Printed RFID Labels Based on Polymer Electronics

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Abstract

Printed low cost radio frequency ident (RFID) labels based on polymer circuits will enable electronic intelligence in nearly everyday product. This will be realized by a new technology, where soluble polymers with appropriate electrical conducting, semiconducting and insulating properties are applied via high volume web printing processes. It is more likely that new markets will be generated, than standard electronics based on silicon will be replaced, because of the fact that future polymer applications will be found on products within supply chains or on consumer goods.

By using this technology, PolyIC combines soluble electronic polymer materials with high volume printing processes to achieve low cost, high volume printed electronics. We present results based on our expertise of processing the polymers into microelectronic circuits and devices. Structured layer compositions of the functional polymers set up thin film polymer field-effect transistors. These constitute the basic building blocks of integrated polymer circuits (IPCs). The particular functionality of an integrated circuit is achieved by an appropriate circuit design. Fast, high life time integrated polymer circuits and results of a 125 kHz demonstrator RFID tag are presented.

Introduction

Completely new prospects for microelectronic applications were opened with the discovery of organic semiconductors and conductors. The inventors of these new materials have been honored with the Nobel Prize in 2000.[1-3] Nowadays in microelectronics applications, crystalline semiconducting materials are used, above all silicon. Apart from silicon, there are only few semiconducting materials which also have attained an economic importance, such as gallium arsenide (GaAs) in optoelectronic elements. However the amount and complexity of the processing steps limits throughput and pricing of conventional semiconductor devices.

With newly available organic semiconductors and conductors, completely new approaches can be made. For the production process, organic semiconductors and conductors have enormous advantages, as many of them can be processed in solution, i.e. liquid. Hence organic electronics can be printed as thin film on polymer substrates and applied on packages. This will bring electronics even closer to nearly every product, as they can be produced at high volume as low cost applications.

Since organic semiconductor do not exhibit the high degree of ordering as known for crystalline semiconductors charge carriers move considerably slower through this material. A comparison between polymers and Si in its amorphous, polycrystalline and crystalline states is shown in Fig. 1a.

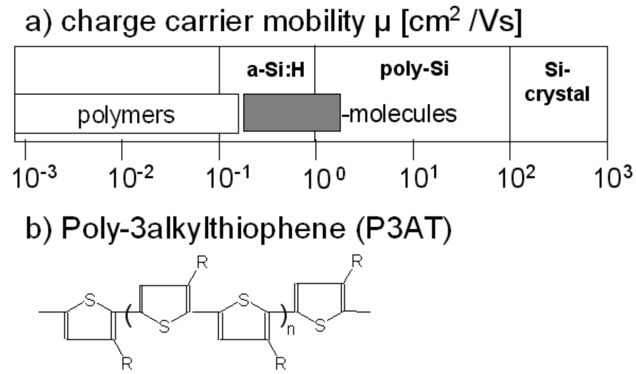

Figure 1. a) Comparison of charge carrier mobility of polymer and silicon; b) Chemical structure of poly(3-alkylthiophene)

The charge carrier mobility µ is a material dependent parameter, which indicates the speed of electrons and holes being transported through the semiconductor. In turn, it also defines the speed limit at which the device can be operated. Though polymers do not exhibit a defined ordering, they are still capable of showing a mobility around 0.2 cm2/Vs[4] such that they reach values of amorphous silicon. With small molecules, even values up to 1.5 cm2/Vs and more have been observed.[5-6] In Fig. 1b. the chemical structure of the most widely known semiconducting polymer poly(3-alkylthiophene) (P3AT) is depicted. Together with appropriate conducting and insulating materials, croelectronic devices and circuits can be realized. The most fundamental element for microelectronics is the transistor. More complex circuits consist of logical combinations of transistors.

