near the cathode will be shown by means of local illumination measurements.

1. Introduction

Organic electronic devices are gaining interest due to their endless possibilities and interesting properties. Often the organic devices can be designed using the knowledge of inorganic semiconductors. One should however keep in mind that the parameters of the organic materials, for example the charge carrier motilies, are not at all comparable to those of inorganic semiconductors. This can lead to unexpected behavior of the organic component due to unjustified simplifications. Often also the inorganic device performs much better than their organic implementation. For instance organic photoconductors, which are widely used in photocopy machines, cannot compete with inorganic devices to convert an optical signal into an electrical current unless they show a special feature.

In literature we found only a few examples of photoconductors [1][2][3] consisting of a single organic layer, often a blend. For detection of near-infra red a single layered device was developed by Natali et al. [4]. Ho et al. [5] present a photoconductive sensor consisting of an organic double layer.
According to Kun Gao et al.[6] the double layered device has an advantage over a single layer. If the organic materials of the double layer are chosen well excitons can easily dissociate at the organic/organic interface via a charge-transfer state .

Here we present a transparent photoconductive sensor consisting of an organic double layer based on the device described by Mr. Ho. The performance of the device is examined by performing current-voltage measurements under different illuminations and a spectral response measurement.

A local illumination experiment is presented to measure the current response of the sensor as a function of the position of the generated excitons. The local illumination experiment reveals the presence of a space-charge region for voltages above the threshold.

2. Experimental procedures

The organic photoconductive sensor has a lateral architecture consisting of a set of parallel electrodes covered with two organic materials. To obtain a sufficiently large active area the parallel electrodes are organized in an interdigitated manner, forming a finger pattern (Figure 1b). For the electrodes the transparent indium tin oxide (ITO) is used. The organic material in direct contact with the electrodes forms the hole transport layer (HTL) which is also transparent. The second organic layer is absorbing, it is named the exciton generation layer (EGL) .

As hole transport material we selected 1,3,5-Tris [(3-methylphenyl) phenylamino] benzene (m-MTDAB, Sigma Aldrich), the exciton generation material is 3,4,9,10-perylenetetracarboxylic bis-benzimidazole (PTCBI, Sensient). Figure 1a. shows a cross section of the photoconductive sensor with two adjacent ITO fingers. Note that the figure is not to scale, the HTL is typically 40nm and the EGL 10nm thick. The ITO electrodes are 65nm thick and 80μm wide. Each electrode finger is separated from the next by a gap of 20μm.
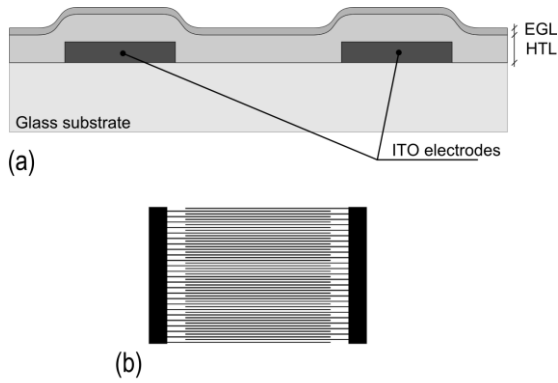
Figure 1 Cross section of one period of a photoconductive sensor. On top of the fingers two organic layers, a HTL and an EGL are deposited by thermal evaporation (a); top view of two interdigitated electrodes (finger pattern) (b)

The functionality of the photoconductive sensor is tested by measuring the current-voltage characteristics for different device illuminations. To that end the sensor is connected to a Keithley SourceMeter 2425, as voltage source, in series with a Keithley PicoAmpMeter 6485, as ampere meter. Different illuminations are provide using an LED backlight. The luminance of the backlight is controlled with a Keithley 220 current source, and the luminance output is measured with a Chroma 5 Colorimeter (X-Rite).

The spectral sensitivity of the photoconductive sensor is estimated from it's absorption. To measure the absorption as a function of the wavelength a Lambda 35 photo-spectrometer from Perkin Elmer is used. First a baseline measurement is performed with a bare glass sample, next a sensor sample is loaded and a measurement performed. The difference between the measurement of the bare glass and the sensor sample is an indication for the absorption.

For the local illumination experiment, a dedicated sample with just two, 10mm long, parallel electrodes is manufactured. The sample is placed on a Nikon Ti Eclipse microscope and connected to the measurement equipment described above to apply a voltage and measure the current. The illumination of the photoconductive sensor consists of two parts, the microscope light and the local stimulus. The local stimulus is made with a 5mW red laser (635nm, Thorlabs L635P005) that is shaped into a line and coupled into the microscope. The laser line is projected onto the sample through the objective and is oriented parallel to the electrodes. On the device the laser line has a width of approximately 1µm and a length of 1mm. The position of the line with respect to the electrodes is changed by moving the microscope stage. The coupling of the laser line into the microscope can be prevented by removing a dichroïc mirror from the optical path. This allows to turn the local stimulus on and off. The background illumination from the microscope light is maintained constant.

During a local illumination measurement the laser line is consecutively turned on and off to exclude other factors that may cause the current to change. The voltage across the sensor is fixed during the current measurement as a function of the laser line position.