Polymer Transistor

In the field of polymer electronics there exists a large variation of different types of organic or polymer transistor devices. Our group employs the concept of a p-type, top-gate polymer field-effect transistor (PFET). The p-type semiconductor P3AT is utilized to guarantee long life times as well as stable operation of the PFETs. In Fig. 2. the set-up of a polymer field-effect transistor (PFET) with source drains and gate electrodes is depicted.[7] Since the gate electrode is fabricated in the last step on top of the devices it is named top gate set up. Between the electrodes an insulating and semiconducting layer is introduced. Without a gate voltage the channel region between source and drain (distance L) is insulating and no charge carriers can flow. When a voltage is applied to the gate electrode a narrow conducting channel is formed at the interface between semiconductor and insulator; charge carriers can flow between source and drain electrodes.

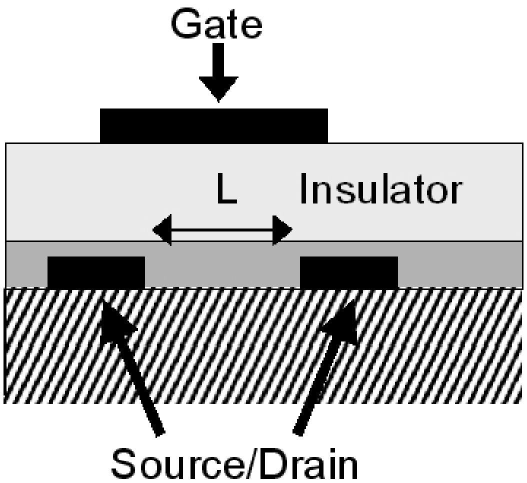

Figure 2. Sketch of a polymer field-effect transistor (PFET)

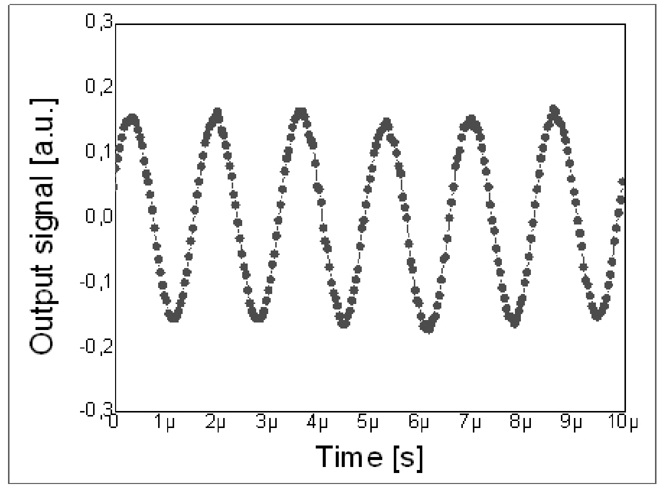

Figure 3. Output signal of a 5 stage ring oscillator with clock frequency of 0.6 MHz.

For the fabrication process we applied standard thin film techniques like spin coating and optical lithography. This approach was chosen to test new materials and principels of circuit designs.

First, a gold layer is sputtered onto a polymer film and afterwards patterned by lithographical means. In the next step dissolved semiconductor and insulator is spin coated in homogeneous layers consecutively. Finally another gold layer is sputtered on top and the gate electrode is again defined by lithography. With these techniques simple PFETs but also more complex devices like ring oscillators and circuits can be manufactured.

Integrated Polymer Circuits

A ring oscillator is the simplest set-up for proof-of-principle experiments testing the functionality for logical circuits. A ring oscillator is constructed through the placement of an uneven number of inverters, each of which consists of two PFETs. The performance of a single PFET has to be high enough to enable logical operations. The uneven number of inverters leads to a periodically oscillating signal amongst the inverters when a constant voltage is supplied. The clock frequency of the measured output signal shows the quality of the circuit layout and of the employed single PFETs.

Figure 3 shows the output signal of a 5 inverter stage ring oscillator. The channel length L of the PFETs was 0.8 µm. This device reached a remarkable clock frequency of 0.6 MHz.

For polymer electronics, stability is an important aspect, as it limits performance and life time of devices and applications. With the described setups a promisingly high stability could be determined in shelf life and operation lifetime tests. Figure 4 presents a comparison of ring oscillator performance before and after harsh conditions. The devices were exposed to a hot and humid atmosphere in a climate chamber with a temperature 85° Celsius and 85% relative humidity. After 92 hours the clock frequency only dropped from 56 kHz to 47 kHz.

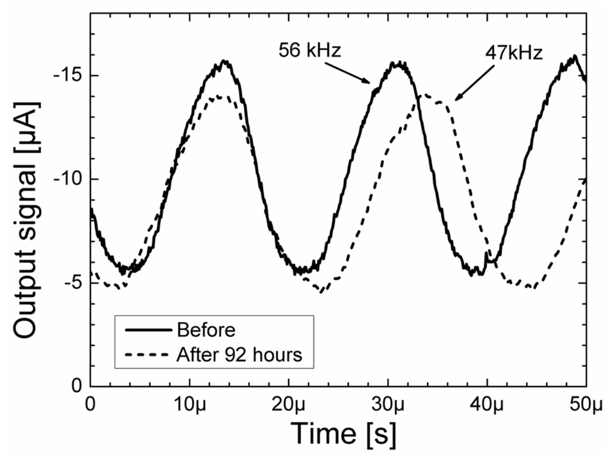

Figure 4. Output signal of a 7 stage ring oscillator before and after harsh conditions.

For further details about stability considerations with stability and operation life time tests on PFETs for up to 1000 hours and ring oscillators up to 200 hours refer to Ref [8].

The above described work concentrated on evaluating the limits of materials and circuit concepts. However, the main potential of polymers lies in the capability of being printable. In this context we also already presented fully printed all organic ring oscillators. As for printing techniques, we employed gravure off set printing and doctor blading, which can be exploited as high volume web printing processes.[9]

RFID Labels

The main focus of PolyIC is the development of radio frequency identification (RFID) labels based on polymer electronics components. Such labels carry information which can be read out contact less via radio frequency. In Fig. 5. the functional principel is depicted. The label consists of an antenna, a polymer rectifier and a polymer integrated circuit. The sender/reader unit emits a radio signal at a defined frequency. Typically 125 kHz and 13.56 MHz are used. Higher frequencies do exist but currently they are not in the reach for the performance of polymer circuits and rectifiers. The antenna of the RFID label is tuned to the corresponding resonance frequency by a capacitor. Through the rectifier, the chip is supplied with voltage and the chip starts to read out any stored information. This information is sent back to the reader as a modulation of the radio signal by the antenna.

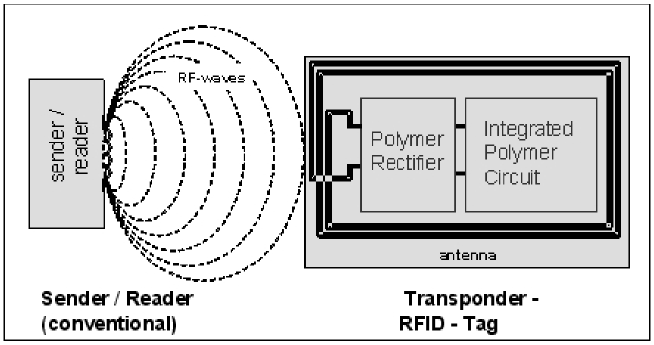

Figure 5. Sketch of sender/reader unit and RFID label.

A demonstrator system of a 125 kHz RFID system was already fabricated at PolyIC's laboratories, showing the advances already make on the way to printed applications. It should be emphasized that contrary to existing technologies the polymer RFID labels have the potential to be produced cost effectively at high volumes.

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Author Biography

Alexander Knobloch studied physics in Erlangen and has taken his doctor's degree in the printing of polymer microelectronic circuits at Siemens Corporate Technology at Erlangen. In 2003 he joined Siemens Corporate Technology and since the formation of PolyIC in November 2003 he has been senior research scientist in the PolyIC Technology department and develops the printing of the polymer RFID system.