3. Result and discussion

Figure 2 shows the current as a function of the voltage for ten different illumination levels of the sensor and also the dark current. Each of the curves shows a similar behaviour, a sharp (linear) increase at low voltages and a modest (linear) increase at high voltages. Both linear sections are separated from one another by a transient region at the threshold voltage (V_t).
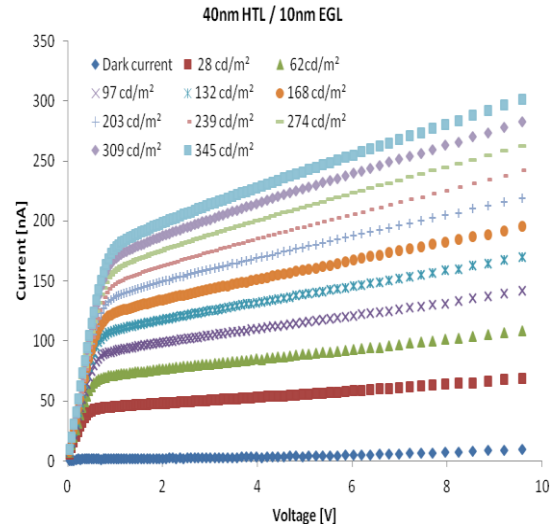

Figure 2 Current-voltage measurements of an organic photoconductive sensor sample with 40nm HTL/10nm EGL for different illumination levels and in the dark.

Comparison between the different curves indicates that the current (at a certain voltage) and V_t show a non linear relation with the illumination of the sensor.

There is a resemblance between our current-voltage measurements and those described by P. W. M. Blom et al. [7]. The similarity suggests that there exists a space-charge in the photoconductive sensor.

Figuur 3 shows the transmission spectrum of the photoconductive sensor. The shape of the curve closely resembles the transmission of PTCBI [8] which indicates that the EGL is the main absorbing layer
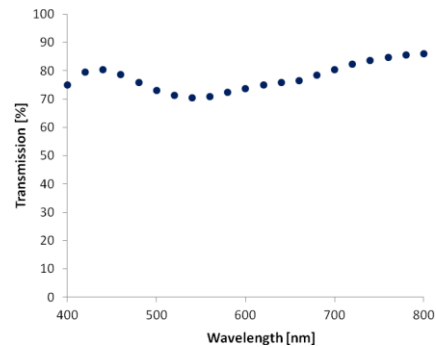

Figuur 3 Transmission spectrum of the organic photoconductive sensor with 40nm HTL and 10nm PTCBI.

The local illumination experiment is performed for a set of four voltages, 1.5V, 3V, 6V and 9V. The voltages are chosen below and above V_t. The laser line is shifted from above the anode towards and above the cathode in steps of 1µm. The edge of the anode with the gap is selected as the reference point for the position. At each

position the current through the photoconductive sensor is measured with and without the local illumination. Figure 4 shows the current measurements as a function of the position for the four voltages.
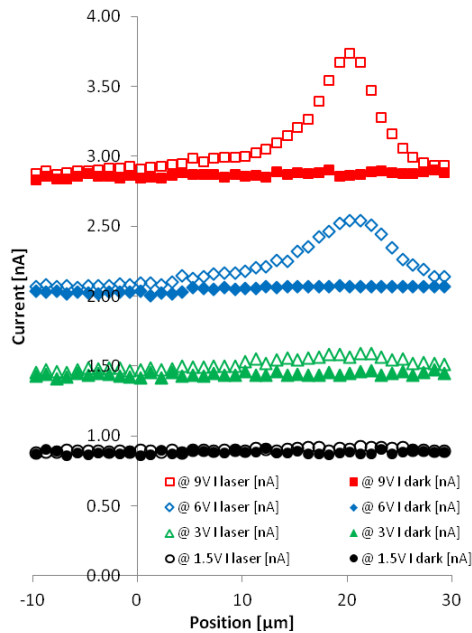

Figure 4 Current through the photoconductive sensor as a function of the position of the laser line with respect to the anode. The experiment is performed at DC voltages 1.5, 3, 6 and 9V . At each position the current is measured twice, once illuminated with the backlight only (dark) and once illuminated with backlight + laser line (laser).

For each of the four voltages the current is more or less constant if the sensor is only illuminated with the microscope light. When the laser line is projected the current becomes a function of the position and the applied voltage. At 1.5V the addition of the laser line has little impact on the measured current. When the voltage approaches V_t at 3V there is a small increase in current when the laser line is projected closer to the cathode. For voltages higher than V_t, 6V and 9V the current peak near the cathode is more pronounced. At 9V the current is slightly increased in the gap with a peak near the cathode. The increased sensitivity in the gap is explained by a positive space-charge near the cathode. The high electric field of the space-charge region causes electrons and holes to drift so fast that the probability of them to recombine reduces to nil. Thus in the space-charge region nearly all of the generated charges will contribute to the current.

Note that also above the cathode an increased sensitivity is noticeable. Above the cathode the electric field is close to zero, thus the large current must be caused by diffusion.

3. Conclusion

We presented a transparent photoconductive sensor consisting of a double layered organic stack. The current-voltage behaviour as a function of illuminance and and the spectral response of the device have been presented.

The occurrence of a space charge region in the vicinity of the cathode is demonstrated by means of a local illumination experiment.

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